

Linköping University, Norrköping, Sweden
15th to 18th June 2026

The 43rd International Pupils' Attitudes Towards Technology Conference



Technology Education Across Boundaries

Edited by

Jonas Hallström, Jeffrey Buckley,

Nina Kilbrink, Louise Lundberg,

Manus McDyer, Matt McLain,

Charlotta Nordlöf &

Per Norström

PATT43
Norrköping 2026

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UNIVERSITY

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Conference Website: <https://liu.se/en/research/patt43-pupils-attitudes-towards-technology-conference>

e-Proceedings: <https://ecp.ep.liu.se/patt>

DOI: <https://doi.org/10.3384/ecp213>

Email: patt43@liu.se

Proceedings reference:

Hallström, J., Buckley, J., Kilbrink, N., Lundberg, L., McDyer, M., McLain, M., Nordlöf, C., & Norström, P. (Eds.). (2026). *Proceedings of the 43rd International Pupils' Attitudes Towards Technology Conference 2026: Technology Education Across Boundaries. Linköping Electronic Conference Proceedings 213*. Swedish National Centre for School Technology Education (Cetis) and Technology and Science Education Research (TekNaD). <https://doi.org/10.3384/ecp213>

Paper reference

[SURNAME(S)], [INITIAL(S)]. (2026). [PAPER TITLE]. In J. Hallström, J. Buckley, N. Kilbrink, L. Lundberg, M. McDyer, M. McLain, C. Nordlöf, & P. Norström (Eds.), *Proceedings of the 43rd International Pupils' Attitudes Towards Technology Conference 2026: Technology Education Across Boundaries. Linköping Electronic Conference Proceedings 213* (pp. [PAGE RANGE]). Swedish National Centre for School Technology Education (Cetis) and Technology and Science Education Research (TekNaD). <https://doi.org/10.3384/ecp213.XXXX>

Parenthetical citation: (Hallström et al., 2026)

Narrative citation: Hallström et al. (2026)

Cover photograph: Katarina Rehder

2026 Linköping University

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eISBN: 978-91-8118-083-1

ISSN: 1650-3740 (ECP)

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Welcome

Dear PATT43 Delegate,

It gives me great pleasure to welcome you to Norrköping, Sweden, for the 43rd International Pupils' Attitudes Towards Technology Conference. On behalf of the Conference Committee, the Swedish National Centre for School Technology Education (Cetis), and Technology and Science Education Research (TekNaD), Linköping University, we are delighted to host PATT43 from 15th to 18th June 2026.

PATT has long provided an important international forum for researchers, teacher educators, teachers, doctoral researchers, and other colleagues concerned with technology education. Across its history, the conference has supported the exchange of research, the development of scholarly networks, and the continuing advancement of technology education as a field of inquiry and practice. PATT43 continues this tradition by bringing together colleagues from different national, curricular, and research contexts to discuss the current state and future direction of technology education, closely related to design, engineering, STEM, and more. In short, technology education across boundaries.

Linköping University (LiU), Campus Norrköping, is the host of this year's PATT conference. LiU is a relatively young university, established in 1975, and is known for interdisciplinary and innovative research and education encompassing 46,200 students and 4,700 employees. To solve current societal challenges, LiU is in continuous and close contact with industry and society. International rankings position LiU among the world's top universities, and our students are attractive in the labour market. It is believed that all this stems from a courage to think freely and innovatively at LiU. LiU includes a prominent Faculty of Educational Sciences and a Faculty of Science and Engineering, including the research unit Technology and Science Education Research (TekNaD) that together with the Swedish National Centre for School Technology Education (Cetis) host the PATT conference.

The theme of PATT43, *Technology Education Across Boundaries*, reflects the interdisciplinary, innovative, and boundary-crossing nature of technology education internationally. It also recognises the many opportunities for cooperation between technology education and other subjects, disciplines, and educational contexts. The contributions to this year's conference engage with this theme in diverse ways, addressing areas such as learning, assessment, curriculum, design, engineering, STEM and STEAM education, artificial intelligence and digital technologies, modelling and making, sustainability and ethics, equity and inclusion, teacher education, vocational education, policy, philosophy, culture, theory, and research methodology. Together, these contributions illustrate the breadth of contemporary technology education research and the importance of working across curricular, disciplinary, methodological, and cultural boundaries.

As with all PATT conferences, PATT43 is fundamentally about its community. We are pleased to welcome delegates from 31 countries across 5 continents, representing a wide range of research traditions, educational systems, and professional experiences. This international and collegial character is central to the conference. It allows us to learn from one another, challenge assumptions, develop new collaborations, and strengthen the collective contribution of technology education research.

I would like to sincerely thank all authors for their contributions to the conference proceedings, and all reviewers for their careful, constructive, and collegial work during the review process. Their efforts have helped ensure the quality and relevance of the papers included in this volume. I wish to especially thank the proceedings co-editors, Jeffrey Buckley, Nina Kilbrink, Louise Lundberg, Manus McDyer, Matt McLain, Charlotta Nordlöf, and Per Norström, for their dedicated and invaluable work in preparing this collection. They spent countless hours managing papers and putting together the proceedings, and together they epitomize the true team effort that our work has been.

I would also like to acknowledge the support of colleagues at TekNaD and Cetis, as well as the support of Linköping University and the Norrköping Municipality (*Norrköpings kommun*). Conferences of this kind depend on the generosity, expertise, and commitment of many people, and I am grateful to all those who have contributed to making PATT43 possible.

Finally, I would like to thank Charlotta Nordlöf, Claes Klasander, Malin Åberg, and Anna Ericson, as part of the PATT43 organising committee, for their dedication, professionalism, and collegiality throughout the planning of the conference. It has been a privilege to work with colleagues who are so committed to supporting international dialogue and advancing technology education research. Just as the editorial work, the conference organisational preparations have been a collective effort where I always felt that I can rely on everyone to do their part.

I wish you all an inspiring, enjoyable, and thought-provoking conference.

Yours sincerely,

Jonas Hallström

Conference Chair PATT43

Conference Theme

The PATT43 conference theme is Technology Education Across Boundaries, to signify not only the interdisciplinary, innovative, and boundary-crossing characteristics of technology education worldwide but also the broad array of cooperative opportunities that exist between technology and other subjects and subject areas in the school and teacher education.

Papers were invited to contribute to this overarching theme in a variety of ways, related but not limited to the following suggested topics:

- technology education and STEM/STEAM;
- technology education and sustainability;
- technology education and social sciences;
- technology and craft, maker or design education;
- technology and vocational education;
- technology education and digital tools (e.g. AI);
- technology education for 21st-century readiness;
- assessment in technology education;
- technology and philosophy/history;
- technology and gender, engagement and recruitment;
- technology and engineering education; etc.

Conference Program

	MONDAY JUNE 15	TUESDAY JUNE 16	WEDNESDAY JUNE 17	THURSDAY JUNE 18
8:00-8:30		Registration	Registration	Registration
8:30-9:00	Registration	Daily Briefing	Daily Briefing	Daily Briefing
9:00-9:30	Welcome to PATT43			
9:30-10:00		Paper Sessions	Paper Sessions	Paper Sessions
10:00-10:30				
10:30-11:00	Fika	Fika	Fika	Fika
11:00-11:30	Paper Sessions	Paper Sessions	Paper Sessions	Paper Sessions
11:30-12:00				
12:00-12:30	Lunch			Lunch
12:30-13:00	Lunch Poster Session	Lunch Poster Session		
13:00-13:30				
13:30-14:00			Social Activity	
14:00-14:30	Paper Sessions	Paper Sessions		Closing Session
14:30-15:00				
15:00-15:30			Fika	
15:30-16:00	Fika	Fika		
16:00-16:30			Paper Sessions	
16:30-17:00	Paper Sessions	Paper Sessions		
17:00-17:30			Free time	
17:30-18:00		Social Activity Visualisation Centre		
18:00-18:30	Welcome Reception		Conference Dinner	
18:30-19:00				
19:00-Late				

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Taste as an Analytical Lens for Students' Interest in Technology Education

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Abstract

This paper conceptually explores how students' interest in technology may be examined in situ through the concept of taste. Drawing on a pragmatist–Bourdieuian perspective, taste is understood as socially learned and enacted judgement, through which feelings, cognition, and norms are intertwined in social interactions. Using illustrative examples from programming activities with robots, the paper shows how students' and teachers' distinctions concerning procedures, language use, and ways of being become visible in interaction. These distinctions orient action in relation to the purposes of the activity and highlight how moments of frustration, alignment, and closure contribute to students' participation and emerging interest in technology.

Key Words: Interest, Taste, Aesthetics, Learning, Technology Education

1 INTRODUCTION

Research on students' interest in STEM education has usually relied on self-report measures such as surveys and interviews (e.g., Potvin & Hasni, 2014). While valuable, such approaches capture students' recollections rather than how interest emerges in classroom activity. This paper offers an exploratory contribution by approaching students' interest in technology in situ through a Bourdieu-Pragmatist perspective on taste, understood as socially learned and enacted judgement (Bourdieu, 1984; Dewey 1934/2005; Wickman, 2006). In this perspective, feelings, cognition, and norms are understood as intertwined in the flow of activity. Taste becomes visible in the distinctions teachers and students make about how to talk, act, and be, reflecting socially negotiated views on what counts as appropriate or valued (Anderhag et al., 2015). These distinctions are aesthetic, involving feelings of pleasure and displeasure and the objects toward which these feelings are directed (Wickman, 2006).

The aim of this conceptual paper is to explore the potential of taste as a lens for analysing students' interest in technology education as it becomes observable in classroom activity. Drawing on earlier classroom studies of programming, the paper illustrates how students' interest is (or is not) enacted through aesthetic judgements and learning, and relates these enactments to students' purposeful action, as discussed in research on volition in technology education.

2 THE AFFECTIVE, COGNITIVE AND BEHAVIOURAL DIMENSIONS OF STUDENT ATTITUDES TOWARDS TECHNOLOGY AND TECHNOLOGY EDUCATION

Although other methodologies are used within the technology education research field, questionnaire-based approaches - particularly the PATT instruments - remain central to what is known about students' attitudes towards technology (Tzeng & Yu, 2023). Within this research, the affective, cognitive, and behavioural dimensions have been discussed (Raat & De Vries, 1986; Ankiewicz, 2019a; Svenningsson, 2020). Although typically separated in both instruments and theoretical models, the affective and cognitive components are commonly understood as intertwined. Interest, for example, is usually classified as belonging to the affective dimension while also including cognitive aspects (Svenningsson et al., 2021).

Empirical findings suggest that cognition may influence affect (Ankiewicz, 2019a), while affect may likewise influence cognition (Svenningsson et al., 2021). Together, these dimensions influence student behaviour, which may be described as intended behaviour due to questionnaire-based data (Ankiewicz, 2019a). While students' attitudes are the primary focus of the PATT instruments, research has shown that cognitive and behavioural dimensions receive less emphasis than the affective dimension (Ankiewicz, 2019a; Svenningsson et al., 2021). In response, Ankiewicz (2019a) calls for more holistic approaches address the behavioural component of students' attitudes. One such development is the introduction of the Mitcham score, aimed at exploring relationships between behavioural, cognitive, and affective components (Svenningsson, 2020; Svenningsson et al., 2021).

In technology education research, volition originates in Mitcham's (1994) philosophical work and has been described as "the ability or power to decide that you want to do something, and then act upon it and take relevant action" (Hallström & Ankiewicz, 2023, p. 2). Volition has been used to elaborate how affective and cognitive components relate to behavioural orientations and technological action (Ankiewicz, 2019b; Svenningsson et al., 2021). Volition thus overlaps with constructs concerning students' orientations toward technological activity, including interest and motivation, which in turn are connected to values and feelings (cf. Koballa & Glynn, 2007). From this perspective, Hallström and Ankiewicz (2023) emphasise that technological action, particularly design activity, is shaped by values guiding how design choices are interpreted and pursued.

Similar issues were central in our earlier work operationalising taste to examine students' interest in science. While volition has been concerned students' orientations toward technological action, taste is not treated here as an overlapping construct, but as an analytical lens for examining how such orientations take form in classroom activity.

3 TASTE AS AN ACTION-ORIENTED PROXY FOR STUDENTS' INTEREST

In educational contexts, students' interest in a subject is not only a matter of attitudes toward content, but also of how students come to recognise themselves in relation to what is valued within a subject practice (Archer et al., 2010). It is, for example, well documented that students may

perform well in science while still positioning themselves as “not a science person” (e.g., Carlone et al., 2014; Lyons, 2006). Interest can thus be understood as involving processes of identification and participation. Taste for science was developed as a didactic model to capture such processes as they unfold in classroom interaction (Anderhag et al., 2015). Drawing on Bourdieu (1984) and Dewey (1934/2005), taste is understood as socially learned and embodied through upbringing and education, and as closely tied to participation in social practices. Analytically, taste concerns how aesthetic experiences become visible through the distinctions participants make and negotiate in practice. These distinctions are not merely individual preferences, but socially situated judgements that orient action and participation in an activity (Wickman, 2006).

Having a taste for something - such as classical music or football - does not only express a positive attitude but also involves knowledge of the domain and a habitual ability to discern what works, what fits, and what makes sense. For example, what counts as a *beautiful* pass or what makes a particular game *interesting*. When making such distinctions, individuals position themselves and may be recognised by others, as someone who likes and knows things about football. In this way, taste functions as a social mechanism that enables participation and draws its boundaries, including some ways of knowing and being while excluding others. In classroom practices, similar distinctions become relevant when students encounter situations that require them to proceed, making visible how ways of using language, acting, and being are valued within the activity.

What follows is a brief account of the analytical rationale; for a full description of the methodological framework and its use in designing and evaluating teaching, see Anderhag et al. (2015). The methodology is grounded in a pragmatist perspective on learning in which words and actions gain meaning through their use and consequences in situated activities (Dewey, 1913/2012; Wickman & Östman, 2002). Here, aesthetics refers to evaluative judgements of what is experienced as beautiful, ugly, clear, or frustrating in a given situation, in line with a Kantian understanding and as operationalised by Wickman (2006). In this view, the meaning of an utterance such as “This is a beautiful code” is derived from what is going on in the situation, rather than treated as an expression of an inherent or fixed property. Evaluating a piece of code as “beautiful” is thus closely related to making sense of what the code does and why it works, as learning is tied to purpose and aesthetic experience in the ongoing activity. As aesthetic judgements concern facts and phenomena encountered in terms of what is the case (a beautiful code) they are continuous with cognitive learning (Jakobson & Wickman, 2008; Wickman, 2006).

Analytically, taste is approached in relation to how the purposes of a classroom activity become intelligible to students and allow them to proceed purposefully. When such purposes are taken up in interaction, taste becomes visible through the distinctions students and teachers make in practice. Such distinctions concern (1) how procedures are distinguished, that is, how participants choose to proceed in action by including and excluding particular acts as more or less appropriate ways of acting in relation to the purposes of the activity; (2) how language usage is distinguished in a multi-representational sense, including the use of words, symbols, diagrams, or other signs; and (3) how ways-to-be are distinguished, that is, how participants relate to themselves and others as certain kinds of students in relation to the activity. These distinctions are examined in terms of whether they orient students’ actions and judgements toward or away from the purposes of the activity.

4 ILLUSTRATING DISTINCTIONS OF TASTE

The following excerpts illustrate how distinctions of taste may be analysed in programming activities in technology class. They were selected to clarify the analytical approach rather than to represent empirical cases or categories of student responses. The excerpts are drawn from two earlier collaborative teacher–researcher classroom studies based on video and audio recordings: one with primary students programming Blue-bots (Anderhag et al., 2021), and one with grade 9 students programming Lego robots to follow a curved line (Anderhag et al., 2024). In the first study, teaching was examined in relation to how it supported students’ understanding of code as a form of technical solution. In the second study, the focus was on the students’ programming strategies. While these studies did not focus on students’ interest, the excerpts are here revisited to illustrate how distinctions of taste may be identified in classroom interaction.

In both settings, students’ actions were oriented towards the purpose of the activity, namely to write a program that made their robots move in a specified way. This process was observable through anticipatory and consummatory aesthetic judgments of taste made during the activities. Even if the classroom climates were positive, feelings of frustration were evident in both settings and typically aroused when the students did not understand why their code did not work as expected. Example 2 demonstrates this. The student (grade 9) was talking with the teacher about the movement of the robot, and thus indirectly about the code, which he could not understand.

4.1 *Example 1: Getting stuck*

1. Student 1: This was incredibly *disgusting*. Because, you see, the problem before was that they were driving backwards, and now they are driving forward. When you turn. When you turn them around, then it starts moving forward. But then, they do not go at the same time. Which is quite *strange*. I mean.

Here, the student cannot act. Student 1 does not understand why the code fails and feels disgusted by the strange behaviour of the robot. If situations like these are prevalent in a technology classroom, being confused and not able to succeed with what you are doing, it is not likely that students develop a taste for programming or technology. Within the field of science education, it has been shown that students may describe their experiences of the science classroom in these terms - namely that it is difficult, boring, and even alienating (Potvin & Hasni, 2014). This episode illustrates how students’ expectations regarding how their ongoing actions should work in order to achieve what they are currently trying to accomplish are not fulfilled, resulting in a negative aesthetic experience articulated through negative aesthetic judgements. These judgements signal a breakdown in how to proceed and temporarily limit purposeful action.

4.2 *Example 2: Support moving forward*

In the primary classroom, distinctions of taste revolved around what constitutes “good” code in terms of its functionality, for me and others (cf. Björkholm, 2014). The students in the excerpt below used lines to represent the step wise forward movement in their code. Before the example, the class had talked about what characterise a good code and one thing that they agreed on was

that if they wrote a code using verbal language (e.g., “Gå fem steg framåt [Go five steps forward]”), people not knowing Swedish would not be able to follow it. Some of the students then started to use symbols instead. When the teacher joined the discussion, the students were counting aloud while pointing at the lines they had drawn as one of them pressed the corresponding buttons on the Blue-bot. In this context, the teacher asked the students whether their code could be expressed more clearly:

1. Teacher: Hmm, but you know, that is quite easy to misread. Could you have made it a bit clearer in some way?
2. Student 1: Uh, I know! [Gets up to fetch a pen]
3. Teacher: How could you have done it then?
4. Teacher: What does it look like here? [Points to the Blue-Bot’s buttons]
5. Student 2: They’re arrows [pointing forward, back, left and right turn].
6. Teacher: Arrows, yes. Could you have used those, perhaps?
7. Student 2: [laughs] Yes, arrows!

Several things happened in this short excerpt, initially in turn 1 the teachers made the students aware of aesthetic aspects of their code “Could you have made it a bit *clearer*”. That is, there are values associated with code and programming and a code could be, for example, clear or unclear and there were ways to produce a clear code. The teacher then prompts them to use the symbols on the robot - arrows - instead of straight lines (turn 4). The situation was summed up in turn 7 as the student agreed joyfully, as evident through their laughter, that they instead should use arrows. After turn 7 the students made arrow heads on the lines and continued with the activity. This episode illustrates how distinctions of language usage may re-align students’ ways of proceeding with the purposes of the activity. By drawing attention to clarity as a valued quality of code and introducing arrows as a more appropriate representation, the teacher supports the students in distinguishing representations that better afford meaningful action. The students’ affirmative response and continued engagement indicate a moment where aesthetic judgement, ways of representing the code, and action come into alignment with the purpose of the activity.

4.3 *Example 3: Reaching the goal*

Finally, the last example is from the grade 9 classroom and demonstrates a situation where processes come to closure. The two students had been working on their code for some time and had experienced, as the student in example 1, frustration and anger when their code did not work. At the end of the lesson, they tested if the latest changes done - which they had discussed - would make any difference:

1. Student 1: Go. Try it.
[the students execute their program].
2. Both: Aaaaaah! [Observing the robot]
3. Student 2: Who’s as smart as me!
4. Student 1: It works! Oh my god! [clapping their hands].

5. Student 2: Who's as smart as me!
6. Student 1: [Name of Student 2], what a freaking genius!

As described earlier, having taste for something does not only mean that you know things (such as coding) but also that you can make distinctions on what is good-bad, beautiful-ugly or, as in Example 1, agreeable-disgusting. By making distinctions of taste, you also distinguish yourself (implicitly or explicitly) as belonging or not. It is likely that experienced programmers hold similar views on the aesthetics of coding (such as what characterise a nice, beautiful, etc., code) that the novices yet have to learn. Sense of belonging is thus an important part of developing a taste and the last example demonstrate the third type of taste distinctions that have been demonstrated in the context of science education. That is, distinctions on ways-to-be. When the students succeeded in making the robot move as intended, they reacted with relief, surprise, and joy. As evident in turn 3, 5–6, Student 2 also saw themselves as, and was recognized by their friend as, a competent technology student. They humorously concluded that Student 2 was both a genius and a smart person who could fix the code.

In situations like these students do not only learn things about the subject (such as coding) but also who they are in relation to the subject, that is whether I am person that can code or not. It is likely that experiences of fulfilment, as when you learn something, is central for students (developing) interest for a school subject. From a taste perspective, this episode illustrates how distinctions of ways-to-be emerge when students' actions successfully align with the purposes of the activity and the process reaches closure. The students' expressions of joy and mutual recognition signal positive aesthetic experience tied to successful action, through which they position themselves and one another as competent participants. Analytically, such moments of closure make visible how experiences of fulfilment may support the development of a taste for technology by affirming both what counts as appropriate action and who can be recognised as belonging in the practice.

5 DISCUSSION

This conceptual paper explores the potential of taste as a lens for analysing how students' interest in technology education becomes constituted in classroom activity. Drawing on a pragmatist–Bourdieuian perspective, interest is approached not as a pre-existing attitude or disposition, but as something that becomes observable through the distinctions students and teachers make in interaction.

The examples illustrate how distinctions of taste concerning procedures, language usage, and ways-to-be offer a way to examine how students feel about the ongoing activity and what objects their interest becomes oriented to. Breakdowns between action and outcome may be observable in negative aesthetic judgements, while alignment and closure may be observable in positive ones (Wickman, 2006) - for example, when students recognise themselves as competent participants. In this sense, taste can function as an action-oriented proxy for examining how interest unfolds in classroom interaction. Such moments are observable to teachers and may thus serve as guidance for orienting students' feelings, talk, and actions towards the purposes of the activity.

Conceptually, this perspective may complement existing research on students' attitudes and volition in technology education. Previous research has conceptualised students' attitudes in terms of affective, cognitive, and behavioural dimensions, and highlighted the importance of understanding how these relate to students' engagement in technological activity. Within this line of research, the concept of volition has been used to describe students' capacity or willingness to act in technological practice (Hallström & Ankiewicz, 2023; Svenningsson et al., 2020). The analysis presented here suggests that such orientations to act may also become visible through the aesthetic distinctions students make in classroom interaction. These distinctions make visible how affective, cognitive, and behavioural dimensions become intertwined in students' participation, and how orientations to act take shape through situated judgements about how to proceed in an activity, thereby potentially complementing the notion of volition. In this way, the concept of taste may be useful for examining how interest in technology is constituted in situated classroom activities. Further studies in different educational contexts and with other technological content are needed to explore its usefulness for both analysing and informing the planning of teaching.

6 DISCLOSURE STATEMENT

No artificial intelligence (AI) tools were used in the preparation of this manuscript. All writing, data analysis, and interpretation were conducted entirely by the authors without assistance from AI technologies.

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Intimacy in Intra-Action with Students, Material, and Emotions in the Laboratory

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Abstract

Practical activities and laboratory work are essential parts of technology education. It brings together theory and practice by applying theoretical knowledge through practical work. The handling of instruments and laboratory equipment develops experimental hands-on skills and technical competencies, such as data handling, process control, and monitoring. Another aspect of incorporating practical elements in natural science and technical education, often highlighted by teachers and in research literature, is that it makes the subjects more interesting and engaging. This can, of course, be the case, but it is just as common for practical activities to provoke other emotions, such as anxiety about making mistakes or about damaging expensive equipment. In this study, we use Barad's theory of agential realism to examine how upper secondary school technology programme students approach and establish relationships with the materials they need to use during laboratory work in biotechnology. Barad emphasizes that everything is entangled and that these entanglements create our reality. This means that both people and matter actively contribute to shaping our world. To describe the process that occurs in these entanglements, the concept of intra-action is used. We have observed and video-recorded experimental activity sessions on different occasions over the course of one semester. Through Barad's theory of the agency of matter, we conducted the observations with a focus on the intra-actions between the students' bodies and the materials used during the laboratory sessions, as well as the emotions that became visible. In the presentation, we will elaborate on the concept of intimacy to describe certain intra-actions in which the material seems to "call" to the students, prompting them to explore it in playful and emotional ways.

Key Words: Agential Realism, Biotechnology, Emotions, Intimacy

1 INTRODUCTION

Practical activities and laboratory work are essential parts of technology education. Even so, a common argument for experimental activities in technology and science education is that it ‘cannot be meaningful to students without worthwhile practical experiences’ (Hofstein & Mamlok-Naaman 2007, p. 105). The handling of instruments and laboratory equipment develops hands-on skills and technical competencies, such as data handling, control, and monitoring of production processes. It is also seen as a way to illustrate and apply theoretical knowledge to promote students’ conceptual understanding (Kalthoff, Theyssen & Schreiber 2018). Another aspect of incorporating practical elements in technology and science education, often highlighted by teachers and in research literature, is that it makes the subjects more interesting and engaging for students (Lombardi et al. 2014). This can, of course, be the case, but it is just as common for practical activities to provoke other emotions, such as anxiety about making mistakes or about damaging expensive equipment. It is even the case that many students perceive experimental exercises as unimportant in their learning (Hofstein & Lunetta 2004).

The laboratory work that takes place in teaching often includes many different elements in which students encounter a variety of materials and instruments that they need to learn to understand and handle (Gullberg et al. 2025). The laboratory instructions outline what students should do to conduct the investigations and ensure their success. However, the students have their own agency and may explore the material in their own ways. In this study, we are interested in what happens “behind the scenes”, what actions are possible beyond the laboratory instructions in a biotechnology class in upper secondary school technology programme. By zooming in on what happens between students and the material, we want to examine students’ relationships with the instruments and other material, and the feelings that arise in this encounter. In analyzing our empirical data, we found that the concepts of intimacy and play describe the intra-actions between the student and the laboratory material.

The research questions are:

- (i) In what ways do technology students engage with experimental equipment, within and beyond what is expected?
- (ii) What kind of connections between humans and materials become visible?

2 LITERATURE REVIEW

2.1 *Agential realism*

In this study, we draw on physicist and science philosopher Karen River Barad’s theory about agential realism (Barad 2007). In agential realism, agency occurs in the instantaneous encounter of matter, human and nonhumans. Boundaries defining those objects are not given once and for all but are constantly contested or confirmed in an iterative way, through what Barad calls agential cuts. The complexity of agency is illustrated by the term intra-actions as opposed to interactions, which take place between pre-existing entities. Matter participates actively in intra-actions, just

as humans and other living organisms do. Even the researcher is actively participating in intra-actions and cannot be a passive observer. In fact, the researcher actively participates by making agential cuts and defining boundaries, thereby achieving objectivity.

2.2 *Experimental work in technology education*

Experiments have a long history within technology and engineering, characterized by manipulating one or more parameters believed to affect a particular outcome (Norström 2015). Bernhard (2015) highlighted the importance of laboratory activities in technology and engineering education to enhance engineering students' technology competences, such as handling data, controlling and monitoring production processes. He claimed that exploring the structure of an artifact and to learn to use it "changes the structure of human interaction with the world" (Bernhard 2015, p. 407). However, Bernhard (2015) pointed out that research in technology and engineering education is mainly concerned with instruction, concepts, and ideas, or the organization of laboratory exercises, and adds that there is consequently a lack of research on the importance of instrumental technologies for student learning in laboratories. He calls for the handling of experimental equipment to be given cognitive value as well. In addition to these arguments, doing laboratory work requires managing unexpected events and interpreting measurement errors (Bybee, 2000). Knowledge about the messiness of experimental work provides insights into the complexity of scientific work and technological methods.

2.3 *Feminist and critical perspectives on experimental activities*

Barad is one of several feminist scientists and philosophers who have problematized the narrative of science and technology as objective and rational activities by introducing relational aspects closely tied to research practice. In her biography of Nobel laureate Barbara McClintock and her genetic research, Keller (1983) showed that objectivity and rationality must be supplemented by empathic understanding and emotional involvement to provide a more complete description of scientific activity. McClintock emphasized the importance of letting the material speak to you, meaning that the researcher should become part of the system rather than an outside observer. According to Keller "She herself [McClintock] cannot quite say how she "knows" what she knows. She talks about the limits of verbally explicit reasoning; she stresses the importance of her "feeling for the organism" in terms that sound like those of mysticism. But like all good mystics, she insists on the utmost critical rigor, and, like all good scientists, her understanding emerges from a thorough absorption in, even identification with, her material" (Keller 1983, p xxii).

In a more recent study, Lorenz-Meyer (2014) showed how laboratories are cultural, emotional practices, shaped by spaces, objects and people, and come into being in contact with others, where this *other* can include the non-human. She studied postdoctoral scientists struggling to calibrate mass spectrometers. To succeed requires training, but also to reach a kind of entanglement, a 'feeling' for the instrument, a skill that is hard to verbalize and instruct. In moments of failure, socio-material relations embedded and embodied in practices tended to become visible (Lorenz-Meyer 2014).

Describing the agency of matter as claiming the user's attention has also been done in science and technology preschool education. For example, Günther-Hanssen (2020) has described scientific phenomena as playmates when children bodily explore forces, acceleration and oscillation in interaction with a swing. Together with Barad's (2007) concept of intra-activity, she showed how the physical phenomena were not there as "pre-existing" learning content, but rather came into being through the child's repeated physical interaction with the swing. She concludes that: "This means that becoming scientific and/or creating a science identity is something that is enabled in entanglements and not something one can do by oneself (Günther-Hanssen, 2020, p. 905).

Otrel-Cass (2018) stated that, to date, research has given little attention to the importance of sensorial body-mind experiences for learning in technology and science. Although not all bodily experiences are educational, she argued that the senses are necessary and intertwined with scientific investigations. Visual-sensory expression predominates in experiments and observations, but Otrel-Cass (2018) wants to reinforce the importance of other senses in encounters with materials and instruments. The sense of touch, for instance, is primarily linked to the domain of the hands, where several different receptors send different nerve impulses to the brain (regarding pressure, pain, heat and cold). The sense of touch is involved in handling materials and to become skilled, one must learn the technique and refine one's dexterity. She called for sensory pedagogies or body-mind pedagogies that consider materials and allow for subjective and emotional experiences.

As exemplified above, there is recognition of laboratory work as an embodied activity that requires practitioners to entangle themselves both kinesthetically and affectively (Myers 2015). Following Myers, Mehrabi (2018) found that the concept of intimacy in laboratory contexts worked very well to describe the emotional-material-discursive process that involves relationships between bodies, not necessarily human. We usually associate the notion of intimacy with family, partnership and care. However, even in the laboratory, intimacy is intertwined with empathy and affect, a responsible attention to others, both humans, other living beings and the non-living. Through intimacy, according to Mehrabi (2018), bodies simultaneously perform and animate each other.

3 METHODOLOGY

3.1 *Empirical design and analysis*

Data collection for this study took place in laboratory settings within the technology and natural sciences programmes in upper secondary schools in Sweden. In total, we video-recorded 14 hours of laboratory lessons supplemented with field notes. For this paper, we have used the material from the biotechnology setting at the technology programme, where 16 students (10 girls and 6 boys) completed the laboratory exercises "Mini-format bioreactor", "Isolation of starch phosphorylase from potatoes" and "Detect pepsin". The students were informed about the study and signed a consent form to participate. To get sight of the human-material intra-activity as well as the overarching intentions and beliefs of people involved in the activities, we used three complementary methods: observations through video, micro-interviews and individual interviews. The video recording focused on the intra-actions involving students and the

instruments/material/equipment they handled; intra-actions between students and lab assistants; intra-actions between students and lab instructions. Micro-interviews were conducted during lab sessions, during which we asked participants questions about their activities and any feelings that may have emerged. We, researchers, are present during laboratory activities and thus part of the agential cut that frames the phenomenon that arises through intra-actions. Even if the students are initially aware of our presence, they quickly shift their attention away from us. The focus on practical work, combined with the fact that our presence is soon experienced as self-evident, makes them seem completely unaffected by it.

Diffraction analysis applies agential realism in practice by acknowledging and engaging with the dynamic and changing aspects of theories and concepts to generate results (Barad, 2007). This method breaks with dualism and static perspectives by using diffraction as a metaphor to illustrate complex patterns and reciprocal relationships, for example, between humans and non-humans or between ideas. In diffraction analysis, the researcher reads different perspectives or materials, such as theoretical concepts, texts and pieces of empirical data, through each other (Barad, 2003). The researcher is seen as part of the phenomena being studied, not just an objective observer. In our analysis of the films, we brought with us concepts such as “intra-actions”, “intimacy”, and “feeling for the materials” as grids through which we searched for general patterns, as well as critical incidents, in which these concepts became particularly prominent and relevant. In the first step, the films were individually analyzed by the researchers and interesting sequences were transcribed, and tentative themes/agentic cuts were produced. In the next step, these were discussed by the entire research group while the film sequences were analyzed again alongside the relevant theoretical concepts. The themes were confirmed or reconsidered through this second step.

No generative AI tools were used either in the analysis of the data or in the writing of the article.

4 RESULTS

In line with Myers (2015) and Mahrabi (2018), we found that intimacy between humans and material is kinesthetic and affective. The result is presented through the agential cut constructed from intimacy-students-teacher-emotions-materials. We illustrate this with examples from the starch phosphorylase lab, where we show how the material seems to “call” to students, prompting them to explore its tactile properties in playful and emotional ways. The results are described under the following headings: Reducing the personal territory, The tactile properties of the material manifest themselves and Transforming experimental equipment to non-scientific attributes.

4.1 *Reducing the personal territory*

In one of the observed biotechnological laboratory sessions (lasting 1.33 hours), ten girls and two boys participated. The lab involves preparing starch phosphorylase from raw potato juice. The enzyme is purified by ammonium sulfate salting-out. Different proteins precipitate at varying salt concentrations and can therefore be separated from each other by centrifugation. The students must peel and grate potatoes. Ammonium sulfate is added to the squeezed potato juice in a

centrifuge tube, which is then left in an ice bath. The precipitate that forms when ammonium sulfate is first added consists of proteins other than starch phosphorylase, which are therefore present in the solution. The sample is centrifuged several times, buffer is added, and the solution is transferred to different test tubes using automatic pipettes. The students follow detailed instructions like a recipe in a cookbook.

Through the activities performed and due to the joint examination of relatively small samples, intimacy between human bodies and material arises. The material enables people to cross boundaries that are typically within the personal sphere. The students must get closer to each other. The students stand close together, one decants liquid into a centrifuge tube and the other then screws on the lid. When both hold the little tube, their hands are close together, even touching. The students examine the material from different angles. Bea, one of the collaborating students, looks at the remaining potato liquid in the bowl for a long time after they have poured it into a tube. She shakes the bowl back and forth several times at different angles and speeds, without speaking, studying closely what happens to the slightly gooey liquid. Bea and Cecilia examine the pellet in the test tube up close at hand after centrifuging the liquid. When the teacher approaches to look at the pellet that has formed in the small tube, she also comes close, with her head just a few inches from the students'. Reducing personal territory, illustrated here, recurs throughout all laboratory sessions.

4.2 *The tactile properties of the material manifest themselves*

Anida has grated potatoes and is filtering them through a sieve. She clasps her fingers together and repeatedly presses the grated potato with both the outside and the inside of her hand to get rid of the liquid. "How nice it feels", she exclaims into the air, not to any particular recipient. She continues pressing the substrate with an attentive expression that indicates that she is sharing the emotional sensation.

Cecilia and Bea have placed their centrifuge tube in a beaker of ice and water and are waiting to centrifuge. The tube floats up. Bea stands by the beaker. After a while, she begins pressing the tube with her fingers, causing it to sink below the surface. She releases it so that it pops up. She repeats this a few times. She then tries to balance an ice cube on top of the lid of the centrifuge tube, which, after a short while, slides into the water. She repeats this balancing act.

4.3 *Transforming experimental equipment to non-scientific attributes*

There is a long wait in the laboratory while starch phosphorylase is to be salted out with ammonium sulfate. The reaction takes place in the cold on an ice bath, precipitates must be centrifuged, and volumes must be pipetted and measured again. Cecilia has just pipetted solution into a test tube and is sitting at the lab bench waiting for starch phosphorylase to be salted out. She has used the automatic pipette with a relatively coarse pipette tip, which is left on the bench. Suddenly, she put it on her little finger and moves her hand a little here and there. She doesn't make a big deal out of it, but Bea is watching, they make eye contact and without any words, they smile a little at each other. After a while, she has placed two pipette tips on her hand, elongating her fingers. She drums them on the tabletop and waves them in various playful, yet quiet ways so as not to attract too much attention. Only her labmate, Bea, seems to take any notice.

5 DISCUSSION

Compared to other school subjects, the technical and science classrooms are initially foreign environments with unfamiliar furniture, equipment and materials. Added to this are the impersonal written laboratory instructions, stripped of emotion and lacking details about the human activities expected to take place during the experiment. Nor do they usually include information about how the material should be handled and what handling is required. This can create confusion among students and further intensify feelings of alienation. In the situations we have described, students find their own ways of familiarizing themselves with the material. Sensory experiences created feelings that were expressed nonverbally through facial expressions and verbally, further stimulating playfulness. In the situations presented, the grated potato, the test tubes, the ice bath with ice cubes, and pipette tips function as playmates (Günther Hanssen 2020) and "call" Anida, Bea, and Cecilia to intra-act in a manner that exceeds expectations in the experiment itself. The material calls attention, inviting and enabling certain actions, for instance, the shape of the pipette tip enables bodily extension, the encounter between the resistance of the water and the buoyancy of the centrifuge tube creates a pressure against Bea's fingers, and the structure of the grated potato pulp responds to the receptor cells in Anida's hands. Repeated play with the material produced small shifts and changes in the intra-action. It opened up new ways of acting together with the material. Bea, who pushed the test tubes several times into the ice water, changed focus after a while and instead placed the ice cube on the test tube. The iterative process was part of exploring the different possibilities of the test tube in a liquid, while test tubes are usually arranged in a rack. The play became an entry point for understanding the materials' properties in new ways. Exploration requires agency, which may not be sanctioned by the teacher and may also challenge boundaries such as safety, as well as the students' inherent boundaries of fear and uncertainty.

The bodily, sensory, often nonverbal encounters students have with classroom materials can contribute to the creation of emotional relationships with classroom artifacts and with the technology subject. Relationships between different bodies, intertwined with emotions, care and intimacy are aspects that are traditionally connoted as feminine. Technology, on the other hand, is a carrier of masculine values (Tellhed et al., 2023). We would therefore like to encourage teachers to start looking for and make space for intimacy entangled with emotions and playfulness in their technical and scientific classrooms, central dimensions also in the researcher's relationship with their research object, as shown by Keller (1983). It could be a way to invite more inclusive technology education and break with the stereotypical notions of the technology subject as masculine. The intimate process of physically approaching the material in these different ways can, in the long run, lead to familiarity with it, fostering a sense of belonging to the laboratory context in technology.

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The Pedagogy for Technology Education: In Search of a Rigorous Theoretical Framework

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Abstract

The literature on the teaching of technology often refers to constructs like constructivism (including cognitive, radical and social constructivism), experiential, cooperative, inquiry- and discovery-based learning. It also supports problem-; project-; and design-based learning and teaching in authentic contexts. However, the said pedagogical constructs are dealt with in an arbitrary way without contextualising them within a rigorous theoretical framework. The purpose of this conceptual paper is to develop a rigorous theoretical framework for a pedagogy for technology education. The research questions are: What are the components of a theoretical framework for technology education pedagogy, and how do these components relate to one another? For over three decades, the research methodology has employed systematic literature reviews and qualitative meta-syntheses to explore the theoretical foundations of technology education pedagogy. Throughout my career, in collaboration with colleagues and postgraduate students, we have worked to develop and refine technology education pedagogy (or subject didactics) as a relatively new field by deriving it from general learning and teaching theory. By considering the philosophy of technology, we have reviewed relevant learning theories, perspectives on and sub-approaches to constructivism, and congruent teaching approaches or strategies. With the general theory of learning and teaching as a point of departure, we have deduced specific pedagogy for technology education, which has served as a fundamental aspect of our teaching programmes. The findings outline that the design-based teaching strategy is specifically relevant to technology education. It builds on problem- and project-based teaching strategies which are rooted in experiential, cooperative, inquiry and discovery learning as sub-approaches to constructivist learning and teaching approaches. Furthermore, design-based teaching strategies relate to the social constructivist perspective when students learn cooperatively, and to the cognitive and radical constructivist perspective when students learn individually.

Key Words: Technology Education, Constructivism, Pedagogy, Teaching Approaches and Strategies

1 INTRODUCTION: PROBLEM STATEMENT, PURPOSE AND METHODOLOGY

The literature on the teaching of technology often refers to constructs like constructivism (including cognitive, radical and social constructivism), experiential, cooperative, inquiry - and discovery-based learning. It also supports problem-; project-; and design-based learning and teaching in authentic contexts that mirror real-world technological problems, tools and practices, and that have transferability to students' lives beyond school. However, the said pedagogical constructs are dealt with in an arbitrary way without contextualising them within a rigorous theoretical framework. Instead, effective teaching and learning require a thorough, carefully designed framework that clearly distinguishes its components and clarifies their relationships. The purpose of this conceptual paper is to develop a rigorous theoretical framework for a pedagogy for technology education. The research questions are: What are the components of a theoretical framework for technology education pedagogy, and how do these components relate to one another?

For over three decades, the research methodology has employed systematic literature reviews and qualitative meta-syntheses to explore the theoretical foundations of technology education pedagogy. The literature has been selected, updated, and expanded to reflect advancements in technology education. This was achieved by searching and analysing key terms such as 'behaviourism', 'constructivism', their various 'perspectives' and 'sub-approaches', and associated 'teaching strategies'. Beyond reviewing literature on general didactics, the study reviewed technology education literature, drawing on PATT conference proceedings (since 1986), three leading international journals, and two authoritative handbooks.

Throughout my career, colleagues, postgraduate students, and I have developed and refined technology education pedagogy—or subject-matter didactics—by deriving it from general learning and teaching theory, or general didactics (cf., Arnold, 2012). By considering the philosophy of technology, we have reviewed relevant learning theories, perspectives on and sub-approaches to constructivism, and congruent teaching approaches or strategies. With general didactics as a point of departure, we have deduced a rigorous theoretical framework for technology education pedagogy, which has served as a fundamental aspect of our teaching programmes.

Due to space limitations, this paper presents an overview of the theoretical framework and its components. Parts of the theoretical framework have been published in alternative formats and genres, such as appropriate learning theories for technology education (De Swardt et al., 2005); a conceptual framework for learning and teaching in technology education (Reddy et al., 2005); design as the basis of an integrated STEM philosophy (Hallström & Ankiewicz, 2019); Minecraft Education (Nkadimeng & Ankiewicz, 2022); and approaches to teaching STEM (Ankiewicz, 2024). For a comprehensive overview, readers should consult the referenced publications. This iterative process reinforces the framework's validity, demonstrating that it remains current rather than being frozen in an earlier theoretical period.

2 THEORIES ON LEARNING OR LEARNING APPROACHES

An approach in this context should be viewed as a broad means of tackling a job. Despite the paper's focus on constructivism as a learning theory and an approach to learning which underlies technology education, it also recognises behaviourism as an important learning theory and an approach to learning.

Teaching based on behaviourist learning theories in technology education is appropriate when students must learn factual knowledge (embedded in conceptual knowledge) and develop basic skills in using and operating tools and equipment (associated with lower-order procedural knowledge) (Ankiewicz, 2003; Reddy et al., 2005). It is for teachers to translate behaviourist learning theories into congruent behaviourist teaching approaches or strategies, for example direct teaching and demonstration (De Swardt et al., 2005; Killen, 2007). However, behaviourism alone is insufficient for technology education (De Swardt et al., 2005; Reddy et al., 2005).

Constructivism has been defined in many ways by different scholars, including a Piagetian and Vygotskian view (Barak, 2018; De Swardt et al., 2005; Kanuka & Anderson, 1999; Muller et al., 2017). The basic premise of constructivism is that knowledge is acquired individually and cooperatively through active construction and reconstruction of theory and practice (Davis et al., 1990; De Swardt et al., 2005; Jenkins, 2000; Reddy et al., 2005; Taylor, 1999).

Johnson (1997) asserts that if intellectual skills development is to become the larger focus of the technology education curriculum, it does not imply that behaviourist theories of learning be abandoned in favour of the more contemporary constructivist theories. In fact, some teaching approaches or strategies could be based on a combination of both theories (Ankiewicz, 2003; Hammer, 1997) where teachers blend, for example, transmissionist lecture with cooperative, team-based, constructivist pedagogy. Bowen (2009) alludes to the fact that content-based learning, which is associated with behaviourism, is not the antithesis of cognitive-based learning, which is associated with constructivism (Reddy et al., 2005).

Constructivist learning theories and approaches to learning can be translated by teachers into constructivist approaches or teaching strategies to bring about a constructivist learning environment (Killen, 2007). The following section examines the perspectives and sub-approaches derived from constructivist approach (Nkadimeng & Ankiewicz, 2022).

3 CONSTRUCTIVISM: PERSPECTIVES AND SUB-APPROACHES

3.1 *Perspectives on constructivism*

The perspectives representing constructivist theories of learning are radical, cognitive and social constructivism (Cobb, 1994; De Swardt et al., 2005; Killen, 2007; Reddy et al., 2005). Both cognitive and radical constructivism relate to the Piagetian view, which focuses on the experiential world of the individual student (De Swardt et al., 2005). The view of knowledge suggested by both *cognitive* and *radical constructivism* is that human beings are, from birth,

constantly engaged in the process of adaptation of knowledge which is based on the individual's unique experience (Biehler & Snowman, 1997).

The perspective of *cognitive constructivism* is underpinned by Piaget's principle that knowledge is not passively received but actively constructed by people (Dart, 1994; Dart et al., 1998; Muller et al., 2017). A person learns individually by the process of adaptation which creates a good match between one's conception of reality and the real-life experiences one encounters. Adaptation consists of two subprocesses, namely assimilation and accommodation. (Biehler & Snowman, 1997).

Von Glasersfeld established the perspective of *radical constructivism* by adding a second underlying principle to cognitive constructivism. This second principle states that the function of cognition is adaptive and serves the organization of the experiential world and not the discovery of ontological reality. The principle is considered as radical as it suggests that there is no independent reality as nothing can be taken as proven. Thus, the emphasis is solely on the individual's knowledge construction, focusing the analysis on the way an individual constructs personal understanding (Candy, 1991; Muller et al., 2017; Reddy et al., 2005; Zietsman, 1996). Radical constructivism is concerned with both the structure and the construction of meaning in learning (Doolittle & Camp, 1999), and it advocates for the independent learning of students through creative and critical thinking, decision making, problem solving and design (Reddy et al., 2005).

Both cognitive and radical constructivism draw heavily on the work of Piaget—essentially focusing on the individual's constructions of knowledge that are developed through personal interactions with the environment (De Swardt et al., 2005; Killen, 2007). However, teachers should understand the continuum where students' knowledge is either entirely individually constructed within themselves through interacting with their own thoughts and unique activities in the world or socially constructed through interacting with other students and other students' views and experiences (Guzdial, 2018; Kanuka & Anderson, 1999; Phillips, 2000). Despite the distinction between individually and socially constructed knowledge, knowledge is always constructed within the individual.

While the experiential world of the individual student is the central focus of the Piagetian view (cognitive and radical constructivism), learning in the Vygotskian view (social constructivism) is placed firmly in the social and cultural domain (Barak, 2018; De Swardt et al., 2005; Kanuka & Anderson, 1999). *Social constructivism* places the student in a specific "cultural space" so that the student is seen to be engaged in constructing knowledge not in isolation, but in a "context that is shaped and modified by the influence of the society he/she finds himself/herself in" (Magadla, 1996, p. 83). The student appropriates meaning from the social and cultural environment (Barak, 2018; Magadla, 1996) before meaningful learning takes place.

The implications of social constructivism for learning and teaching in technology education are that students' social and cultural environment, i.e., home and family milieu, living conditions, religious and socio-economic factors, need to be considered. The nature of technological activities lends itself to social constructivist theories of learning where students engage in practical

activities and interact with one another when solving problems and designing in cooperative learning environments as part of projects (Barak, 2018; Grobler et al., 2022; Johnson & Thomas, 1992; Reddy et al., 2005).

Several sub-approaches to constructivism stem from the constructivist approach to learning (Black & Ammon, 1992; De Swardt et al., 2005; Reddy et al., 2005).

3.2 *Sub-approaches to constructivism*

3.2.1 *Experiential learning*

Experience is a key tenet of constructivist learning theories and approaches to learning. Thus, experiential learning is the overarching sub-approach to constructivism. Experiential learning emphasizes the importance of learning from experience that is goal driven, activity-based and problem centred (Johnson, 1997). Henak (1992) contends that meaning is added when students are actively involved in learning experiences. Meaning can come from activities that are relevant to real life problems (Reddy et al., 2005).

Technology education focuses on real life, authentic problems. Experiential learning is seen as a powerful and empowering tool to make technology education more meaningful and relevant to the lives of students. The activity-based nature of technology education provides ample opportunities for students to engage in experiential learning (Reddy et al., 2005).

3.2.2 *Cooperative learning*

Cooperative learning is a sub-approach to constructivism and relates to the social constructivist perspective. It shifts the focus of intellectual development from the solitary individual to the individual in a highly interactive social milieu (Black & Ammon, 1992). Rogoff and Lave (1984; cited by Johnson, 1997) state that all cognitive activity is socially defined. Cooperative learning is a learning approach in which students work together in groups to achieve a particular learning outcome (Slavin, 1980). It encourages positive interdependence, individual accountability, shared leadership, and improved social skills (Cavalier et al., 1995; Johnson & Johnson, 1989; King, 1984).

Social constructivism can be implemented through group discussions or collaborations on projects, which allows students to generalize and transfer their knowledge (Rezniskaya et al., 2007). Through the exchange of ideas, students develop shared meanings that allow group members to communicate effectively with each other (Wheatley, 1991).

Technological activities lend themselves to social constructivist theories of learning where students engage in practical activities and interact with one another when solving problems and designing in cooperative learning environments as part of projects (Barak, 2018; Grobler et al., 2022; Johnson & Thomas, 1992; Reddy et al., 2005). By interacting with others in the technology classroom, students can learn from one another, share knowledge, engage in co-operation and competition and negotiate meaning.

3.2.3 *Inquiry learning*

Inquiry learning is whereby students question, investigate and seek out information, thereby assuming responsibility for their own learning, with the teacher playing a facilitative role. Inquiry learning is an investigative learning process which is often equated to experimentation, problem solving and discovery (Schwaller, 1995).

The problem-solving nature of the technological tasks provides ample opportunities for students to engage in inquiry learning (Best, 2018; Reddy et al., 2005). Investigation and research in technology education are rooted in inquiry learning. Involving technology students in inquiry learning is one of the most effective ways to help them develop their higher order critical thinking skills (Eggen & Kauchak, 1996; Reddy et al., 2005). In accordance with the Piagetian view, inquiry learning advocates for independent learning through problem solving and discovery (Friesen & Scott, 2013).

3.2.4 *Discovery learning*

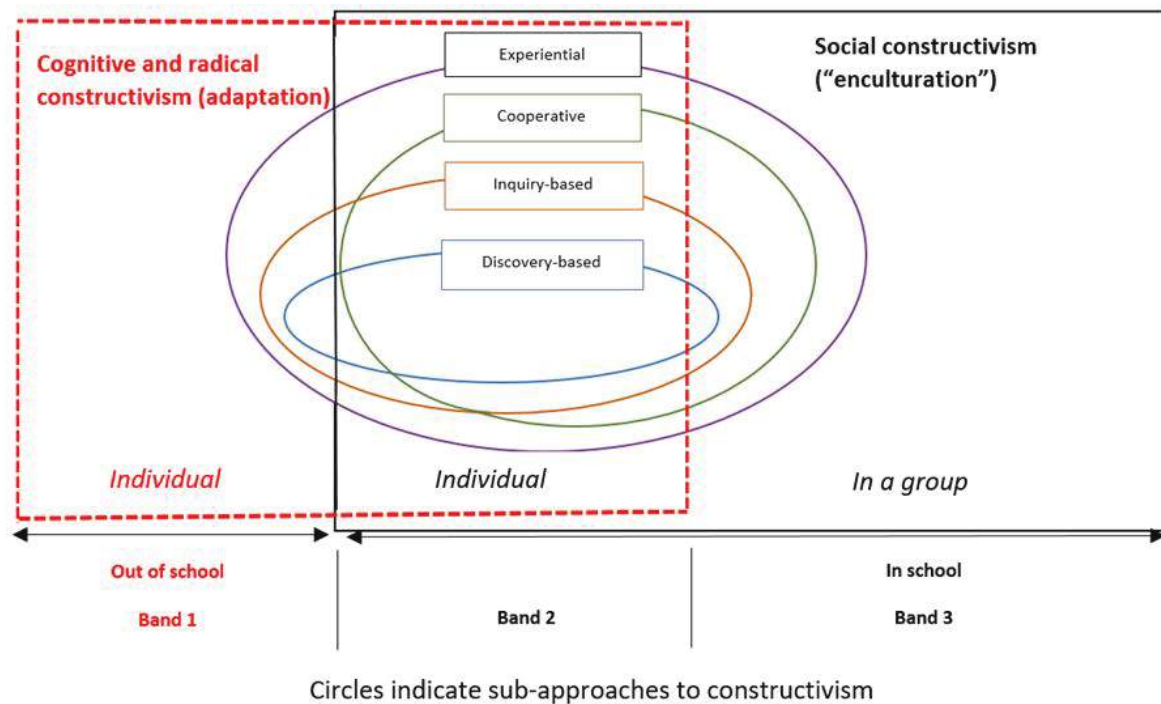
Discovery learning is a sub-approach of inquiry learning (Bruner, 1961), and it involves the discovery by students of what they can think and do for themselves (Bruner, 1966). To achieve discovery, students must incorporate and integrate information with what is already known so that new relationships are formed, specifically the discovery of relationships between parameters (Biehler & Snowman, 1997). Discovery does not necessarily mean coming up with knowledge that is unknown to someone else but coming up with knowledge by oneself (Mwamwenda, 1995). It involves rearranging or transforming information to obtain new insights.

Given the problem-solving nature of technology education, the discovery approach to learning is a valid form of knowledge construction, whereby students take responsibility for their own learning. Innovation—the process of improving and refining technological solutions—in technology education has its roots in discovery learning as it is a product of discovery (Reddy et al., 2005).

As learning is neither entirely individual, nor entirely cooperative, but a mix of both, Figure 1 depicts the Piagetian (cognitive and radical constructivism)—on the left—and the Vygotskian view (social constructivism) as part of constructivism—on the right. The four sub-approaches associated with constructivism have been superimposed onto the three perspectives. Generally, students out of school may learn entirely individually by inquiry-based learning and discovery-based learning (Band 1). However, when learning in school they also present as individuals who might learn in a similar way (Band 2) than out of school (Band 1). Furthermore, when learning together with their peers in school (Band 3), they may also learn cooperatively, including inquiry- and discovery-based learning. The fact that students interpret and construct meaning from existing socially-constructed systems, does not diminish the importance of personal construction of knowledge (Guzdial, 2018; Phillips, 2000). Knowledge is always constructed within the individual.

Figure 1

Superposition of Constructivist Sub-Approaches onto the Three Constructivist Perspectives (Ankiewicz, 2024; Nkadameng & Ankiewicz, 2022)



The focus now turns to translating constructivist approaches into congruent teaching strategies (De Swardt et al., 2005; Killen, 2007).

4 CONSTRUCTIVIST TEACHING APPROACHES OR STRATEGIES IN TECHNOLOGY EDUCATION

4.1 *Converting learning approaches into teaching approaches or strategies*

Technology education involves, *inter alia*, creativity, problem solving and design (Jones et al., 2013). As “... (learner) activity is that pivotal event in which knowledge and skills unite to bring artefacts into existence ...”, technology education should at its core also be activity-based and constructivist (Ankiewicz, 2003, p. 10, Ankiewicz, 2013, p. 5; Jones et al., 2013). Unlike constructivism as a learning theory and an approach to learning, teaching strategies are more confined/narrowed and they indicate ‘a plan’, ‘...a procedure of how to go about it...’. Technology education is best situated within constructivist theories of learning (Grobler et al., 2022; Reddy et al., 2005).

When applying a constructivist or behavioural teaching approach, a variety of teaching strategies (Jakovljevic & Ankiewicz, 2016) are essential for technological problem solving. Based on constructivism, problem-; project-; and design-based teaching approaches or strategies are key to technology education.

4.2 *Problem-based teaching approaches/strategies*

Problem-based learning centres on authentic, real-life problems that are ill-structured, open-ended and ambiguous (Banks & Barlex, 2014; Williams et al., 2008), and it is driven by the inquiry process (Best, 2018). Its congruent teaching approaches or strategies are based on the social constructivist perspective on and the cooperative and inquiry-based sub-approaches to constructivism (Allen et al., 2011; Best, 2018; Jakovljevic & Ankiewicz, 2016; Schwartz, 2013; Stage et al., 1998).

Technology is essentially problem solving (Best, 2018). Although a distinction is made in technology between design and problem-solving (Johnsey, 1995; McCormick, 1997), there is a connection between these concepts. The design process is seen as the manifestation of the problem-solving process (McCormick et al., 1994). According to De Vries (International Technology Education Association [ITEA], 1997) design is a particular type of problem solving in technology (Ankiewicz, 2003, Ankiewicz, 2013; Ankiewicz et al., 2006). Problem-based learning in technology education “is not about problem solving per se, but rather it uses appropriate problems to increase knowledge and understanding” (Wood, 2002, p. 8 in Best, 2018).

4.3 *Project-based teaching approaches/strategies*

Project-based learning is founded on the Piagetian and the Vygotskian views which account for learning as individuals constructing knowledge in interaction with others and with the environment (Major & Govers, 2014). Project-based learning engages students in complex tasks based on challenging or ‘driving questions’. Where the project is based on a real-world problem, it encourages students to carry out authentic tasks based on their ‘real-life’ experience (Banks & Barlex, 2014; Cheng et al., 2007; Hawari & Noor, 2020; Major & Govers, 2014; Svärd et al., 2017).

Student activities in a project-based classroom require different approaches to learning (e.g., experiential, cooperative, inquiry and discovery learning) (Bednar et al., 2013; Jakovljevic & Ankiewicz, 2016; Johnson, 1997; Johnson & Johnson, 1991; Rogoff & Lave, 1984). Technological activities lend themselves to social constructivist theories of learning where students engage in practical activities and interact with one another when solving problems and designing in cooperative learning environments as part of projects (Barak, 2018; Grobler et al., 2022; Johnson & Thomas, 1992; Reddy et al., 2005).

Project- and problem-based learning tend to be two sides of the same coin. Problem-based learning focuses on students proposing solutions to a problem or a situation to increase knowledge and understanding. Project-based learning involves an authentic context for doing something — collecting data, designing a product, or doing practical work. The desired outcome of problem-based learning is new knowledge and understanding; of project-based learning is an artefact, system, or process manifesting that new knowledge (Banks & Barlex, 2014). There is a connection between problem solving and design in technology education.

4.4 Design-based teaching approaches/strategies

Design is the primary methodology of technology which is more intuitive (De Vries, 2018) than engineering design as it has an element of trial and error to it (Williams, 2011). Design in technology will typically lead to the making of an object, or system (cf., Vermaas et al., 2011).

In design-based learning students need to seek out information in service of reaching a solution to a problem that has become important to them. Learner engagement fosters deep, probative, just-in-time learning.

5 CONCLUDING DISCUSSION

5.1 Components and constructs of a theoretical framework for technology education pedagogy

Figure 2 provides a simple outline of the components of a theoretical framework and the related constructs which were discussed in the paper. The dotted lines between the components and constructs indicate that they are related or part of one another. The shaded constructs are particularly related to technology education.

Figure 2

Components and Constructs of a Theoretical Framework for Technology Education Pedagogy (Ankiewicz, 2024)

Components	Constructs		
Learning theories or approaches	Constructivism		
Perspectives on constructivism	Cognitive	Radical	Social
Sub-approaches to constructivism	Experiential		
	Cooperative	Inquiry	Discovery
Teaching approaches or strategies	Problem-based	Project-based	Design-based

Consistent with the paper's purpose to develop a rigorous theoretical framework for technology education pedagogy, it firstly, described the tenets of the constructivist theory and learning

approach. It also emphasised that technology education is prone to constructivism. Secondly, the paper discussed various perspectives on constructivism, namely radical, cognitive and social constructivism. Thirdly, arising from the constructivist theory and learning approach, it deliberated on the various sub-approaches, namely experiential, cooperative, inquiry and discovery learning. It asserted that technological activities lend themselves to social constructivist perspectives of learning where students engage in practical activities and interact with one another when solving problems and designing in cooperative learning environments. Fourthly, based on constructivism, the paper reviewed congruent teaching approaches or strategies which are key to technology education, namely problem-; project-; and design-based teaching.

The design-based teaching strategy is specifically relevant to technology education. It builds on problem- and project-based teaching strategies which are rooted in experiential, cooperative, inquiry and discovery learning as sub-approaches to constructivist learning and teaching approaches. Furthermore, design-based teaching strategies relate to the social constructivist perspective when students learn cooperatively, and to the cognitive and radical constructivist perspective when students learn individually.

5.2 *Implications for technology teachers*

Based on Figure 2, the theoretical framework is valuable not only to researchers but also to pre- and in-service technology teachers. The rigour of the framework provides, *inter alia*, sound guidelines on how to manoeuvre between behaviourism and constructivism, as well as project-, problem-, and design-based teaching. For example, if a teacher intends to teach different types of gears and gear trains as factual knowledge, behaviourism—utilising discussion and demonstration as teaching approaches or strategies—would be an appropriate learning theory or approach.

If a project brief in a unit/lesson requires students to engage in a cooperative design project within an authentic context (e.g., designing and making a mechanical control system involving gears), the teacher might choose a constructivist learning theory or approach underpinned by a social perspective, utilising cooperative learning as a sub-approach to constructivism. Such a unit/lesson could begin with problem-based teaching supported by inquiry learning; here, the teacher expects students to identify and propose solutions to the problem embedded in the project brief.

Furthermore, if the unit/lesson requires students to construct various gear trains to discover relationships between parameters—such as the link between speed or torque and the gear ratio—it shifts towards project-based teaching underpinned by discovery learning. Finally, as students design and make their solutions by producing mechanical control systems as physical artifacts, the teacher ultimately applies design-based teaching.

6 AI DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Laughing at Energy Solutions: Humour, Expertise, and Belonging in Engineering Culture

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Abstract

In this study, we explore humour in engineering education and its relation to disciplinary culture. Previous research has shown that humour is not merely a form of entertainment or relaxation in educational settings, but a powerful discursive tool through which values, hierarchies, and belonging are negotiated. Our aim is to capture how students' humour reflects engineering norms, as well as their engineering identity. In this study our empirical data consist of a video recording of four engineering students who were working on a project concerning the wolf population in Sweden. We zoomed in on moments when the students laughed of any reason. One particular episode, in which they made jokes about ill-conceived energy-saving solutions, was chosen for deeper analysis using positioning theory. The jokes were primarily ironic suggestions for solving energy shortages, such as installing wind turbines on cars or positioning two wind turbines to face each other. These jokes made everyone in the group laugh and the humour functioned both as a means of releasing tension and as a way of fostering group cohesion. However, our analysis also shows that the engineering students positioned themselves as knowledgeable about how energy works, in contrast to politicians, who were positioned as ignorant. At the same time, technical knowledge was positioned as the most valid form of knowledge. According to the jokes, engineers were positioned as more reliable decision-makers on national issues than politicians. In other words, although technology and engineering have traditionally been described as apolitical subject areas with a weak connection to social change, these engineering students constructed themselves as important contributors to society at large, through humour.

Key Words: Humour, Engineering Identity, Responsible Engineering

1 INTRODUCTION

In this study, we explore humour in engineering education and its relation to disciplinary culture. Within engineering education research, it has been argued that engineering culture is partly underpinned by an 'ideology of depoliticisation', which frames all 'non-technical' concerns as peripheral (Cech, 2014). This includes viewing politics as irrelevant to 'real' engineering practice.

The ideology of depoliticisation manifests itself within engineering education when engineering is positioned as a purely ‘technical space’ and social and political issues are presented as ‘tangential to engineers’ work’ (Cech, 2013, p. 67). Humour is part of every culture (Kuipers, 2015), even engineering cultures. Many professions have a series of jokes about themselves, generally told within the group and drawing on stereotypical behaviour within that profession (Riley, 2008). In science education, it has been pointed out that humour has consequences for student learning (Berge & Anderhag, 2025), even though talking science is based on the premise of being serious and based on facts. In engineering education humour has also been debated, but more in relation to problematic humour and ‘canned jokes’ that describes engineers or engineering. Riley has used jokes about engineers to investigate the culture of engineering and thereby draw out ‘some mindsets commonly found in engineering’ (p. 33). The following joke is from her book *Engineering and Social Justice*: “Real engineers . . . have politics that run toward a corner office and a parking space with their name on it” (p. 38).

Fully aware that not all engineers fit into this stereotype, Riley points out that this joke portrays a mindset of an engineer that is politically inactive, disinterested, or uninformed. This form of humour emphasises the ‘corporate context in which engineers often work and a mindset of managerialism in which organizational bureaucracy is an end in itself’ (p.38), which is very close to the ideology of depoliticisation, described by Cech (2013; 2014). However, although canned jokes portray engineers as apolitical, we know little about how engineering students engage with political humour in situ within engineering education. This study addresses this gap. Our aim is to capture how engineering students’ humour reflects engineering norms, as well as their engineering identities.

2 BACKGROUND

In jokes about engineers, they are often stereotyped. Riley’s research (2008) illustrates how engineers are often constructed as proficient problem-solvers while simultaneously being characterised as lacking social competence. Similar patterns were identified in Keren and Kapon’s analysis of English-language jokes on Google (2023). However, humour is always very context-dependent. In Turkey, it is common for female engineering students to be mocked through jokes portraying them as having moustaches (Pehlivanli-Kadayifci, 2019). According to Pehlivanli-Kadayifci, this joke (which she explicitly rejects) carries two symbolic meanings: (1) it signifies masculine competence in Turkish culture, and (2) it invokes the image of ‘dishevelled’ female engineering students. Such toxic humour functions to ridicule female students who are hardworking and perceived as not ‘caring about their appearance’ (p. 1194). Male and MacNish have also described how toxic humour can make life difficult for female engineers. In their example, the women’s gender was ‘amplified’ because the men told them they could not tell the same jokes when (the very few) women were around. When the women protested, the joke came out: ‘What makes nine out of ten people happy? Gang rape’ (p. 141), making the women even more uncomfortable. Leppälä and Lehtimäki’s ethnographic research (2024) on a Finish engineering workplace shows how installation humour can become a form of empowerment for the employed engineers. Material expressions, like painting a canoe on a serious placard in a stairwell, formed a resistance towards managerial initiatives within an organisation. This humour ‘emerged, was temporarily realized and then, quietly disappeared’ (p. 215).

As illustrated above, engineering humour occurs in many places, although we do not find the same jokes funny. From humour research, we know that humour is not merely a form of entertainment or relaxation, but a powerful discursive tool through which values, hierarchies, and belonging are negotiated (Billig, 2005). Previous research has shown that humour and laughter function to develop norms in learning settings (Kobayashi & Berge, 2022). Humour can be used to explore norms because humour is connected to expectations. This is underscored by the three humour theories: incongruity theory, relief or release theory and superiority theory (Friedman & Friedman, 2019). Humour arises from a contrast between what is expected and what actually occurs or is said, meaning that laughter is triggered by the unexpected (incongruity theory). Humour also functions as a tension release in relation to expectations within a situation (relief or release theory). As an example, nervous laughter in a meeting can signal that a PhD student is uncertain of her living up to expectations. Humour is also closely connected to hierarchy (superiority theory) since we have different expectations of humorous behaviour depending on social status and humour may be used to connect with people as well as shaming and disciplining them. So far there is an overwhelming emphasis on the positive aspects of humour, such as social bonding and having fun, while many studies overlook its darker sides (Plester, 2015). However, as mentioned before, humour carries strong rhetorical power (Bayarri Toscano et al., 2025; Brantner et al., 2020; Merrill et al., 2025). Capturing the values expressed through humour therefore requires being open to both positive and negative behaviour within an environment.

In this study, we conceptualise humour as a collective and interactive process, drawing on Franzén, Jonsson, and Sjöblom's analysis of how humour is 'constructed and transgressed in social interaction' (2021, p. 764). We understand cultural norms as shaping the ways we navigate them; at the same time, as we embody these norms and become part of culture, new and previously unimagined ways of acting may emerge. In this way, identities, values, and norms are fluid and adaptable in practice. Moreover, the performance of identity is influenced by intersecting dimensions such as gender, ethnicity/race, (dis)ability, and social class (Phoenix, 2006). This means that, when we investigate engineering students' humour, we not only explore engineering norms but also possible engineering identities within engineering education. Thus, this study goes beyond our previous studies which conclude that engineering students' laughter constructed the project group as a collective 'we' (Holmén & Lönngren, 2025), to analyse what is behind the laughter.

3 METHODOLOGY

Our empirical data consist of video recordings from groups of engineering students working together on sustainability-related problems, as part of our research project about emotions in engineering education EMOTE, (for further details regarding data collection see Holmén and Lönngren (2025)). In this study, we 'zoom in' on a particular moment in one recording within our video data set. This moment stands out in the whole material because of two reasons. First, the whole dataset is filled with markers of interactive humour (Burgers & van Mulken, 2017), for example, figurative speech (linguistic markers), tone of voice and laughter (paralinguistic markers), and facial smiling, lip tightening, and raised eyebrows (visual markers). When skimmed through the videos on what's being said at these instances, we identified humour as intrinsic parts of the groups' mutual problem solving, and the students' humour and laughter functioned as a

form of ‘tension release’ (Friedman & Friedman, 2019) when the task was difficult or when they suggested ideas, similar to previous research (Berge, 2017). However, in this particular ‘instance of enjoyment’ (Holmén & Lönngren, 2025), a group of students’ laughter was significantly powerful in terms of volume and unity, compared with how these four students expressed themselves for the rest of the time together. Moreover, their humour did not concern themselves or the problem-solving task, but their interaction was focused on politics and politicians, contrasting with Cech’s description of engineering culture as partly underpinned by an ‘ideology of depoliticisation’ (2014).

In our analysis, we examined how humour is constructed and transgressed in social interaction (Franzén, Jonsson & Sjöblom, 2021), with particular attention to the taboos and norms invoked. In addition, through detailed analysis of each speech act and its function within the conversation (Berge, 2017), we sought to capture how engineering identity was positioned within the humorous interaction. Positioning theory (Kayi-Aydar, 2018) was employed to examine who or what was positioned as funny, and by whom. The analysis included silence and body language and was conducted in Swedish. GenAI was used for a first translation of transcripts from Swedish and for copy editing.

4 RESULTS: IT LOOKS BLEAK, BLEAK FOR SWEDEN

The humour episode comes from group of a third-level engineering students who were working on a project together. It consisted of Anders (A), Bertil (B), Cecilia (C) and Dina (D), all from different parts of Sweden. The project concerned the controversial issue of maintaining a stable wolf population in Sweden and their overarching was to devise and administer a survey about people’s attitudes towards wolves. This group appeared to work mainly individually and in silence in front of their computers most of their time, although they also had good discussion about their shared responsibility regularly, (which was part of their work description). In other words, although they sat around a big table facing each other this group did not have much interaction compared to several other groups, and there were no irregularities either.

The humour episode begins with Anders introducing politics, seemingly out of nowhere:

1. A: Did anyone listen to the party leaders’ debate yesterday?
2. C: n[o]
3. D: [no] hehe
4. A: I can only say [that it] looks bleak for Sweden
5. B: [I wrote a p-]
6. C: What [did you say?]
7. B: [what did] you say?
8. A: It looks bleak, bleak for Sweden.
9. D: hehehe
10. B: right
11. A: the politicians are more stupid than ever.
12. D: thehe

Nothing in Anders' face reveals that he intends to make humour here. However, Anders' very calm and unengaged voice indicates that he intends to be humorous since he uses the strong and affective words 'bleak for Sweden', which becomes a form of incongruity (Plester, 2015). Dina giggles nervously (a form of tension release) throughout this conversation (3, 9), which we interpret as a personal trait, as this behaviour is typical of her interactions across all our recordings. Bertil and Cecilia, on the other hand reacts with confusion (6, 7), not prepared to discuss politics. Anders continues with a sarcastic line about politicians (11) and Dina giggles nervously again (12). We interpret this as Anders expressing an interest in talking about politics; however, in line with Cech (2013, 2014) he makes this move with a certain distance, by appearing calm and his dry tone that can be interpreted as humorous in this context. This move is not picked up by the other students in the group neither. Bertil answers vaguely (10) and Cecilia and Dina do not pick up the subject. To talk politics appears to be taboo in this setting (as well is in many other Swedish settings (Eriksson et al., 2022)).

Anders makes several similar attempts with the same tone of voice to talk sarcastically about the debate he listened to the day before: 'The right-wing parties want to build expensive nuclear power' and 'They [the right-wing parties] say that's how they're going to solve everything with nuclear power.' Cecilia answers this but looks unengaged, she might be afraid to talk politics but might also want to focus on their work. Anders continues: 'Yes, according to the politicians, the Swedish people supposedly want high electricity prices.' Bertil answers but looks uncomfortable and Cecilia tries to get them to talk about the wolf-population again. None of these attempts get any humorous response (Burgers & van Mulken, 2017) apart from nervous giggles from Dina.

Then Anders, with the same tone mentions wind energy:

- 13. A: And Ulf [the Swedish prime minister] pointed out in the debate that the wind doesn't blow all the time.
- 14. B: Hehe.
- 15. D: That's actually true – fair point, really.
- 16. B: Yeah, bloody hell, I've honestly thought about that, like, so if you just told the engineers, who build the wind turbines, then you...

Bertil and Dina make unengaged affirmations of hearing Anders (14, 15), but suddenly the conversation change structure. Bertil has laughter in his voice when he says, 'bloody hell' (16) like he has understood something important, and then he brings in engineers in the conversation, positioning engineers as alternative thinkers to the politicians. Bertil starts to build on Anders' humour here with an ironic joke about a supposed knowledge gap between politicians and engineers. Bertil positions engineers as the people who build the wind turbines (which can be discussed) and engineers as more knowledgeable and smarter than politicians. Dina and Bertil then continue talking with laughter in their voice about different silly places where wind turbines can be put.

When this is said Cecilia for the first time since Anders started talking about politicians shows engagement in her face and says:

17. C: But what do you mean? We could just put the wind turbines facing each other-
((smiles and makes illustrating gestures with her hands))
18. D: - then it blows backwards ((gestures with hands))
laughter
19. C: yeah
20. D: a really great idea
21. C: alright ((makes a convincing hand gesture))
22. D: why have they never done that?
23. B: nah ((smiles))
((C shakes head))
24. D: Or they could have one there and then [we] blow on them
25. C: yeeah
26. D: ((illustrates someone blowing with their mouth)) hehe
27. C: Yeah, it's probably just a fan in front of them
28. B: Or we could put wind turbines on cars?
Lots of laughter

Cecilia and Dina propose with serious voices that the wind turbines could be placed facing each other (17, 18), and groups laughs genuinely together, Anders too. There is no ambiguity about this being humour, and they are all positioned as sharing an understanding that this is an idiotic suggestion and bad technological solutions (19, 20, 21, 22, 23). Dina builds on Cecilia's humour again, suggesting that people could blow on wind turbines and generate energy that way (24, 26), and Bertil proposes that wind turbines could be placed on cars (28). Bertil finds himself so funny that he cannot sit on his chair anymore but slips down. Again, they all laugh genuinely together, bonding as a group, as their ironic suggestions for solving energy shortages position them as understanding the issue better than politicians and perhaps even better suited to make decisions in these matters. After this they continued to work with the problem with stable wolf population.

5 DISCUSSION

The tendency to distrust and make fun of politicians' competence is not unique to engineers or engineering students (Billig, 2005). However, in this interaction, the student Anders repeatedly attempted to introduce political discussion (p. 5) but received no response until the students engaged in a shared humorous discourse in which they all seem comfortable participating. It is not the distrust itself that is of interest here, but rather how the humour, after some work, is mutually constructed. This engineering humour is not for anyone: to appreciate the humour here a basic understanding of physics and of how large wind turbines/cars are is required. Unfortunately, we do not believe that the students learnt from this interaction, in contrast to previous studies (Berge & Anderhag, 2025). However, the humour functioned both as a means of releasing tension, partly there because Anders brought up politics, and as a way of fostering group cohesion, which are a common function of humour (Plester, 2015). Humour in form of funny and idiotic technological solutions became a way to touch the subject of politics.

This form of humour positioned technical knowledge as the most valid form of knowledge to make good decisions for the society. More important is that students positioned themselves as knowledgeable about how energy works, in contrast to politicians, who were positioned as ignorant and thereby constructing engineering identity. Although technology and engineering have traditionally been described as apolitical subject areas with a weak connection to social change (Ceck, 2013; 2014; Riley, 2008), these engineering students constructed themselves as important contributors to society at large, through humour. However, the humour redirected their attention towards silly and impossible solutions rather than what should and can actually be done regarding Sweden's future energy policy. The humour also shifted the presumably more serious topic of which political party to vote for (although we can infer that Anders is unlikely to vote for a right-wing party) towards a framing in which all politicians are portrayed as idiots, a common theme in humour (Billig, 2005). In other words, humour opened up politics as a topic of conversation, but without any depth, and this is presumably not a way to encourage engineering students to engage with politics or society.

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Studying and Comparing Students' Collaborative Practices in a Design Project

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Abstract

In technology and engineering education, there is a growing emphasis on curricula that include collaborative design projects. However, detailed studies of how students interact over longer periods of time are rare. In this study, students in a design project in the fifth semester of the Architecture and Design programme at Aalborg University, Denmark, are studied. The students had the task of designing a real office building in collaborative groups of 5–6. Video (2–5 cameras per group) was used in situ to record students' preparation for an upcoming status seminar. Drawing on interaction analysis, we have examined how students' activities unfold across an entire day within different groups. The social interactions were found to be complex and dynamic. Students fluidly shifted between individual work, dyadic and triadic engagements, and full group collaboration across different spatial configurations. Moreover, their collaborative work progress in the design project was not static, nor did they follow predefined scripts. Instead, they were temporally evolving, contextual, deeply embodied, and challenging conventional dichotomies between cooperation and collaboration. However, a comparative analysis of the social interactions between the groups also revealed differences in how students collaborated and how well they worked together within groups. The groups organised, structured and designed their collaborative practices differently over the period of an entire day. This raises the question of what constitutes good collaboration and effective collaborative skills. Moreover, through visits to design projects in high schools and at various years in university-level engineering education, we have also observed an apparent progression in students' collaborative skills. This raises a second question: How should the development of these skills be best facilitated at different levels of education?

Key Words: Design Project, Collaborative Learning, Group Practices, Video Ethnography, Interaction Analysis

1 INTRODUCTION

1.1 *Importance of design education in engineering and technology education*

The ability to develop and design products, processes, and systems, as well as to demonstrate effective teamwork and collaboration, has become a core requirement of engineering degrees in many countries. For example, Swedish national university regulations stipulate that, to be awarded an engineering degree, students must “demonstrate the ability to develop and design products, processes and systems [and] demonstrate the capacity for teamwork and collaboration”. Reflecting these expectations, there has been a growing emphasis on the inclusion of collaborative design projects within engineering education, a requirement that is also embedded in the CDIO standards (e.g. Crawley et al., 2014; Edström & Kolmos, 2014).

Given the central role that design-based learning activities now play in engineering and technology education, there is a clear need to develop a deeper understanding of students’ learning processes within design projects. Furthermore, it is important to investigate how students, through participation in such projects, develop the capacity for teamwork and collaboration—specifically, how they become skilled in collaborative design work.

1.2 *Teamwork and collaboration*

However, the concepts of collaboration and cooperation are often insufficiently differentiated, and important nuances are consequently lost in their definitions. Following Dillenbourg (1999), Stahl (2013, 2016), and related work, we understand cooperative learning as an activity in which students divide the work among themselves and subsequently integrate their individual contributions. In contrast, collaborative learning involves students working together on the task itself.

Collaboration and collaborative learning thus imply a shared activity directed towards a common purpose, characterised by mutual interdependence in achieving the intended learning outcomes (Dillenbourg, 1999). Stahl (2013, 2016) further argues that research on collaborative learning should focus on small-group phenomena and treat the group, rather than the individual, as the primary unit of analysis. From this perspective, collaborative groups construct knowledge through shared understanding, co-construction, and interaction within a joint problem space.

Building on this view, Stahl proposes that studies of teamwork and collaboration should draw on post-cognitive theoretical frameworks. Accordingly, a project group engaged in a collaborative design project can be conceptualised as a community of inquiry. Indeed, cognition in engineering design projects (Brereton, 2004) has been described as an example of distributed cognition (e.g. Goodwin, 1995; Hutchins, 1995), insofar as achievements emerge not only from individual reasoning but also from collaborative thinking distributed across members of the design team and mediated by the use of epistemic tools (Goodwin, 2018).

1.3 *Short literature review and our earlier studies*

More than three decades ago, Tang and Leifer (1991) argued for the use of video recordings and interaction analysis (Jordan & Henderson, 1995) as a means of studying group-based design activity. Despite these early methodological advances, empirical research on students' design processes has, until relatively recently, been dominated by variants of "think-aloud" methods combined with verbal protocol analysis (Craig, 2001). Such studies have primarily focused on individuals working in artificial or laboratory-like settings (Bernhard et al., 2016), often involving tightly bounded design tasks completed within relatively short timeframes of one to two hours (e.g. Atman et al., 2007; Atman et al., 1999; Cardella et al., 2008).

Only a limited number of studies have examined engineering students' design processes using interaction analysis in naturalistic group settings. To our knowledge, Campbell et al. (2018), alongside our own work, constitute rare examples of research adopting this approach. More broadly, a small but growing body of literature has employed ethnographically inspired methods to investigate students' design work in authentic educational contexts. These studies have made use of audio recordings (e.g. Gilbuena et al., 2015), video recordings (e.g. Campbell et al., 2018; Goncher & Johri, 2015), and combinations of photographs and field notes (e.g. Juhl & Lindegaard, 2013). Collectively, this research has contributed important insights into the situated and interactional nature of students' design activity.

Our previous studies have built on this line of work through video-based investigations of a fifth-semester design project within the problem-based learning (PBL) Architecture and Design programme at Aalborg University. These studies demonstrated that students displayed epistemic fluency (Markauskaite & Goodyear, 2017), characterised by the skilful use of a rich repertoire of bodily and material resources. Students worked both "by hand and by computer," using these resources as epistemic tools to support collaborative thinking during design activities (Bernhard et al., 2019; Bernhard et al., 2020; Ryberg et al., 2021). Through such practices, students developed a professional dialogical space that was constituted not only through verbal discourse, but also through embodied and material interaction (Davidsen et al., 2020). In related work, we have further analysed the different forms of knowledge embedded in, and emerging from, students' collaborative and embodied interactions (Ryberg et al., 2020).

Within the broader literature on collaborative learning, the composition of collaborative groups is typically treated as static and stable over time (e.g. Borgford-Parnell et al., 2013; Menekse et al., 2017). However, analyses of video data from our earlier studies revealed that students often approached specific design problems in shifting subgroups of one, two, or three students, as well as in whole-group sessions. This observation suggests that collaborative groups in design education may be considerably more dynamic than is commonly assumed in the literature.

1.4 *Research question*

As the issue of group dynamics of collaborative work in students' design project practices has received limited explicit attention, we addressed it directly in a recent study, (Bernhard et al., 2023a; Bernhard et al., 2023b; Davidsen & Bernhard, 2026). That study was driven by the question how could we describe and understand the dynamics of students' individual and

collaborative work in a design meeting? That study showed that collaboration in the studied group was highly fluid, encompassing a wide range of configurations, with students moving in and out of ‘private conversations’ alongside shared design dialogue. However, in the previous study, only one group of six students were observed and analysed.

In this study, we extend the previous study's question to include an additional group of six students. The research questions thus became:

- (i) How could we understand the dynamics of students’ individual and collaborative work in a design meeting in two student groups?
- (ii) Which similarities and differences in the collaboration patterns of the two groups could be observed?

2 SETTING AND METHODOLOGY

2.1 *Setting*

The setting of this study is the Architecture and Design (A&D) programme within the Aalborg problem-based learning (PBL) model, which was created in response to the call for engineering programmes to include collaborative design projects of varying length and complexity. The A&D programme includes elements of architecture education, but also builds on knowledge, skills, and competencies from engineering. In the Danish context, this was a novel approach when the programme started in the 1990s, as architecture and engineering were traditionally separated. The creation of the A&D programme was an attempt to combine the “technical theoretical” knowledge of engineering with the “aesthetic and artistic” artisanship of architecture, to create a new interdisciplinary education.

The data analysed in this paper is from a period 14 days into a project work where fifth semester A&D students are tasked with designing an office building for an external partner. The particular session studied is where student groups are preparing to take part in a formal review session the next day. The sessions lasted almost six hours. After the review session the groups have approximately four weeks left to complete their design of the building. The preparation for the review session was selected for analysis as it is what Jordan and Henderson (1995) refer to as a natural unit of analysis – limited in time and with a particular purpose.

Each group had a designed main workspace that was encircled by a fixed wall with windows, and two “walls” consisting of whiteboards, pinboards and blackboards. The “board walls” are used for various design ideas and sketches. In the midst of each group space is a “working table”.

2.2 *Data collection and method for analysis*

To obtain a rich account of students’ individual and collaborative work, and to enable studies aimed at enhancing our understanding of engineering students’ learning processes in collaborative design projects, we recorded group interactions using 2–5 digital camcorders throughout the

entire session (Goodwin, 2018; Heath, 2016; Jordan & Henderson, 1995; “Big Video”, e.g. Mcilvenny & Davidsen, 2017; Tang & Leifer, 1991). In this case, the session lasted almost six hours.

For the purposes of this study, the recorded videos from two groups (group 1: one female, five males, and group 3: four females, two males) were viewed and analysed through a coding process that identified the constellations in which students worked (e.g. individually, in subgroups, or as a whole group). In addition, students’ membership of subgroups was documented, as were the points in time at which constellations changed. To be counted as a member of a given constellation, a student was required to demonstrate active participation, either verbally or through bodily action.

Figure 1

Still pictures from videos displaying first individual work (pictures a and b) and a transition to a dyad between Ina and Mette (c and d). See also Transcript 1



As an example of the analysis, Figure 1 and Transcript 1 illustrate a transition from individual work by all four female students in group 3 to a dyad involving Ina and Mette, alongside continued individual work by Sine and Heidi (corresponding to Episodes 19 and 20 in Figure 2). For a more thorough description of the coding methodology, see Bernhard et al. (2023a) and Davidsen and Bernhard (2026). Figures 2 and 3 graphically illustrate the temporal diagrams constructed from the results of this coding. In the temporal diagrams, each student is assigned a distinctive colour, making students’ participation in the different constellations visible according to the coding of their interactions.

Transcript 1

Related to Figure 1 – part of episodes 19 and 20. Time from the beginning of the session is 01:03:40 – 01:11:57 (h:min:s)

1	Ina	((Figures 1a – 1b. From 01:03:40 Ina first sits silently and make drawings on her iPad, but after a while she puts it away and instead put some layers of a 3D Styrofoam model and begin to use a pencil to trace the contours of the styrofoam model onto a paper.))
2	Ina	Mette? ((Figure 1c. Calls for Mettes attention at 01:11:14)) (3.2)
3	Mette	why why
4	Ina	this is also two hundred (.) I just started to think about it
5	Mette	Ehmmm (9.0)
6	Ina	Mette?
7	Mette	yes
8	Ina	that is because (.) I do not know if it is stupid (.) what I am doing
9	Mette	what are you doing? (4.5) ((Figure 1c. Mette moves over to the position of Ina still sitting on her chair))
10	Ina	that is because I have actually changed something in it
11	Mette	have you changed it?
12	Ina	it is because I think
13	Mette	It is over here at the rear (.) because I think this that you (.) that you (.) well (.) here you get both (.) here you get both a terrace (.) but you also get a terrace here too ((Figure 1d. Mette has rolled over to Ina and points to the 3D-foam model))

Although parts of the video-recorded interactions were transcribed, these transcripts were not used in this part of the analysis. This decision was made because conventional transcripts primarily capture verbal interaction, whereas identifying collaboration patterns required a primary focus on embodied interaction. It should be noted that the students spoke Danish and that all student utterances in figures and transcripts have been translated into English.

The study was conducted in accordance with the ethical guidelines in place at Aalborg University and Linköping University, as well as relevant Danish and Swedish laws. Informed consent forms

were signed by each research participant. In this paper, participants have been given pseudonyms to protect their anonymity.

During the preparation of this work, the authors used Grammarly to improve grammar and check spelling. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content. No other use of generative AI has been made during the research process.

3 FINDINGS

We have analysed and coded the full group meetings (almost six hours) for both groups and constructed temporal diagrams. The findings briefly described below are based on the analysis of the full session for both groups. However, for space reasons, only the temporal diagram for one hour (starting 44 minutes into the session) is displayed in Figures 2 and 3.

Figure 2

Temporal diagram of students in group 3's collaboration during one hour of the project meeting, showing their different forms of collaboration as seen in the main group room. Each student is assigned a colour, making their participation in different constellations visible. The scale on the time axis is in hours and minutes from the beginning of the session. Episodes are numbered from the beginning of the session. The two males in the group, Anders and Sven, have gone somewhere else to work on their task

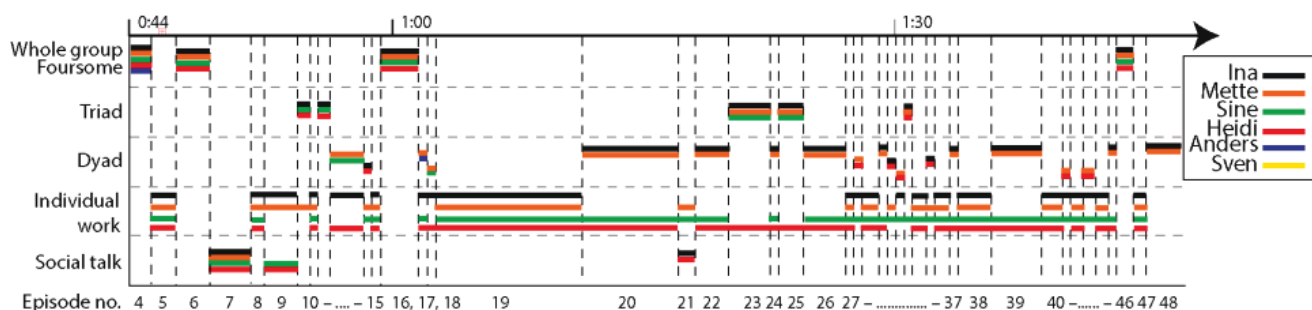
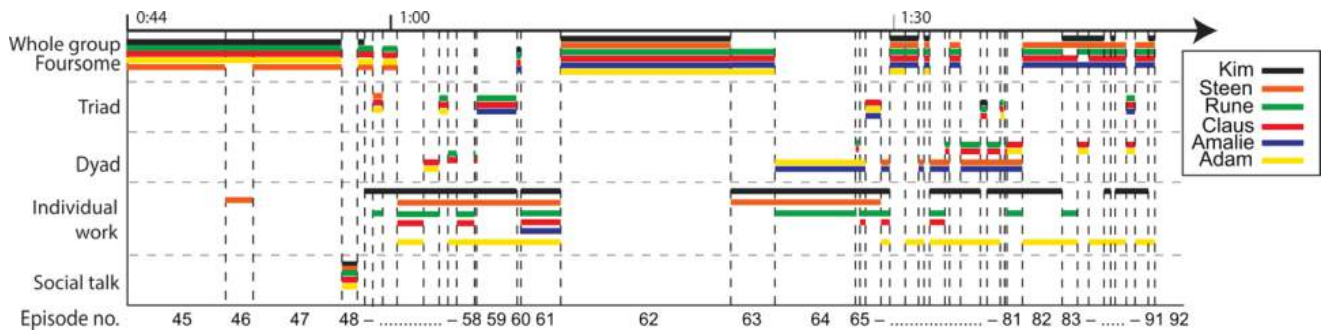


Figure 3

Temporal diagram of students in group 1's collaboration in the project meeting. The figure is constructed similarly to Figure 2



The collaborative patterns and group dynamics in both groups displayed both similarities and differences.

The students in group 3 had their work during the day divided into phases with more distinct interaction patterns. In some phases, they held full-group discussions to make decisions or coordinate their work. In other phases, they worked individually or in dyads and triads on specific tasks. Figure 2 represents such a phase (For a fuller description of group 3's whole day, see Bernhard et al., 2023a; Davidsen & Bernhard, 2026). On the other hand, distinct phases in the interactions of group 1 were not apparent. Throughout the day, this group displayed the “blurred” interaction patterns visible in Figure 3. The work in group 3 appeared more organised, though this was tacit, as no clear group leader could be identified in our analysis of the videos.

Both groups demonstrated considerable individual work. However, in group 3, individual work was performed for longer, continuous periods. Moreover, the individual work in group 3 was mostly done during the phase displayed in Figure 2. In both groups, individual work is interspersed with several longer and shorter collaborations in dyads and triads, in shifting constellations, as shown in Figures 2 and 3. In group 1, large-group work is interspersed with individual work and collaborations in dyads and triads. Furthermore, all work in group 3 is not done in the main group room, and the males have gone elsewhere to work undisturbed, whereas group 1 perform all their work in the group room around the working table. The problem with this approach sometimes becomes apparent when members of group 1 attempt to do individual work while the rest of the group discusses in a larger constellation. Furthermore, the members of group 3 appear to be more focused on their task at hand, with minimal disturbance from one another. On the other hand, some members of group 1 appear not be fully focused.

4 DISCUSSION

That study was driven by the question of how we could understand the dynamics of students' individual and collaborative work in a design meeting by analysing the interaction of an additional

group. Could similar patterns be observed, and what were the similarities and differences comparing the two groups?

A limitation of the previous study was that we had only had the opportunity to conduct an in-depth investigation of the group practices of a single collaborative design group. In this study, we have extended the analysis to two groups. However, this is still a limitation. This necessarily constrains the conclusions that can be drawn. Nevertheless, we argue that several important conclusions may still be derived from our findings. Previous research by (e.g., Borgford-Parnell et al., 2013; Menekse et al., 2017) has reported intra-group practices within relatively static groups. In contrast, our analysis of video recordings reveals that the fine-grained patterns of students' social interaction within the observed collaborative design group are complex and dynamic. These interactions display both fluidity and structure (cf. Sørensen, 2022), as students worked in many different constellations throughout the day.

We observed that students frequently changed constellations, breaking into subgroups of one, two, or three students to carry out specific tasks before later reconvening as a whole group. Thus, our findings indicate that collaboration patterns in the day-to-day work of groups are not static but exhibit a wide range of configurations. To our knowledge, the fluidity of constellations and the documentation of complex collaborative patterns in students' group work have not been reported previously, except in our previous studies.

Furthermore, in line with the observations of Ryberg et al. (2018, p. 240), we found that the distinction between cooperative and collaborative work becomes blurred when students' interactions are examined in detail. In their activities, students alternated dynamically between individual, cooperative, and collaborative work patterns. Consequently, our results challenge both a naïve individual–collaborative binary and a simplistic cooperative–collaborative distinction. Rather, the observations from this study suggest that individual work may constitute an important component of constructive, skilful collaborative design work.

Taken together, our results point to the need for more detailed investigations of group practices, as well as individual and collaborative learning, in design project groups and other collaborative learning environments. In particular, there is a need to better understand which features—such as collaborative patterns and the skills required of students—are critical for successful learning and effective collaborative work in student design projects, and how these features can be fostered and developed within engineering education. The findings of this study indicate that there are indeed differences in the collaborative patterns of the groups that need to be explored further.

Moreover, through visits to design projects in high schools and at various years in university-level engineering education, we have also observed an apparent progression in students' collaborative skills. We have collected a substantial corpus of video data from A&D students at Aalborg University across their first, fourth, and fifth semesters, providing a strong empirical basis for further exploration of the questions raised in this study.

For engineering education researchers to formulate realistic and well-founded pedagogical recommendations, and for engineering educators to make sound instructional decisions, it is

essential to develop a robust understanding of how students' design processes unfold in practice. As noted above, a limitation of the present study is that we have thus far examined group practices in only two collaborative design groups, which limits the pedagogical recommendations that can be drawn from our empirical material. Nevertheless, one conclusion is that spaces in which collaborative work takes place need to be designed or adapted to support flexible group work. A further, tentative conclusion is that instructors should actively encourage fluid patterns of collaboration in students' collaborative activities.

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From AI to Critical Thinking: Teacher Students' Analyses of Copilot-Generated Technology Stories

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Abstract

Artificial intelligence (AI) tools such as ChatGPT and Copilot are increasingly present in education, raising questions about their potential for both learning and bias reproduction. Building on a previous pre-study by the authors, this research explores how AI-generated storytelling can be used to foster critical thinking in technology teacher education.

In a university course, pre-service teachers were asked to generate children's stories using Copilot and then analyse the technological content using a framework derived from an earlier study by one of the authors. The students were instructed to use an identical prompt (i.e., create a technology story for primary school children), and common narratives in the Copilot-generated stories involved a child and a robot discovering the wonders of coding or saving the world through new technologies (that they had developed together).

To interpret the students' reflections, we draw on Langdon Winner's critical philosophy of technology, using his perspectives as an analytical lens to identify how notions of neutrality, determinism, and the politics of artefacts appear in the students' reasoning. Our analysis of the students' written reflections shows that most of them present an uncritical view of technology. Few of the students demonstrated deeper critique of technological implications, ethical dilemmas, or socio-political dimensions. These findings suggest that without explicit scaffolding, AI-based storytelling risks reinforcing techno-optimistic perspectives rather than challenging them. We argue that integrating structured critical analysis – supported by frameworks such as Winner's – is essential for developing reflective and responsible approaches to technology in teacher education.

Key Words: Technology Education, Storytelling, Copilot, Critical Thinking, Artificial Intelligence

1 INTRODUCTION

Artificial intelligence (AI) tools such as ChatGPT and Copilot are increasingly present in education, raising questions about their potential both to support learning and to reproduce bias. While these tools can generate ideas, explanations, and narratives, they also produce patterned errors and “hallucinations” that challenge their reliability (Johnson & Hajisharif, 2025).

In technology education, responses to AI’s rapid emergence have been cautious. On the one hand, AI as a sociotechnical phenomenon clearly belongs within the technological knowledge domain and is therefore a legitimate topic for teaching and learning (Hallström, 2024). On the other hand, discussions have often lacked conceptual clarity and philosophical grounding, tending to emphasise safety, accuracy, or usability over teachers’ and students’ lived experiences and interpretations of AI (Hallström, 2025). A pedagogically meaningful engagement with AI thus requires a clearer understanding of how learners actually interpret and reason about AI-generated content.

Within the Swedish curriculum, the school subject of technology aims to provide pupils with knowledge in and about technology, recognising technology as an integrated and essential part of human activity – historically and today. Pupils are expected to understand how technical solutions work, how they are constructed, and how technology influences society, the environment, and the future. They should also be able to apply technological knowledge, tools, and methods to solve problems and meet human needs (Skolverket [The Swedish National Agency for Education], 2024). Such understanding forms a cornerstone of technological literacy and is vital from both civic and democratic perspectives.

However, several studies have described pupils’ work in Swedish technology classrooms as characterised by ‘unreflective doing’ (Skolinspektionen [The Swedish Schools Inspectorate], 2014). Practical activities may dominate while reflection, analysis, and evaluation receive less attention, making it difficult for pupils to develop a critical stance toward present and future technologies. In this context, AI-generated stories may offer a productive way to scaffold critique.

Building on a prior pre-study (Axell & Boström, 2023), this study investigates how pre-service primary teachers analyse AI-generated technological stories and what forms of critical thinking their analyses reveal. It also examines the extent to which AI-generated storytelling can serve as a productive approach for fostering critical thinking within technology teacher education.

The study is guided by the following research questions:

- (i) What forms of critical thinking become visible when pre-service teachers analyse AI generated technological stories?
- (ii) How do pre-service teachers identify, interpret, and evaluate biases, errors, and “hallucinations” in AI generated stories?
- (iii) In what ways can the analysis of AI generated stories function as a method for supporting the development of critical thinking in technology teacher education?

2 LITERATURE REVIEW

2.1 *Research on Critical Thinking in Technology Education*

In technology education, technological literacy is widely understood to involve both understanding how technologies function and are constructed, and making well informed judgements about their societal implications, risks, and benefits. From a civic and democratic standpoint, this means learners should be able to weigh evidence, compare alternatives, and consider multiple perspectives rather than treating technology as merely a set of artefacts or procedures (Dakers, 2014; Garmire & Pearson, 2006; Turja, Endepohls Ulpe & Chatoney, 2009; Williams, 2009). These competencies are central to critical thinking, including the capacity to approach technological issues from multiple perspectives. Within this framing, critical thinking goes beyond technical problem solving; it includes interrogating assumptions, articulating values, and situating technology in its socio environmental context (e.g., Axell, 2017a; Dakers, 2006; Keirl, 2006; Petrina, 2000; Williams, 2009).

Despite this centrality, critical thinking has received limited explicit attention in technology education research: terms such as “critical thinking” and “critical reasoning” are not among the most common keywords in major reviews (Christensen et al., 2015; Williams, 2018). Where the topic appears, the emphasis tends to be on students’ design tasks, teachers’ critical thinking, or students’ relationship to internet information rather than on learners’ sustained, evidence seeking sociotechnical critique.

In response to these gaps, prior work has proposed or explored contexts that can elicit critique. In the anthology *Critique in Design and Technology Education* (Williams & Stables, Eds., 2017), some chapters theorise critical thinking conceptually. Related proposals include Barlex’s (2017) use of disruptive technology to provoke reflection and Axell’s (2017a) demonstration of how children’s fiction with technological content can create meaningful contexts for critical reasoning about relationships between technology, humans and nature. Although empirical studies are fewer, they are instructive. Gardelli (2016) documents wide variation in students’ ethical awareness in discussions about technology choices and internet privacy, concluding that practice in ethical reasoning can strengthen critical thinking and counteract intolerance. In higher education, Axell and Björklund (2018) asked pre-service teachers to analyse potentially disruptive technologies by identifying advantages and disadvantages for different stakeholders; the pre-service teachers could list pros and cons but were not accustomed to problematising technology from critical perspectives, indicating a need for earlier and more structured practice.

Alongside these strands, Axell and Boström (2023) add an AI specific dimension. Their qualitative content analysis of AI generated technological stories showed several dominant themes, a predominantly positive, uncritical portrayal of technology, and a recurring focus on high tech, male coded technology. The pre-study argued that chatbot generated stories can function as useful starting points for visualising technology bias and cultivating a critical gaze among pre-service teachers – provided that learning designs explicitly target critical reflection. More recent work at the intersection of AI and education aligns with the importance of task framing. For example, Famaye et al. (2025) report that AI workshops with children (ages 7–12) elicited mostly functional appraisals with limited consideration of wider societal impacts,

suggesting that the design of prompts and scaffolds strongly shapes the depth of critique. At the same time, research on large language models highlights patterned biases, inconsistencies, and “hallucinations,” which makes AI generated artefacts suitable for exposing epistemic limitations that can animate critique (Johnson & Hajisharif, 2025). Despite this potential, there remains a lack of empirical work that examines how pre-service teachers critique AI generated representations and what forms of critical thinking are thereby elicited.

2.2 *Conceptualising Critical Thinking*

Most people have an intuitive sense of what critical thinking entails, yet it is difficult to capture precisely in words (Facione, 2015). Ennis (2018, p. 166) offers a succinct definition: “reasonable reflective thinking focused on deciding what to believe or do.” Complementing this, Willingham (2007) highlights three essential features: novel thinking (engaging analysis when situations are unfamiliar rather than relying on rote responses), self-directed thinking (independently evaluating claims rather than merely following instructions), and effective thinking (reasoning guided by logical principles such as weighing evidence and considering opposing views). In technology education, this means helping learners move beyond description to justified judgements about technologies and their implications.

Despite a growing interest in AI within education, little is known about how AI-generated materials can be used pedagogically to support the aims of technology education, particularly the development of technological literacy and the ability to critically examine how technology affects individuals, society, and the environment. This study contributes to addressing that need by investigating how pre-service teachers analyse AI-generated technological stories and by exploring the extent to which such stories can serve as a meaningful tool for fostering critical thinking in line with the educational purposes of the school subject of technology.

In this study, we use Langdon Winner’s (1977; 1980; 1986) philosophy of technology as an analytical lens for examining pre-service teachers critical thinking as expressed in their interpretations of AI-generated technology stories. Winner argues that technologies are never neutral but embody social and political values that shape modern life. As Axell (2017a) notes, he highlights how technological systems become deeply embedded and often invisible, structuring power, citizenship, and everyday practices.

Winner’s claim that “artefacts have politics” captures his view that technologies both reflect and impose particular forms of social order, sometimes democratic, sometimes authoritarian. He also challenges deterministic beliefs in autonomous technological progress, instead urging a critical examination of technologies as “forms of life.”

In this study, six of his dimensions guide our analysis: technologies as forms of life, autonomous technology, technology is not neutral, the political aspect of technology, democratic vs. authoritarian technology, and a decentralised, democratic politics of technology.

3 METHODOLOGY

The study was conducted within a pre-service teacher education course for primary school teachers taking place during their third semester. Participants were 30 pre-service teachers completing an assignment designed to explore how generative AI represents technology when prompted to write a technology story for children. This was the pre-service teachers' first course in technology didactics, and therefore they had no prior formal education in technology critique. Prior to data collection, the participants provided informed consent through a form that explained the purpose of the research and procedures for data handling. Only the work of pre-service teachers who consented was included in the research dataset.

Using pre-service teachers as informants is particularly valuable because they will soon be responsible for guiding pupils toward becoming technologically literate, democratic citizens. Their perspectives therefore provide essential insight into how future generations may learn to interpret, question, and engage critically with technology in society.

The empirical material derives from a two-part assignment. First, the pre-service teachers were instructed to use Copilot to generate a 500-word children's story focusing on technology for eight-year-old readers. All pre-service teachers used the same fixed prompt, presented in English translation as:

“Please write a 500-word children's story for eight-year-olds that focuses on technology.”

In the second part of the assignment, the pre-service teachers wrote an analysis of approximately 750 words based on their AI-generated story. This analysis was structured around five guiding questions concerning: (1) what types of technology appear in the story, (2) how technology is portrayed, (3) what view of technology is conveyed, (4) how the story can be understood from a gender perspective, and (5) whether the story would be useful in a teaching context. The pre-service teachers were required to engage with specific course literature to support their analyses. The mandatory texts consisted of Axell (2017b), Axell and Boström (2021), and Axell and Boström (2023).

The pre-service teachers submitted their analysis through an online learning platform. All files were exported and assigned anonymised study codes.

Winner (1977; 1980; 1986) outlines dimensions for critically examining technology, three of which concern political aspects of technological systems (cf. Axell, 2019). For analytical clarity, these three were consolidated into a single category, *Politics of Technology*. Thus, our analysis employed four overarching themes: (1) Life Altering Technologies, (2) Autonomous Technology, (3) Neutral Technology, and (4) Politics of Technology. These adapted themes served as analytical lenses through which the participants' written reflections were examined, enabling us to identify recurring assumptions about technological agency, neutrality, and socio-political implications.

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

4 RESULTS

4.1 *Theme 1: Life Altering Technologies*

In the theme *Life Altering Technologies*, we examined how the participants described the AI-generated stories in ways that revealed technology as an integrated and taken-for-granted part of everyday life. Winner argues that technologies do not merely support human activities but reshape social practices and habits through which people understand the world. In our analysis, we therefore looked for instances where the participants identified – or implicitly reproduced – shifts in how technology structures the ways we speak, think, and act.

Our analysis identified two main sub-themes within *Life Altering Technologies*, each revealing how technology shapes everyday meanings and identities.

In the first sub-theme, *Technology as gendered* we could see how the participants frequently described technology as something associated with gender. Two sub-themes were identified – *Women's interest and career choice* and *A symbol for manhood*. The emphasis on technology as something connected to men is perhaps not that strange, since the literature the pre-service teachers had read in preparation partly focused on gender and technology. But what stood out was how they talked about the importance of strengthening female pupils' interest in technology, and the importance of prompting them to seek out an education in technology (e.g., "...inspire girls to want to learn more about technology and work in technological fields"). During the last fifty years this has been a societal discourse in Sweden, and this could perhaps have influenced their interpretation and analysis of the AI-generated technology tales.

The second sub-theme, *Technology as future-shaping*, revolved around the participants interpreting technology as a force that structures how we envision the future. Two sub-themes stood out – *Artificial intelligence (AI)* and *Environment*. To start, this was a much scarcer theme among the participants' analyses. For an analysis that had a large language model tale as its basis, one would think that a critical gaze of said AI tool would be more prominent. But when AI was mentioned, it was only done in more general statements like "AI will change our future" or "AI will simplify our lives". The environmental theme was only found in three of the participants analyses. These participants spoke of high tech as the solution to society's environmental issues and brought up solar power and wind power as a symbol of a sustainable future, (e.g., "Wind power, which is a symbol of green energy...").

4.2 *Theme 2: Autonomous Technology*

In our analysis of autonomous technology, we drew on Winner's notion that technologies can appear to act independently of human intention or oversight. We focused on moments when the participants, implicitly or explicitly, described technology as functioning as a black box – that is,

as something whose inner workings or developmental trajectories were opaque. For example, instances where they described artefacts or systems as incomprehensible to the user/citizen (e.g., “to construct a robot is complex process /.../ but this is shown as an easy task in the story”) and/or where technological progress was framed as self-propelling or inevitable (e.g., “...the story says nothing about how the technological development has taken place”).

4.3 *Theme 3: Neutral Technology*

In our analysis of how the participants engaged with Winner’s idea that technology is not neutral, two sub-themes emerged that illustrate how they understood technology as value-laden and consequential rather than merely functional – *Technology’s Janus face* and *The informed citizen*.

Some participants emphasised that the AI-generated stories portrayed technology as having both positive and negative sides – what can be described as having a Janus face. Helpful technologies – such as flying machines, robots, or household devices were also described as risky, with potential for misuse, environmental harm, or unexpected consequences. Some of the participants argued that children must learn that technological solutions can generate new problems even as they solve existing ones. This reflects an understanding consistent with Winner’s view that technology embodies values and produces both possibilities and constraints.

A second sub-theme concerned the need for critical, ethical engagement with technology. A handful of the participants highlighted the importance of preparing learners to understand risks associated with AI and robots – including issues of labour replacement, environmental impact, and ethical dilemmas. Some of them noted that AI tends to present an overly optimistic view of technology, downplaying failures and negative consequences (e.g., “It [AI] also shows no setbacks or difficulties with the technology; everything works perfectly and exactly as intended”). These participants argued that informed citizenship requires questioning technological developments rather than accepting them as inherently beneficial.

4.4 *Theme 4: Politics of Technology*

In the theme Politics of Technology, we examined how the participants recognised that technology carry political implications, shaping power relations, opportunities, and constraints in society. Drawing on Winner’s claim that technologies can embody forms of authority and structure social order, we focused on instances where the participants, implicitly or explicitly, brought up that technology influences who (or what) benefits, who (or what) is disadvantaged, and which values or priorities become embedded in everyday practice (e.g., global energy issues, consumer issues).

When this thematic analysis was done, we looked at the participants’ different statements in each theme and evaluated them regarding the depth of critical thinking in relation to Willingham (2007) highlights three essential features: novel thinking self-directed thinking effective thinking. Very few of the participants reach this level of thinking. Most of the time their statements were more in line with simple acknowledgements (e.g., “the more things in society that are dependent on technology, the more things could go wrong” or “Artificial intelligence can reshape the world by replacing humans”). Though, on some occasions, some of them engaged in a more critical way.

For example, when one participant touched upon different perspectives and chains of consequences:

The robots in the garden facilitate work by automating tasks such as planting, watering, and mowing the lawn. This frees up time and energy that can be used for other purposes, while the garden continues to flourish. At the same time, it means that the garden becomes entirely dependent on the robots in order to remain well-maintained. If the robots were to break down, and no one were able to repair them, the system would risk collapsing.

5 CONCLUSIONS

This study investigated how pre-service technology teachers analyse AI generated technological stories by asking what forms of critical thinking become visible in their analyses, how they identify, interpret, and evaluate biases, errors, and “hallucinations”, and in what ways such analysis may support the development of critical thinking in technology teacher education. Using four themes adapted from Winner’s (1977; 1980; 1986) philosophy of technology (cf. Axell, 2019), our findings show that while the pre-service teachers identified several important aspects of how technology is represented in the AI generated stories – most visibly gendered framings and, to a lesser extent, future oriented imaginaries (with environmental aspects appearing in only 3 of 30 analyses) – their critical engagement was often limited (cf. Famaye et al., 2025).

With respect to the forms of critical thinking that became visible, the pre-service teachers’ contributions were typically recognitional and descriptive rather than novel, self-directed, and effective (per Willingham, 2007). They seldom questioned underlying assumptions, traced second order consequences, or independently applied theoretical tools; only occasional reflections moved beyond acknowledgement toward explanation and evaluation.

Regarding how pre-service teachers identify, interpret, and evaluate biases, errors, and “hallucinations”, references to AI were generally generic, and systematic scrutiny of AI specific distortions (e.g., training data bias, spurious claims, or hallucinations) was rare. When bias was discussed, it clustered around gendered framings; examinations of neutrality, socio political implications, or environmental trade-offs were comparatively sparse and seldom grounded in explicit criteria.

As for the pedagogical potential of analysing AI generated stories, the assignment offers a useful entry point for surfacing how technologies are portrayed and for initiating value focused discussion. On its own, however, it did not reliably elicit advanced critical thinking. As the literature suggests, moving beyond recognition to theoretically informed critique requires explicit scaffolding (Axell, 2017a; Barlex, 2017; Gardelli, 2016). The limited engagement observed in our study therefore reinforces earlier claims that pre-service teachers need more deliberate support to develop the forms of critical technological reasoning that underpin democratic technological literacy – particularly in diagnosing AI specific errors, evaluating evidence, and articulating consequence chains. Building on this, we will replicate the assignment in a follow-up study and introduce a preparatory workshop on critical thinking and technology critique,

providing structured analytical tools to test whether pre-service teachers' capacity for deeper, more self-directed and effective critical analysis can be strengthened.

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Understanding Sustainability as a Concept Within R&D Design Projects

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Abstract

The present study investigates how students in the Dutch secondary STEM subject Research and Design (R&D), offered at Technasium schools, reason about the broad and multifaceted concept of sustainability. Within this educational paradigm, students are instructed through a combination of research and design projects developed collaboratively by R&D teachers, clients, and field experts. The concept of sustainability is often an explicit or implicit element in these projects, reflecting the Technasium vision of engaging students with authentic, socially relevant problems. The study focuses on grade K7 novice students (age 12), who attempt to understand and incorporate sustainability into their work through a design brief. The brief has a significant influence on outcomes, particularly when sustainability values are emphasised, so students' interpretations are pivotal. Values can differ, as evidenced by marked differences in design direction from prioritising greening with plants versus reusing materials. The students initially created a design brief without any prior knowledge of sustainability or of design brief formulation. Following the delivery of a concise workshop on the subjects, a revision of the briefs was initiated. Initially, students referred to broad, umbrella concepts such as environment, nature, recycling, and waste, while social and economic dimensions were almost entirely absent. Following the provision of instruction, references to social and economic sustainability increased, and the use of vague overarching terms decreased. The findings indicate that students benefit from developing a foundational understanding of sustainability before.

Key Words: STEM, Subject Research and Design (R&D), Concept, Sustainability, Pedagogy of Design

1 SUSTAINABILITY IN DESIGN-BASED LEARNING

Design-Based Learning (DBL) is a design-oriented, project-based teaching model that is widely used in technical degree programs, such as architecture and computer science. It encourages creativity, collaboration and critical thinking by enabling students to apply theoretical knowledge to design solutions for real-world problems (Azizan & Shamsi, 2022). Within the Dutch curriculum for project-based learning at Technasium, DBL forms a key principle. Students learn

to make design choices, deal with uncertainty and evaluate their process, which strengthens their problem-solving skills and motivation (Samantha & Overdijk, 2022). Although sustainability forms part of the Dutch curriculum, many teachers receive little formal training in this area. As a result, the topic is often covered only superficially and with limited interdisciplinary focus (Keramitsoglou, Litseselidis & Kardimaki, 2023).

Effective sustainability education should be based on evidence-based content to avoid misconceptions and greenwashing, which are still widespread in public debate (Rushton & Walshe, 2025). According to Elkington (2004) the three P's People, Planet, Profit emphasize that education should support human well-being and inclusion (People), encourage responsible actions toward the environment (Planet), and build skills for economic and societal development (Profit). The United Nations Educational, Scientific and Cultural Organization (UNESCO 2015) links these principles directly to the Sustainable Development Goals (SDGs), especially SDG 4: Quality Education, which acts as a foundation for achieving all other goals.

Through education, learners gain the knowledge, values, and competencies needed to address climate challenges, reduce inequalities, and promote peaceful, sustainable societies. Research increasingly emphasizes that education is a crucial driver for achieving the SDGs (Agbedahin, 2019). In this way, the Three P's and the SDGs together guide schools toward teaching that prepares students for a balanced and sustainable future.

DBL has been recognised as an effective pedagogical approach for advancing the SDGs because it starts from real-world problems and engages students in designing solutions to societal challenges (Jiang et al., 2020). The strength of this approach lies not only in its practical orientation but also in positioning students as co-designers of their learning, emphasising active knowledge construction over passive transmission (Oo et al., 2024).

2 SUSTAINABILITY CONCEPT WITHIN THE DESIGN BRIEF

The exploration phase is widely regarded as a first step in any design process. In this phase, the primary objective is to explore, define and delineate the problem, with the simultaneous development of the design brief. The design brief sets out the preconditions and success criteria that the final solution is required to meet. It is therefore important to note that this is not merely a list of requirements, but rather a guiding document that structures and clarifies the thinking and actions of both designers and clients (van der Voordt & den Heijer, 2004; van Doorn, van der Voordt & Rogaar, 2011). Although the drafting of a design brief is typically considered to be one of the primary steps in a design project, research indicates that novice designers, particularly students in lower secondary education, frequently exhibit an absence of prior knowledge concerning the nature and function of the design brief (Haan-Topolscak & Smits, 2021).

2.1 *Why is sustainability critical within the design brief?*

The quality of the design brief has a significant influence on the outcome of a design project (Phillips, 2004). Clients may request different criteria for sustainable design, such as material reuse, energy efficiency, recyclability, social justice, or long-term cost considerations. 'Greening'

the design brief in advance is essential to enable sustainable design choices: the earlier sustainability is integrated, the greater the impact (Dewulf, Wever & Brezet, 2011; Klooster & Koeijer, 2012; Mallindine & Pilz, 2024). In later stages, when the design is largely fixed, adjustments to improve sustainability become more difficult and costly.

Research on sustainability education indicates that explicitly embedding sustainability in the design brief fosters systems thinking, socially responsible design, and awareness of trade-offs between competing interests such as environmental impact versus affordability (Faludi, Smith, Silva, & Bhamra, 2023). However, caution is needed to avoid greenwashing, defined as “the intersection of two firm behaviours: poor environmental performance and positive communication about environmental performance” (Netto, Sobral, Ribeiro, & Soares, 2020).

Making sustainability explicit in the design brief is essential for younger students. They can follow clear guidelines and reflect on them, even if they can't formulate sustainability criteria independently. Using frameworks such as the "three P's" (People, Planet, Profit) or the 17 SDGs helps translate abstract values into concrete design requirements. Not all SDGs will be relevant for every project, but indirect connections can still play a role.

Although students can use frameworks like the three P's and SDGs to formulate requirements concerning sustainability, they struggle to formulate valid, essential, measurable and exclusive design brief requirements (Haan-Topolscak & Smits, 2021). We expect them also to struggle with formulating these as part of their design brief. Research is needed to investigate suitable interventions to help students formulate these design requirements and come to a truly sustainable design.

2.2 *Current study on sustainability concepts and design criteria*

This study investigated how first-year secondary school students (grade K7) taking the R&D subject understand sustainability, and their ability to translate this concept into concrete design requirements for Technasium design projects. The study also examined how the sequence of targeted instructions regarding the formulation of design requirements and sustainability influences the drafting process for a design brief. The findings provide teachers with practical tools to promote the integration of sustainability into Technasium design projects in terms of both content and pedagogy.

3 CONTEXT AND INTERVENTION

Forty-two pupils from grade K7 (age 12) of two Technasium R&D classes (class P and class T) each supervised by a different teacher participated anonymously in the survey on prior knowledge of the sustainability concept and they worked on the same design assignment: an insect hotel. For this design assignment the student had to make a design brief including sustainability principles. To investigate the effect of the instruction sequence, the intervention consisted of three constructive steps: formulating design requirements based on prior knowledge to capture the pupils' spontaneous understanding of sustainability and drafting the design brief; formulating design requirements after instruction on drafting a design brief; and formulating design

requirements after instruction on sustainability. The subsequent design brief reflected the adjustments made after each instruction. For one class, the instruction sequence was reversed to investigate the effect of the instruction sequence. The two teachers used the same teaching material throughout the intervention. The interpretation of the teaching material was free.

The instruction on formulating design requirements was based on criteria such as validity, essence, measurability, and exclusivity (de Haan, Smits, de Vries, 2019). Students learned to develop a design brief by listing, improving, deleting, prioritizing, and refining requirements to ensure they were objective, feasible, and measurable. The instruction on sustainability was based on the Triple Bottom Line theory (Elkington, 2004) and the United Nations Sustainable Development Goals (UNESCO, 2015). Students learned about the pillars of People, Planet, and Profit, learned about global challenges and trade-offs, and used the SDGs as inspiration to formulate design requirements.

AI-assisted tools (Microsoft Copilot and DeepL Translator) were used exclusively for language support, including translation and grammatical refinement.

4 DATA COLLECTION AND ANALYSIS

Data were collected through a combination of survey, analysis of student design briefs, and intervention comparisons between classes. Quantitative data were obtained via structured surveys, including multiple-choice and Likert-scale questions, which were analysed using Microsoft survey software. Qualitative data consisted of open-ended survey responses as well as the content of all student design briefs, which were coded and analysed in Atlas.ti. The analysis focused specifically on the content and development of sustainability criteria in the design briefs.

A categorization system of Atlas.ti was used to map each requirement in the design brief to the UN Sustainable Development Goals (SDGs). Each requirement was reviewed for clarity and classified as either a broad overarching concept or a specific, measurable criterion. Requirements that did not align with any SDG were placed in a separate category and excluded from the sustainability analysis. Comparisons were then made between classes to examine the effect of instructional sequence, and across successive drafts to track changes in specificity, objectivity, and SDG coverage. This approach enabled a systematic evaluation of how instructional content and sequence shaped the inclusion of sustainability criteria in students' design briefs.

5 RESULTS

The results are presented for each part of the research, the survey and the analysis of the design requirements before and after interventions.

5.1 *Survey results on prior knowledge of sustainability concepts*

The survey examined where students learned about sustainability, how they understand it, how they apply it in design work, and which values they prioritize. Results show that first-year R&D

students mainly encountered sustainability in primary school and view it primarily through an ecological lens. This is reflected in their prioritization of the three P's where Planet ranked highest, followed by People and Profit.

When students formulated requirements for an abstract “sustainable something,” they emphasized “Environment and Nature” first and “Recycling and Reuse” second. However, for a more concrete task, design a sustainable school bag, “Material Selection” became the top criterion, followed by “Recycle and Reuse,” with “Environment and Nature” third. This shift indicates that ecological values translate into practical concerns such as using recycled materials and avoiding new plastics.

In rating the importance of the 17 SDGs, students ranked SDG 11 (safe cities) and SDG 2 (zero hunger) the highest, with SDG 3 (health), SDG 15 (life on land), and SDG 16 (peace and justice) also scoring strongly. Although all goals were seen as important, SDG 9 (infrastructure) and SDG 5 (gender equality) were rated lowest, with SDG 5 showing the greatest variation in responses.

5.2 Intervention

5.2.1 Class P

In Class P, students were tasked with writing a draft letter incorporating sustainability values, based on their prior knowledge. The inventory of overarching sustainability requirements in this round showed that five of the developed sustainability requirements (multiple teams – 15 students) were characterized by broad, overarching terms. The design requirements regarding sustainability were linked to SDG 12 (responsible consumption and production) and SDG 15 (land protection) as planet-related SDGs. Following the instructions for writing a letter, the overarching themes were mentioned only once (3 students – one team), and the requirements linked to SDG 15 and SDG 12 were supplemented with requirements regarding SDG 8 (ensuring fair and safe working conditions for all). After the instruction on sustainability, the number of identified overarching themes increased, with requirements regarding these themes appearing six times (multiple teams – 19 students), which is a notable increase compared to the first measurement. A shift has taken place in the requirements: SDG 8 has been replaced by SDG 6 (clean water and sanitation), and the planet-related SDGs 15 and 12 have been supplemented with SDG 13 (climate action).

Table 1

Class P, an example of development of the Design brief requirements from a random team

Iteration	Random team design brief requirements
Iteration 1	Use sustainable materials (SDG 12).
<i>(Existing knowledge)</i>	Ensure sufficient space for at least two insect species (SDG 15). Suggested materials: wood, iron, animal hair, pruning waste, pinecones, dry branches, hay, and bamboo (SDG 12).
Iteration 2	Use natural materials such as wood and garden waste (SDG 12).
<i>(Focus on design brief)</i>	Avoid the use of plastic materials (SDG 12). Use recyclable materials (SDG 12).
Iteration 3	Ensure sufficient space for two insect species (SDG 15).
<i>(Focus on sustainability)</i>	Use sustainable materials (SDG 12). Provide a sheltered area protecting insects from wind and rain (SDG 15). The design must not attract predators of the supported insect species (SDG 15). The insect hotel must be situated in a dry and sunny location. (SDG15).

5.2.2 Class T

In Class T, two overarching (multiple teams - 8 students) sustainability requirements emerged from the design requirements established prior to the instructions. This sustainability requirements could be assigned to People SDG 3 (good health and well-being), Planet SDG 12, and SDG 15. After the instruction on sustainability, one overarching concept was identified (one team - 4 students). Additionally, the sustainability requirements were assigned to as many as 8 different SDGs: 3, 12, 15, 1 (no poverty), 6, 8, 11 (sustainable cities and communities), and 13. After the instruction on drafting the design brief, it became clear that the overarching requirements were outdated. SDG 3, 12, and 15 remain present throughout all three iterations. Next to them SDG 1 and 6 remained and 8, 11 and 13 disappeared. The design requirements were linked to a smaller number of SDGs. SDG 8, 11, and 13 could no longer be linked to design requirements.

Table 2

Class T, an example of the development of the Design brief requirements from a random team

Iteration	Random team design brief requirements
Iteration 1 <i>(Existing knowledge)</i>	Use only natural materials (SDG 12)
Iteration 2 <i>(Focus on sustainability)</i>	Spend no money on the insect hotel (SDG 1) Place food inside for the insects (SDG 15) We will make it waterproof (SDG 12) so that no water damage or flooding occurs (SDG 13)
Iteration 3 <i>(Focus on design brief)</i>	Shape: We want a small insect hotel measuring 15 cm long and 7 cm wide. This insect hotel should fit inside a moving box. Materials: We will use the chosen materials to build the insect hotel, close it properly, and ensure it is safe for the insects (SDG 15). Placement / environment: This insect hotel will be placed in the forest because few people go there and many insects live there. This location is important to keep the insects safe (SDG 15) from birds or other animals that might eat them. Sustainability: We will take sustainability into account by spending no money on the insect hotel (SDG 1) and by using natural materials (SDG 12). Positioning: The insect hotel will be situated in a shaded area. It is intended for beetles, woodlice, and similar insects. The hotel can withstand rain and sun, and possibly even a storm. Materials (additional): We will use wood because it is sturdy and often resistant to water. We will make the hotel sustainable by spending no money on it (SDG 1), placing food inside for the insects, and making it waterproof so that no water damage occurs (SDG 13).

5.3 Comparison

5.3.1 Class P and class T interventions

In class P, the number of broad, overarching requirements increased after each intervention, while it decreased in class T. In both classes, requirements consistently linked to SDGs 12 and 15. SDGs

6 and 13 appeared in both groups after the sustainability instruction, while SDGs 1 and 3 emerged only in class T. Class T showed a clear rise in the number of SDGs addressed after the sustainability instruction, followed by a decline after the design-brief instruction. In contrast, class P showed a steady increase after each step. After both interventions, the difference between the classes was small: both included requirements linked to four or five SDGs, with SDGs 6, 12 and 15 present in both groups.

Table 3

Class P, overview of overarching terms and SDG coverage

Class P	Nr. of umbrella terms	Covered SDGs
Start measurement	5 (15 students)	SDG 12, 15
Instruction on design brief	1 (3 students)	SDG 8, 12, 15
Instruction on sustainability	6 (19 students)	SDG 6, 12, 13, 15

Table 4

Class T, overview of overarching terms and SDG coverage

Class T	Nr. of umbrella terms	Covered SDGs
Start measurement	2 (8 students)	SDG 3, 12, 15
Instruction on sustainability	1 (4 students)	SDG 1, 3, 6, 8, 11, 12, 13, 15
Instruction on design brief	0 (0 students)	SDG 1, 3, 6, 12, 15

5.2.3 Survey and interventions

When students assessed the 17 Sustainable Development Goals (SDGs) in the survey, SDG 11 (Sustainable cities and communities) and SDG 2 (No hunger) scored highly. During the interventions, SDG 2 did not appear at all and SDG 11 only once, following the instruction on sustainability in Lesson T. The survey shows that students prioritize the planet over people and profit last. This pattern is also reflected in the interventions: SDG 12 (Responsible consumption and production) and SDG 15 (Life on Land) were consistently represented in all versions of the design requirements.

6 DISCUSSION

The findings show that grade (K7) R&D novice students primarily developed their understanding of sustainability in primary school, where the focus was largely ecological. This aligns with earlier Dutch curriculum goals that emphasized biology, flora, and fauna (SLO, 2006). In the updated curriculum (SLO, 2026), sustainability is addressed more broadly, including social and economic dimensions. Students also tend to choose familiar themes such as flora and fauna because these are engaging and accessible. This open question finding is indicative of a strong affinity for the Planet.

A marked shift in cognitive approach was evident when students were tasked with ranking the Sustainable Development Goals (SDGs) in terms of their relative importance. This exercise precipitated a transition in their thinking from a previously held sense of global interconnectedness, typified by the Planet affinity, to a more personalized focus, characterized by the People affinity. Consequently, universal human concerns such as peace, hunger, and health were accorded with a heightened priority. In a similar manner, the focus shifted from outlining requirements for an abstract "sustainable" product to delineating specifications for a sustainable school bag. The reduction in abstraction resulted in the establishment of more concrete criteria, including the reuse of materials and the avoidance of new plastics.

In class P, initial design requirements often contained broad notions such as "good for nature." After receiving instruction on what constitutes a design requirement brief (validity, essence, measurability, exclusivity), students formulated more concrete criteria. However, overarching sustainability terms reappeared afterward. This may indicate that students realized some earlier criteria were too vague, and that sustainability priorities depend on the client (e.g., material reuse, energy efficiency, recyclability, social justice, or cost). This highlights the importance of embedding sustainability early in the design brief (Dewulf, Wever & Brezet, 2011; Klooster & Koeijer, 2012; Mallindine & Pilz, 2024).

In class T, the number of overarching terms gradually decreased throughout the intervention. This underscores the importance of instructional sequencing: sustainability should first be explained conceptually before being translated into measurable design requirements. After the sustainability lesson, students linked a broader range of SDGs to their design requirements, followed by a decline after instruction on formulating requirements. This pattern aligns with the emphasis on creating precise and measurable criteria (de Haan, Smits & de Vries, 2019). Planet affinity remained constant in all three steps.

In both surveys and interventions, Planet affinity remained constant particularly SDGs 12 and 15 remained dominant, reflecting a strong focus on the "Planet" dimension.

Several limitations should be noted: student use of AI tools during the assignment was not monitored; instructional variation occurred due to multiple teachers; survey questions may have been shaped by normative assumptions; and the researcher's dual role as teacher may have influenced responses and instructional decisions. Despite these constraints, the design brief appears to be a promising tool for translating sustainability into concrete and achievable design

requirements, provided that ecological, social, and economic dimensions are explicitly introduced beforehand.

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Adaptive Comparative Judgement: A Method in Search of a Theory in Need of an Instrument

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Abstract

Adaptive comparative judgement (ACJ) is increasingly used in technology and design education to assess open-ended student work through holistic pairwise comparisons. Despite strong evidence of reliability, much ACJ research continues to treat the method “as it is”, focusing on algorithmic efficiency and technical feasibility while leaving the cognitive basis of judgement largely implicit. This paper proposes a Cognitive Theory of Comparative Judgment to reframe ACJ as a problem of human decision-making under constraint. The paper (i) deconstructs ACJ as a judgement environment, (ii) advances four initial postulates concerning computational constraint, heuristic strategy, algorithmic tension, and the normative outcome of disagreement, and (iii) introduces OpenACJ, an open-access, adaptable platform designed to operationalise and test these postulates through configurable choice architecture and process data capture. The implication is a shift from asking whether ACJ “works” to explaining how it works, enabling theoretically grounded improvements to validity in the assessment of complex design capability.

Key Words: Comparative Judgement, Decision Making, Cognitive Load, Heuristics, Assessment Validity

1 INTRODUCTION

Adaptive comparative judgement (ACJ) has significant potential to positively impact technology and design education research and practice. It is primarily used as a method of educational assessment, where its utility relates to the reliable assessment of open-ended pieces of student work, overcoming limitations in traditional rubrics. Such limitations include rubrics not adequately capturing the varying ways in which learners can demonstrate capability in open-ended activities and that rubric scores may be incongruent with holistic appraisals from expert, professional educators and assessors (cf. Sadler, 2009). Based on Thurstone’s (1927) Law of Comparative Judgement, ACJ was designed to overcome these challenges by fundamentally changing the question presented to assessors. Rather than having to assign absolute scores against

predetermined criteria, which humans are relatively unreliable at in open-ended scenarios (Laming, 2004; Thurstone, 1927), assessors are presented with two pieces of work and are asked to make a single, holistic comparison and select the “better” of the two. This is typically relative to an overarching criterion, such as which is more creative or which demonstrates more evidence of capability, and is a question type that is answerable more reliably. The extant literature in technology education, and indeed more broadly, illustrates that ACJ can achieve highly reliable assessment of the types of activity, e.g., design activity, characteristic of authentic technological learning (Bartholomew & Jones, 2021; Bartholomew & Yoshikawa-Ruesch, 2018).

Research into the use of ACJ in technology education was borne largely from the e-scape project in the United Kingdom (Kimbell, 2012a, 2012b). The impact of this project on the field was notable, resulting in a special issue in the *International Journal of Technology and Design Education* (Williams & Kimbell, 2012). Since then, research on or with ACJ within technology and design education appears to have taken four forms. First there are studies which explore the utility of ACJ as a valid method of measuring or assessing specific competencies, abilities, or outcomes. For example, Zhu et al. (2025) examined the potential of ACJ to measure student creativity. Second, there are a number of studies in which the reliability of ACJ is examined (Kimbell, 2022), typically in the assessment of work created in response to open-ended activities. Third are studies in which ACJ is used in an applied context for a purpose other than assessment or measurement. For example, in the Learning by Evaluating project, Thorne et al. (2025) expose learners to exemplars through ACJ, and examine the impact on their learning from making holistic comparative judgements. Finally, there is work aiming to use ACJ at scale, such as in the provision of a national rank against which teachers in local classrooms could compare their students work to get a sense of where they lie at a national level (Seery et al., 2022). This work has associated elements such as understanding the technical challenges in implementing ACJ this way (Buckley & Canty, 2022).

Each of these research programs is useful. There is value in understanding, scrutinising and continuously aiming to improve upon the validity, reliability, transferability, and feasibility of ACJ. However, they share an epistemological limitation in that they are asking about ACJ 'as it is', effectively treating the constraints of existing infrastructure as the boundaries of the method itself. This represents a missed opportunity. By narrowly conceiving ACJ as solely an efficient assessment tool (assessment of learning) or as a means to facilitate pedagogical comparisons (assessment as, or for, for learning), we overlook its potential as a powerful instrument for investigating the fundamental nature of human decision-making in educational assessment contexts.

To advance beyond the current state-of-the-art, in this paper a Cognitive Theory of Comparative Judgment is proposed. The rationale is that ACJ primarily concerns decision making and must therefore be understood more broadly through a lens of cognition. Indeed, the educational application of Thurstone's (1927) Law of Comparative Judgement is relatively recent and small in scale with respect to applied evidence, whereas the fundamental study of decision making is a far more developed field.

The development and systematic refinement of such a theory would enable understanding of, for example, how assessors manage the cognitive load of comparison, how heuristics shape their

judgements, and where the limits of human processing constrain the validity of the method. However, building this theoretical understanding requires an iterative relationship between theory and tool. We also need an ACJ instrument that can be responsive to theoretical development, enabling researchers to configure the environment and react to generated evidence.

To this end, this paper simultaneously introduces OpenACJ, an open-access, adaptable platform designed specifically to support this iterative inquiry. The ultimate intention for OpenACJ is to serve as a research sandbox for the field, enabling the generation of fundamental insights and validated theoretical advancements that can subsequently inform and enhance assessment practices in general. In developing the Cognitive Theory of Comparative Judgment, hypotheses will need to be specified and tested, and OpenACJ presents an auspicious tool which can be adapted to enable this in a way commercial tools do not always have the flexibility to do. A useful byproduct of this activity is a tool which is also usable in practice.

The remainder of this paper proceeds in three parts. First, the ACJ method will be deconstructed and its development to date used to demonstrate a need for the Cognitive Theory of Comparative Judgement. Second, theoretical postulates are presented, such as relating to cognitive load theory and heuristics, to formulate a preliminary theory. Finally, the technical architecture of OpenACJ will be described, illustrating how its specific features and adaptability allow these theoretical postulates to be empirically tested.

2 ACJ AND THE NEED FOR A COGNITIVE THEORY OF COMPARATIVE JUDGEMENT

ACJ begins with the decision of whether to use ACJ in the first place. Comparative judgement (CJ) more broadly¹ has been used in assessment across several subject areas (Jones et al., 2015; Seery et al., 2019; Wheadon et al., 2020; Whitehouse, 2013), most often in higher education. The suitability of ACJ does not relate to subject area, but to the nature of what is being assessed. Specifically, ACJ is efficacious when the object of assessment is latent, i.e., a construct not directly observed but inferred. It is unnecessary for cases such as simple arithmetic, as the assessor can directly observe the learner's responses to declarative, closed problems. However, regarding broader constructs such as creativity, reasoning, or expertise, ACJ becomes very useful as the outcomes do not have absolute determinants of correctness but are instead manifestations of capability that exist on a continuum of quality. For this reason, some CJ researchers use the term "representations" to describe the work being assessed (Verhavert et al., 2022). This terminology posits that the pieces of work are representative of an inferred, unobservable construct, rather than constituting direct evidence of an observable competency. In this view, the assessment challenge is analogous to measuring a latent trait, and ACJ is efficacious as the observed assessor decisions which are subsequently discussed are modelled to capture the 'utility' or perceived value of the

¹ The distinction between comparative judgement (CJ) and adaptive comparative judgement (ACJ) lies in the pairing mechanism. In ACJ, there is some "adaptive" algorithm which dynamically selects which pieces of work to present as a pair for comparison, and in CJ this algorithm is static and does not change during the assessment session. The methodological principles are otherwise fundamentally identical.

trait (Yellott, 1977), without requiring the explicit articulation of criteria that is often necessary in rubric-based assessment.

The ACJ session itself involves selecting several people to act as the assessors or judges, and several pieces of work, often called portfolios or representations, to be assessed. For this paper, the terms “judge” and “portfolio” respectively will be used to correspond to ACJ literature in technology education. There are software solutions which then manage the process, such as RM Compare (2023), and for the purposes of this paper, OpenACJ (Buckley, 2026). From the judge perspective, each individual is shown several pairs of portfolios for comparisons in succession, and for each must select the “better” of the two relative to the assessment question, i.e., latent variable or utility, provided by the organiser of the session. There are several ways to determine the number of comparisons required for a single ACJ session. Importantly, it is a question of the number of judgements required, not the number of judges. The number of judgements can be associated with a desired level of reliability (Verhavert et al., 2019), but there is also a common heuristic of having the total number of judgements equal to 10 times the number of portfolios, with this amount then divided amongst the judges.

From the system perspective, there is an algorithm dictating which pairs of portfolios to present to each judge and in what order based on some criteria. The decisions made are then recorded as wins/losses for each comparison, and these are modelled using a ranking model, typically the Bradley-Terry-Luce (BTL) model, providing outputs including a rank from “best” to “worst” of the portfolios, with relative differences, along a single latent continuum, and misfit statistics.

Research into ACJ (and CJ) aiming for improvement has typically been concerned with increasing algorithmic efficiency and transparency (Buckley & Lin, 2024; Gray et al., 2024), or in standardising the outputted relative ranks across sessions to enable merging or contrasting (Benton, 2021; Buckley & Canty, 2022; Verhavert et al., 2022). It has been less concerned with understanding the theoretical basis (Kelly et al., 2022). There is a need to connect both ideals, and hence the need for a Cognitive Theory of Comparative Judgement. For example, Pollitt (2012) spoke about an “improvement” to ACJ, being able to create a “chain” in the comparisons received by each assessor. Specifically, according to Pollitt (2012):

This brings a further improvement since the system is able to ‘chain’ comparisons once the Rasch method is in use. Suppose a judge has compared portfolios P77 and P93: the next decision they are asked to make may be between P93 and P21, and then P21 and P67—each comparison only involves one new portfolio rather than two. This may make little difference when comparing oriental rugs, but the time saved when comparing complex portfolios is substantial. (p. 163)

While Pollitt (2012) acknowledges a potential concern in chaining bias, he defends the gain in efficiency as worth the risk, stating that the bias would apply in a small and random way to each portfolio. However, this is an entirely statistical perspective relying on conditions not certain in practice. It assumes a very large number of judges and sufficient randomness in the pairing algorithm to leverage the central limit theorem. Otherwise, there could be too few chains that error would actually be systematic rather than stochastic.

Pollitt himself has suggested moving away from randomness (Kimbell et al., 2009), though others prefer to retain randomness initially (Buckley, 2024), and given that there are several possible adaptive algorithms (cf. Verhavert, 2018), the required number of judges to ensure minimal chaining bias is unknown. Consequently, Pollitt's (2012) goal to make ACJ more feasible at a judge level may actually make the process less feasible at a holistic level. Overlooking the cognitive dimension to ACJ in favour of statistical optimisation risks the creation of a feasible and reliable, but not valid, method.

3 TOWARDS A COGNITIVE THEORY OF COMPARATIVE JUDGEMENT

To work towards a Cognitive Theory of Comparative Judgment, it is necessary to move beyond a procedural description and statistical improvement and examine ACJ as a complex cognitive interaction. Drawing on the decision-making framework established by Bell, Raiffa, and Tversky (1988), this theory is positioned at the intersection of three perspectives: the descriptive (how judges actually make comparisons), the normative (how judges ought to make comparisons), and the prescriptive (how can judges be supported to make better comparisons whilst respecting their cognitive concerns). As described by Baron (2012), the descriptive lens lies in the domain of psychology, the normative in philosophy, and the prescriptive in engineering, or educational intervention (Larrick, 2004). By deconstructing the decision-making process inherent to ACJ through these lenses, we can identify specific postulates regarding the limitations of human processing. Such postulates can be translated into specific research questions or hypotheses and be examined through the manipulation of the assessment environment in tools like OpenACJ. Below are four initial postulates to exemplify the establishment of this theory, though several more are derivable and others would be established as the theory is developed.

3.1 *The computational constraint*

The cognitive demands of ACJ are inherent to the presented comparisons. Whilst the normative assumption of ACJ is that a holistic judgment is superior to criterion marking for assessment, the descriptive reality is affected by the information type, amount, and interactivity relative to the decisions to be made. Drawing on Computational Complexity Theory (Bossaerts & Murawski, 2017), the assessment of complex portfolios can be framed as a problem of tractability. In educational psychology, this concept is congruent with element interactivity within Cognitive Load Theory (Sweller, 2010).

Design portfolios typical of technology education are characterised as having high element interactivity, usually containing several related elements such as a deconstruction of the initial brief, iterative sketches, and technical specifications. When a judge is asked to compare 'Portfolio A' against 'Portfolio B', they are attempting to process two distinct webs of interacting elements. If the cognitive load resulting from negotiating the combined interactivity of these portfolios exceeds the working memory capacity of the judge, the decision problem could become intractable. Consequently, the first postulate suggests that when the cognitive load generated by the element interactivity of the portfolios exceeds the bounds of human processing, the judge cannot engage in the holistic judgment that ACJ purports to facilitate.

Translating this into an inquiry, one could investigate where the theoretical threshold of element interactivity (e.g., portfolio complexity) lies such that the reliability of comparative judgment degrades due to intractability. Having this information then could translate into a task design implication for OpenACJ, wherein portfolios are created which are smaller, lower-interactivity chunks to increase transitivity compared to overly complex comparisons.

3.2 *The cognitive strategy*

When the cognitive limits of a judge during a comparison are exceeded, a strategy must be adopted to facilitate reaching a decision. While the normative expectation is that judges engage in exhaustive information search and integration, the descriptive reality is framed by bounded rationality (Simon, 1990), suggesting an adaptation to the constraint. To manage the associated cognitive load, it is postulated that processing shifts from 'System 2', characterised by slow, analytical evaluation, to 'System 1', characterised by fast, intuitive, and heuristic-based judgments.

The Cognitive Theory of Comparative Judgment therefore requires the categorisation of these heuristic adaptations. For instance, an overloaded judge may employ Elimination by Aspects (Tversky, 1972), where the decision is reached by identifying a single negative or absent feature in one portfolio to justify rejection rather than weighing the total utility of both portfolios. Alternatively, satisficing may occur (Simon, 1990), wherein the first option that meets a minimum acceptability threshold is selected to terminate the cognitive effort.

Consequently, the second postulate suggests that high-cognitive load inducing comparisons bring a reliance on fast and frugal heuristics. Viewed through the lens of ecological rationality (Gigerenzer, 2024), these heuristics are not seen as leading to error, but as adaptive strategies which enable normatively correct decisions within the constraints of the comparative task.

Translating this into an inquiry, it is necessary to determine the behaviours that indicate a shift from holistic assessment to heuristic decision making, and in such cases, which heuristics are used. Specifically do ACJ judges work from an adaptive toolbox (Gigerenzer, 2001). This informs a research implication for OpenACJ, questioning whether the capture of granular process data (e.g., decision latency, navigation patterns) can empirically differentiate between holistic judgements and heuristic shortcuts.

3.3 *The algorithmic tension*

A theoretical tension can exist between the ACJ algorithmic logic and the sequential cognition of the judge. Normatively, adaptive algorithms may assume transitivity, that if $A > B$ and $B > C$, then $A > C$. This transitivity axiom assumes the independence of utility, implying that the relationship between two portfolios according to a judge holds regardless of the context in which they are presented.

However, the descriptive reality of decision-making suggest that utility is emergent and subject to path dependency. Evidence illustrates that judges do not utilise a static set of criteria across all

comparisons, but rather, the criteria are elicited based on the specific comparison presented (Buckley et al., 2022; Zhu et al., 2025). This path dependency is particularly relevant to the chains of portfolios described earlier by Pollitt (2012). Judging a portfolio immediately after a highly exceptional one may fundamentally reformulate the judge's internal standard of quality via the contrast effect.

The Cognitive Theory of Comparative Judgment reframes this path dependency as a mechanism for calibration. It is postulated that the sequence of comparisons serves a pedagogical function, allowing the judge to test and refine their internal criteria and develop their construct of quality framed in Polanyi's (1958) connoisseurship. Consequently, the third postulate suggests a shift from intransitivity to transitivity parallel to the crystallisation or stabilisation of the judge's own view, establishing within-person normativity.

Translating this into an inquiry, it is necessary to determine at what point in a session a judge's susceptibility to the contrast effect diminishes. This informs a prescriptive implication for OpenACJ, suggesting that adaptive algorithms must account for portfolio order and potentially utilise "warm-up phases" to allow for internal stabilisation before judgments significantly weigh on the final rank.

3.4 *The normative outcome*

Finally, for this paper, the theory addresses the nature of disagreement between judges. Having established that individual judges operate within their cognitive bounds (Postulate 1), utilise ecologically valid heuristics (Postulate 2), and stabilise their internal standards over time (Postulate 3), any remaining divergence cannot be dismissed as simple error.

The normative assumption of is that convergence, typically operationalised as high inter-rater reliability or scale separation reliability in ACJ, indicates validity. However, the descriptive reality of complex domains, such as technology and design education, is that they invite multiple legitimate interpretations of capability (Kimbell, 2011). The Cognitive Theory of Comparative Judgment therefore posits that, conditional on two judges being internally stable and adequately calibrated, disagreement may reflect distinct but coherent interpretations of a multidimensional construct rather than random noise.

Consequently, the fourth postulate suggests that the rank positions or ability scores of portfolios in ACJ are not always or necessarily representative of a single underlying consensus. Instead, the validity of the assessment lies in its capacity to capture and aggregate distinct judge perspectives. Disagreement is thus framed epistemologically as a feature of the complexity of the construct being assessed or measured.

Translating this into inquiry, one could ask whether the final unidimensional rank order masks distinct schools of thought. Specifically, can clusters of judges be identified who value specific dimensions (e.g., creativity vs. technicality) differently, but consistently? This creates a research implication for OpenACJ, asking whether the binary comparison data can be modelled in ways

that support multidimensional representations of judgement with better explanatory fit than a single latent continuum.

4 OPENACJ AS TOOL TO SUPPORT THE DEVELOPMENT OF THE COGNITIVE THEORY OF COMPARATIVE ASSESSMENT

With an agenda of inquiry established, the necessity for a bespoke instrument becomes apparent. Refining and validating the Cognitive Theory of Comparative Judgment requires access to the granular process data that underpins decision-making. OpenACJ was developed to enable this.

OpenACJ is an open access, adaptable platform designed to function as a research sandbox. It allows researchers to manipulate the choice architecture of the assessment environment to directly test the theoretical postulates. Currently, the platform operates through three distinct beta configurations.

Version 1 (Single-Device) and Version 2 (Multi-Device) share a core engine but serve distinct experimental needs. Version 1 isolates the judge on a single device, ideal for controlled laboratory settings where variables need to be strictly regulated. Version 2 supports distributed cohorts, mirroring the ecology of typical asynchronous ACJ sessions. As shown in Figure 1, the interface has a neutral presentation to minimize extraneous load. Both versions can be customised to capture psychometric data. For instance, upon making a decision, the judge can be prompted to respond to the Paas Cognitive Load Rating Scale (Paas, 1992) and provide explanatory comments (Figure 2). This feature directly addresses Postulate 1, allowing researchers to empirically identify the "tractability threshold" by correlating perceived mental effort with portfolio complexity.

Figure 1

OpenACJ Version 1 interface. Note that the “portfolios” are AI generated images in response to a prompt to design a bird house, intentionally showing a single idea versus multiple ideas, to support the creation of Figures for this paper

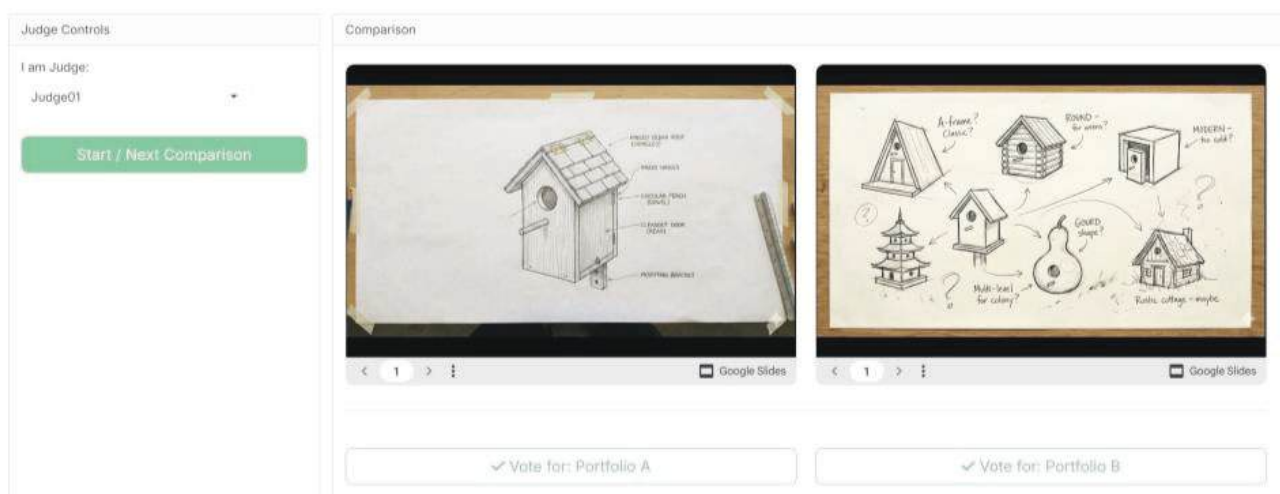
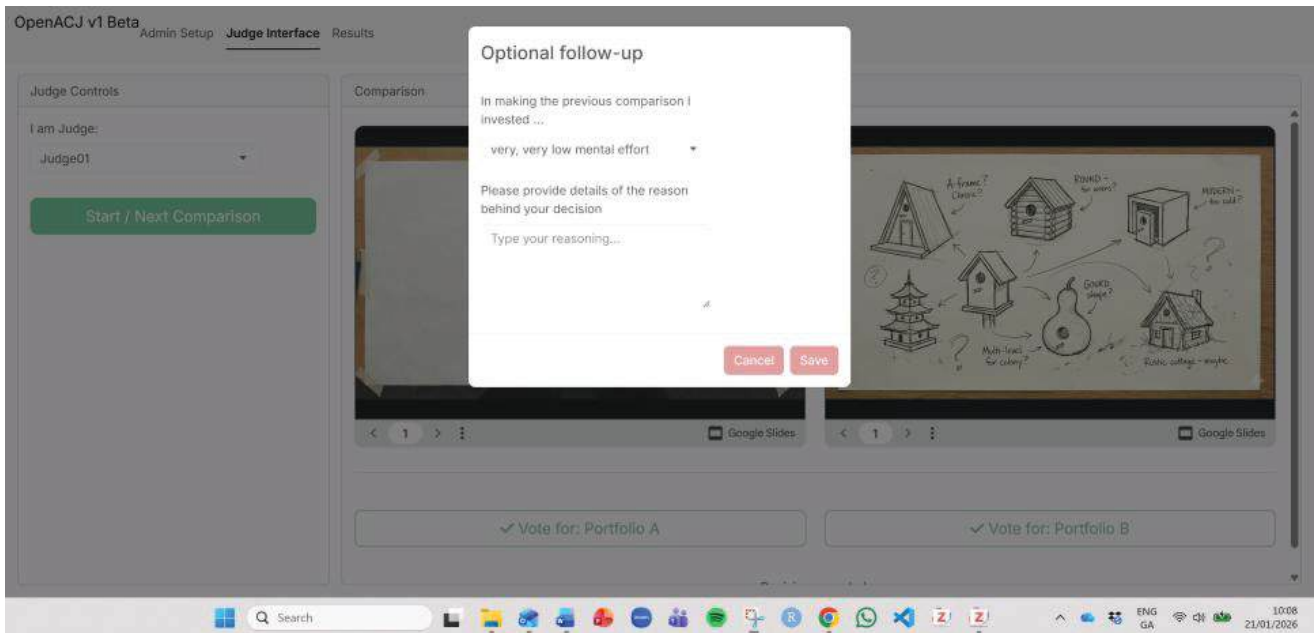


Figure 2

OpenACJ version 1 optional post-comparison data collection



Version 3 is modular, with the currently available module introducing a process tracing to investigate Postulate 2, The Cognitive Strategy. Drawing on decision science methodologies, this configuration overlays the standard interface with mouse-tracking functionality (Figure 3). As illustrated in Figure 4, this generates high-resolution temporal data on where and for how long a judge focuses their attention. By visualizing these trace maps and heatmaps, researchers can empirically differentiate between holistic and heuristic processing, and infer heuristic adoption. While this mouse tracing module is an example, future modules could include, for example, think aloud audio capture or eye tracking.

Figure 3

OpenACJ version 3 mouse tracing module interface

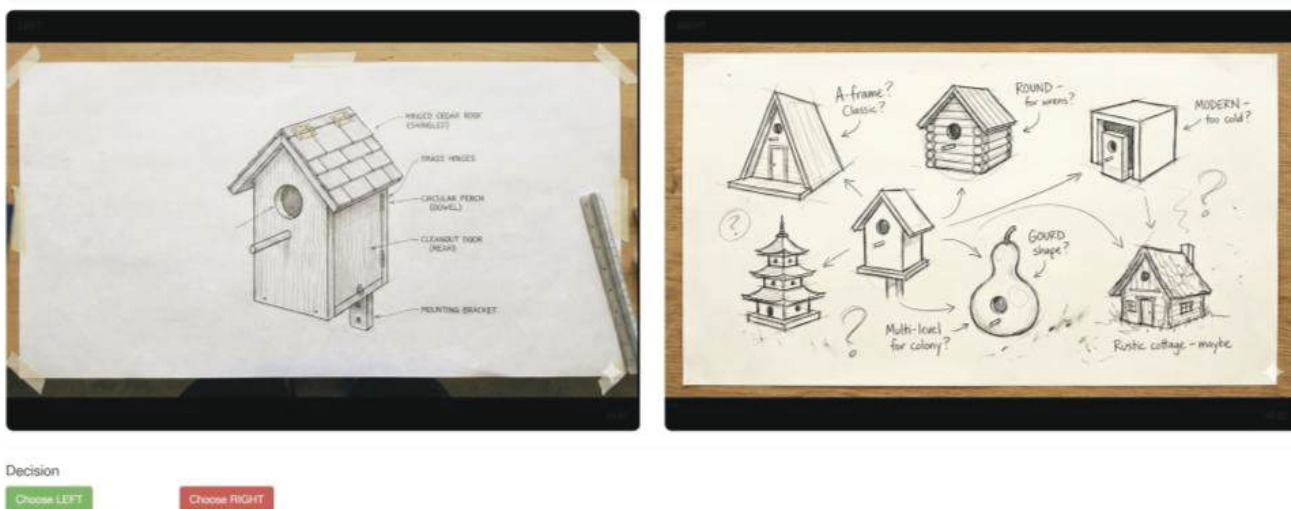
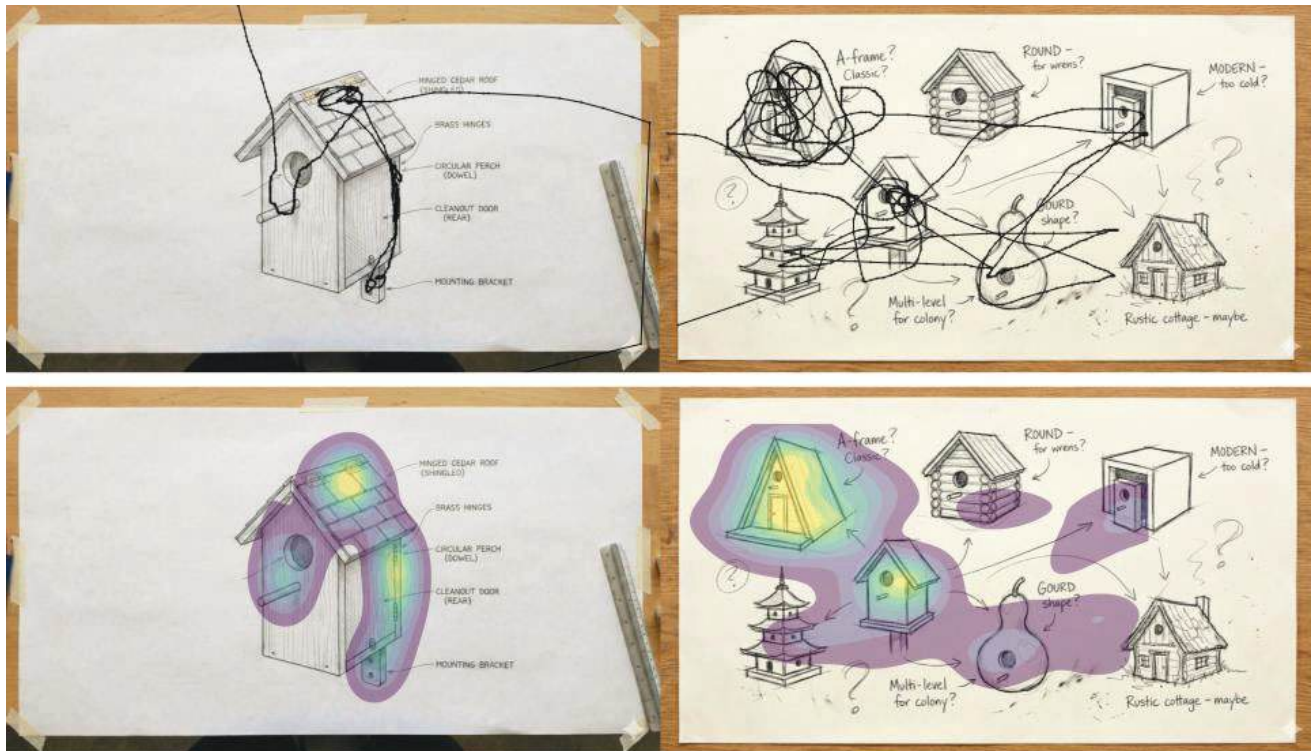


Figure 4

OpenACJ version 3 mouse tracing data output includes the mouse trace (top) and a derived heatmap (bottom)



5 CONCLUSION

This paper presents an initial proposal of the Cognitive Theory of Comparative Judgment to offer a framework to guide continued research into ACJ which merges ongoing algorithmic focus with a fundamental lens of human cognition. However, as this is just an initial presentation, it is inherently limited in potential scope. Further, theory development requires empirical verification. OpenACJ was thus developed to provide the necessary instrumentation to capture the granular process data required to test theoretical postulates. Ultimately, the synergy between this theory and instrument can move the field beyond asking if ACJ works, to understanding how it works, ensuring the method is not just robust, but valid.

6 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used in the generation of images for use in the manuscript as noted. They were further used to correct any spelling errors in the final submission. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Comics as Social Innovation

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Abstract

Rapid social change requires education that supports young people to understand complex societal challenges and consider how they might contribute to meaningful solutions. Introducing social innovation in schools advances this aim by helping learners explore how new ideas and practices can improve community well-being. Yet the conceptual and emotional depth of social innovation can be difficult to access through conventional materials. This paper examines how comics can serve as an effective pedagogical resource for exploring social innovation and argues that comics themselves can be understood as a form of social innovation.

Comics integrate visual, spatial, and written modes, enabling learners to interpret information through multiple pathways. Their multimodal structure supports observation, sequencing, and meaning-making, providing an accessible and engaging format for examining real-world issues. Because comics communicate complex and emotive ideas through imagery as well as text, they accommodate diverse literacy levels, cultural contexts, and lived experiences. This inclusivity creates opportunities for students to consider multiple perspectives, unpack societal challenges, and imagine possibilities for positive change.

The paper further contends that comics function as social innovation by expanding participation and fostering shared understanding. By representing cultural norms, social concerns, and personal experiences in resonant ways, comics help readers recognise common vulnerabilities and reflect on the contexts in which innovation is needed.

Situated within the EU SIDE (European Social Innovation and Democratic Education) Teacher Academy, the paper uses social innovation competencies as a framework to analyse how comics empower learners to understand, participate in, and influence social change. It demonstrates that comics offer a valuable and socially innovative medium for supporting engagement with social innovation in design and technology education.

1 INTRODUCTION

In a period of significant societal change, developing critical awareness of inequality, climate change, digitalisation, health disparities, migration and social exclusion is essential, as these conditions shape the need for social innovation (OECD, 2018). Social innovation has emerged in response to these interconnected challenges and encourages creative, participatory and systemic approaches to advancing social well-being (Ayob, 2016). For educators, this involves supporting learners to analyse complex systems, imagine alternatives and act collaboratively and reflexively in their own contexts (OECD, 2018; Moravec & Martínez Bravo, 2023).

This paper presents a twofold argument for technology education. It proposes that comics offer an effective way to engage with social innovation because their multimodal form helps students think critically, understand systems and develop design-oriented skills within project-based learning (Aman & Wallner, 2022; Jewitt, 2008). It also argues that comics themselves operate as social innovation by widening participation and reshaping how knowledge is shared. Their capacity to communicate complex and affective information supports learners in interpreting, reflecting and acting within more inclusive learning communities (Jewitt & Kress, 2003; Matuk et al., 2021).

Positioning comics within social innovation scholarship is conceptually coherent. Social innovation involves new or reconfigured social practices that respond to needs and create public value by altering relationships and capabilities (Mulgan, 2006; Nicholls & Murdock, 2012). Comics align with this understanding by challenging conventional pedagogical and literacy norms, legitimising multimodal meaning-making and expanding participation through accessible and diverse literacies (Aman & Wallner, 2022; Matuk et al., 2021). They also enable learners to identify needs, model systems and prototype more just and sustainable alternatives (FES Asia, 2018; Matuk et al., 2021).

This paper is situated within the EU SIDE European Social Innovation and Democratic Education Teacher Academy (Universidad de Burgos, 2026; HAMK, 2025–2028). The initiative provides advanced programmes and open-access MOOCs implemented in real school contexts through design-based research (EU SIDE Consortium, n.d.; Design Based Research Collective, 2003).

Within this context, the paper examines how the accessibility of comics enables deeper engagement with social issues. Meaningful engagement is a prerequisite for social innovation, as individuals must first be able to understand the social problem before questioning ideas, developing alternatives or building the agency needed to influence social change. This foundation informs the following section, which considers how comics function as forms of social innovation and how their accessible multimodal form supports understanding and participation in social change.

2 DEFINING SOCIAL INNOVATION

Social innovation is widely understood as the development and diffusion of new or reconfigured social practices that address societal needs while creating public value and transforming social relations (Mulgan, 2006; Nicholls & Murdock, 2012). Although definitions vary, the literature consistently highlights novelty as the reorganisation of existing practices, effectiveness in responding to unmet or complex needs, and value creation through participation, capability building and shifts in power dynamics (Howaldt & Schwarz, 2010; Manzini, 2015). Within EU policy, social innovation is framed as a means to strengthen inclusion, democratic participation and systemic transformation across sectors (OECD, 2018). However, opportunities to participate remain uneven. Barriers linked to literacy, digital inequalities, confidence and access continue to restrict engagement, and disparities in connectivity and digital skills closely reflect income, education, age and geography (Gomes & Dias, 2025; Eurofound, 2025). Research on participatory and democratic initiatives also identifies that exclusion persists when capability gaps and underlying power imbalances remain unaddressed (Bussu et al., 2022; García Espín, 2024). EU strategies therefore emphasise accessible information, digital competence and supportive environments as essential conditions for widening participation (European Commission, 2026; European Parliament Think Tank, 2025). Community-led innovation similarly requires intentional scaffolding to strengthen agency and reduce barriers (Kiresiewa & Gerdes, 2025). Within this uneven landscape, comics are proposed as a medium that can widen participation and amplify voices that are often unheard.

While understandings of social innovation continue to evolve, a central theme emphasises cross-sector collaboration and the restructuring of power relations to expand human capabilities. Mulgan (2020) situates social innovation within processes of tension, mobilisation and iterative development, where diverse actors generate and refine alternatives. In education, this perspective translates into cultivating competencies such as agency, equity, empathy, collaborative problem solving, systems thinking and creativity. These capacities help learners frame problems, test ideas and adapt solutions within real constraints. Social innovation can therefore be understood as the creation and implementation of novel approaches that address social problems more effectively, justly or sustainably than existing practices, with societal rather than individual benefit as the core measure of impact (Mulgan, 2006; OECD, 2025).

Within this educational framing, comics contribute by disrupting conventional pedagogical hierarchies and legitimising visual modes of meaning making. Multimodal theories position image, layout, gesture and writing as coequal resources for learning (Jewitt & Kress, 2003; Jewitt, 2008). The integration of visual and verbal elements makes complex or emotionally challenging topics more accessible and supports comprehension for learners who may struggle with dense or abstract text. Through sequence, imagery and perspective, comics situate social issues in concrete and relatable ways (Belda Medina, 2024).

2.1 *Engaging with the Complexity of Social Innovation*

Understanding comics as multimodal texts clarifies how images are produced and meanings designed. Eisner's (1985) concept of sequential art illustrates how panels, framing and pacing work with text to model processes such as learning and decision making. Comics illustrate the multimodal literacy described by Jewitt and Kress (2003), where learners draw on image, writing, layout, gesture and gaze to construct meaning, and where students design texts rather than simply decode them (Jewitt, 2008). The New London Group's (1996) multiliteracies framework extends this by advocating pedagogies that value diverse modes and cultural practices, enabling learners to design social futures in ways that align with social innovation.

Critical multimodal literacy research demonstrates that students use multimodal resources to re-story experience, retelling and reshaping texts and realities from their own perspectives while critiquing socio political conditions within equity-oriented frameworks (Cappello et al., 2019). Reader response studies similarly demonstrate that understanding comic conventions deepens meaning making, especially when learners also create their own texts (Rogers, 2014; Bender, 2019). Beyond classroom practice, cultural initiatives highlight the civic role of comics in public facing social innovation. Collectively, these strands indicate that comics represent social innovation processes while also serving as tools for developing the competencies required for socially innovative practice.

2.1.1 *Comics as Social Innovation*

Comics can be understood both as a medium that responds to social needs and as a practical form of social innovation within education. Their multimodal form supports learning across subjects and lived experiences by combining image, text, sequence and spatial design in ways that expand opportunities for meaning making (Jewitt & Kress, 2003; Jewitt, 2008). Research suggests that comics communicate complex ideas effectively while sustaining engagement in higher and further education (van der Sluis, 2025). They broaden participation by offering accessible entry points for neurodiverse, multilingual and academically marginalised learners and can be adapted across linguistic and literacy levels (Matuk et al., 2021; van der Sluis, 2025). Their low-threshold production also enables learners to articulate social, cultural and political realities that are often excluded from traditional pedagogies, allowing marginalised voices to be heard (Watkins, 2023).

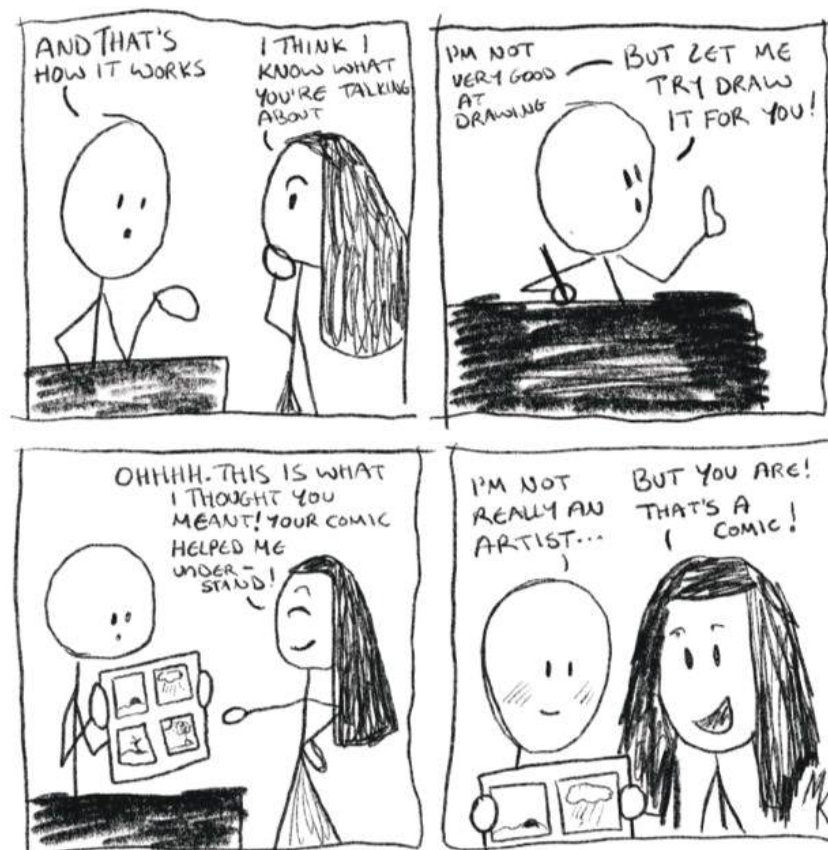
In learning about social innovation, comics help students visualise social problems and recognise themselves as potential agents of change (Sousanis, 2015). Focalisation, or the filtering of narrative through a character's perceptions and emotions, becomes visually explicit. Internal focalisation appears through thought balloons or visual metaphors, while external focalisation is conveyed through speech, gesture and action (Badman, 2010; Horstkotte & Pedri, 2022). This dual access to internal and external viewpoints allows learners to engage with experiences and perspectives that are often invisible or unspoken, deepening their understanding of social issues. It also supports identification with characters whose situations echo shared or marginalised realities. As Kirtley (2020) notes, this accessibility enables readers to see themselves reflected in

the narrative, making visible emotions, perspectives and social dynamics that might otherwise remain unarticulated.

Because comics do not require advanced drawing skills or specialised materials, they lower barriers to participation and support communication, reflection and agency. Through this combination of expression, interpretation and accessibility, comics contribute directly to the development of critical reflection and the capabilities required for social innovation. The image below illustrates how comics provide a low-threshold medium where expression matters more than artistry and where all that is needed is an idea, a pencil and paper.

Figure 1

Comics as a way to communicate and develop ideas with low level requirements. Credit: Kelly (2026a)



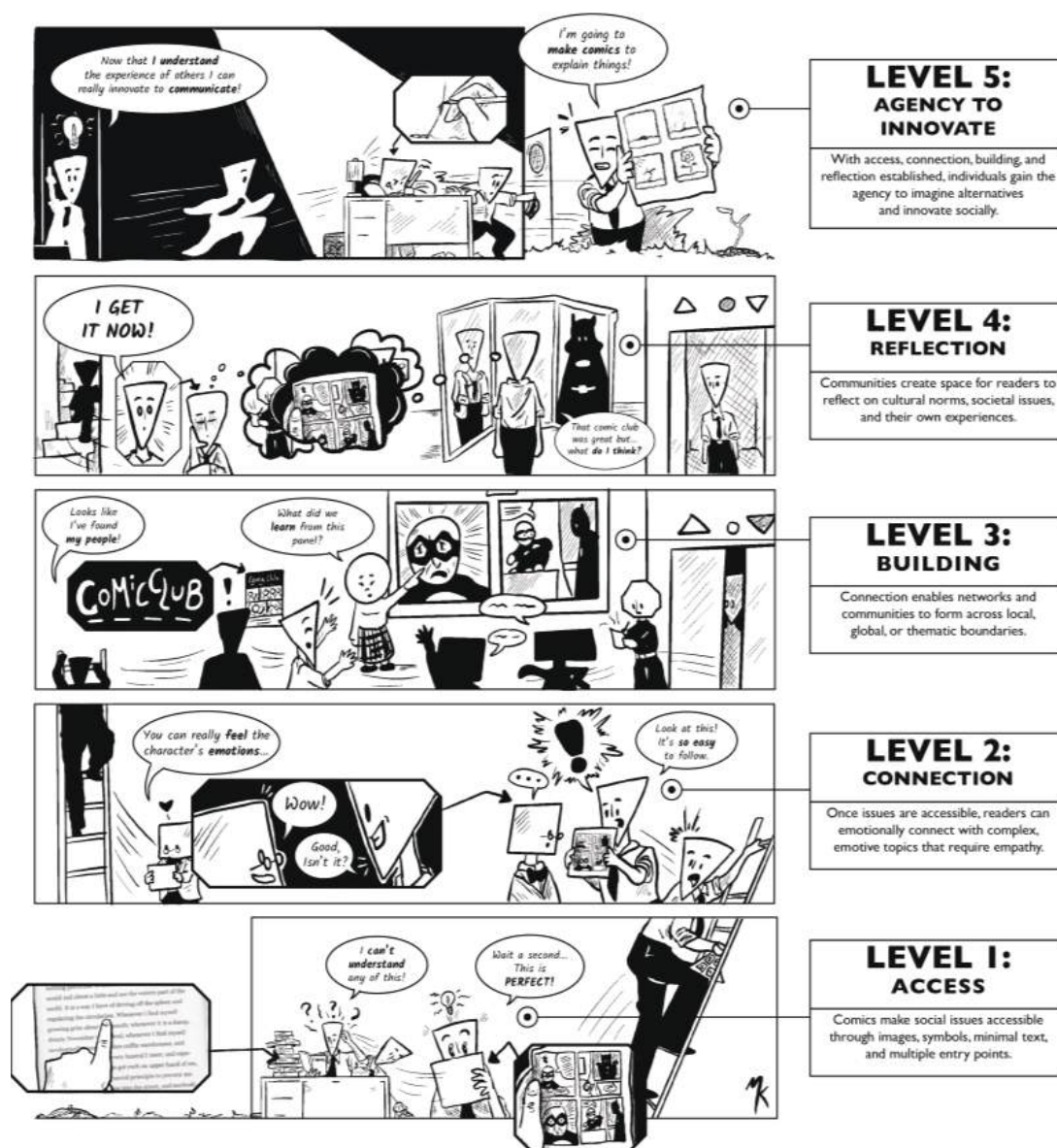
Comics offer a powerful way to understand social problems visually while fostering empathy and perspective taking. Because meaning emerges through the interplay of image, text, and reader interpretation, this expands participation, as comics do not require advanced artistic skill; simple drawings and minimal text can express complex experiences, enabling a wider range of learners to contribute meaningfully (Smyth, 2022). These shifts in agency and participation reflect social innovation practices that reorganise relationships, support new forms of expression, and challenge traditional power structures. In this sense, creating comics functions as social innovation by

helping learners articulate problems, imagine alternatives, and rehearse change-making identities within an accessible, inclusive medium (Kirtley, 2020; Lewis, 2023).

Comics function as social innovation by providing accessible entry points to complex social issues through images, symbols, minimal text, and multiple pathways for engagement, as illustrated in the comic below. This accessibility enables emotional connection, network-building, and community reflection, creating the space for learners to imagine alternatives, develop agency, and actively participate in social innovation

Figure 2

Comics as Social Innovation. Credit: Kelly (2026b)



Comics function not only as artistic media but as social technologies embedded in networks of practice (Latour, 2005). Social innovation depends on competencies such as systems thinking, empathy, creativity and collaboration (Mulgan, 2006; 2010). Comics reflect lived experience and help cultivate these capacities.

2.2 *Exploration of Social Innovation*

The purpose of this paper is to examine comics as a form of social innovation and to explore how their multimodal qualities support engagement with complex social issues. Comics integrate visual and narrative elements that lower literacy barriers, offer varied entry points for understanding, and sustain engagement among diverse learners, including those who struggle with text dominant materials (Belda Medina, 2024; Axelrod & Kahn, 2024). This aligns with multimodal scholarship that treats image, layout, gesture and writing as coequal resources for learning and meaning making (Jewitt, 2008; Jewitt & Kress, 2003). By reflecting readers' communities and experiences, comics foster recognition, belonging and participation (Belda Medina, 2024). They can therefore operate as accessible learning resources and as social innovations that widen participation, support self-development and strengthen agency and voice.

2.3 *Evaluating Comics as Social Innovation*

To demonstrate how comics function as a form of social innovation, it is helpful to consider the social, cultural and temporal conditions that shape both practices. This perspective demonstrates how each influences participation, meaning making and learning.

The table below outlines how comics and social innovation operate as mediated practices shaped by social, cultural and historical forces. Drawing on Vygotsky's (1978) sociocultural theory, it illustrates how both are co constructed through interactions between people, contexts and moments in time. This comparison highlights their shared ability to support collaborative engagement, situate learning within cultural experience and respond to changing conditions. Seen in this way, comics and social innovation function as culturally grounded practices that help learners interpret complex issues, explore multiple perspectives and engage in collective meaning making, reinforcing their value for reflection and imaginative problem solving.

Table 1*Social, Cultural, and Temporal connectivity between Comics and Social Innovation*

	Social	Cultural	Temporal
Comics	Visually depict social interactions; highlight marginalised voices; foster empathy and perspective understanding. (McCloud, 1993).	Reflect, question, and reimagine cultural values through symbols, imagery, and narrative choices. (Tanwar & Arora, 2026).	Evolve over time in style, themes, and representation; support iterative interpretation and learning. (Hansen et al., 2016).
Social Innovation	Address inequalities; promote collaboration; support community-led change. (Mulgan et al., 2007).	Challenge existing norms; co-create new cultural practices and shared meanings. (Westley, 2013).	Adapt to emerging social needs through cycles of experimentation, iteration, and reflection. (Murray et al., 2010).
Connected Enabler	Both act as socially mediated tools that foster empathy, participation, and collective action.	Both function as cultural tools that shape and are shaped by context, enabling shared meaning-making. Voice is given to those who are not generally heard.	Both engage with change over time, enabling iterative learning, empowerment, and agency.

Comics can be understood as a form of social innovation and resource for engaging with social innovation. it. As social innovation, comics visualise complex social, cultural, and temporal dynamics, amplify marginalised experiences, and help people reimagine norms and possibilities. Their narrative qualities make social issues more accessible and support new ways of seeing change. Comics have the potential for earners to connect personal experiences to broader societal structures and engage with empathy, systems thinking, and creative problem solving (Aman & Wallner, 2022). Overall, both comics and social innovation mediate understanding, reshape cultural meaning, and evolve over time, making comics a valuable companion to social-innovation learning.

3 EXAMPLIFY COMICS AS SOCIAL INNOVATION

Comics both embody and enable social innovation. They embody innovation as cultural forms that challenge hierarchies of knowledge production, and they enable innovation by providing creative and participatory media through which people identify needs, imagine alternatives, critique systems and communicate proposals. This dual role positions comics as social innovation, and as social innovations in themselves, widening participation, empowering learners and democratising knowledge.

To ground this argument, the paper examines *An Equal Future – Inspiring Social Innovations* as a case that functions both as communication about social innovation and as a social innovation in its own right. Produced collaboratively by the Finnish Institute in the UK and Ireland and the Lakes International Comic Arts Festival, the anthology uses comics to make complex social innovations accessible across three languages (Finnish Institute, 2021; Lakes International 2021). Conceptually, the paper synthesises social innovation theory and multimodality research to explain how comics operate pedagogically and innovatively (Aman & Wallner, 2022). Empirically, it reads *An Equal Future* as evidence of communicative efficacy and innovative production. The paper clarifies the theoretical frame, analyses the affordances of comics for systems-oriented learning, examines the case study and outlines implications for design and technology education.

The anthology's co creative, transnational production model exemplifies socially innovative practice by distributing expertise and supporting participatory authorship (Lakes International Comic Arts Festival, 2021). Each artist's contribution offers situated social commentary that reimagines relationships between policy, society and everyday life. By marking an institutional milestone with a forward-looking comic. Demonstrating how cultural organisations can adopt innovative communicative practices that broaden participation and support cross border knowledge exchange.

Within this framework, comics emerge as a valuable medium for design and technology education. They enable learners to integrate systems thinking, critique socio technical complexity and explore inclusive and imaginative design futures. In this context, the chapter *Universal Basic Income* by Darryl Cunningham examines the concept and its relevance to social innovation (Cunningham, 2021). The excerpt illustrates how poverty traps develop when returning to work leads to loss of essential benefits, along with the effects on wellbeing. By visualising these dynamics, the comic supports understanding, empathy and critical reflection, showing how limited access to basic income and negative stereotypes constrain agency (Cunningham, 2021).

Figure 3

Understanding barriers to social innovation, by D. Cunningham (2021), in An equal future: Inspiring social innovations from Finland, the UK and Ireland. Finnish Institute in the UK and Ireland. Reproduced with permission.



Through this comic, we see how visual storytelling can build social understanding by humanising the realities behind policy debates. This insight sets the stage for the concluding remarks, where the wider implications of comics as tools for social innovation are considered.

4 CONCLUDING COMMENTS

This paper demonstrates that comics function as a form of social innovation. By supporting recognition and identification, they allow readers to see their own experiences and communities represented. This movement from comprehension to participation helps foster voice and agency.

The paper also considers how comics operate within social innovation practice. In many European contexts, uneven digital access, variations in skills, and socioeconomic or geographic inequalities continue to limit who can participate in innovation processes (Gomes and Dias, 2025). Comics offer a practical response to these constraints because they reduce literacy demands, support meaning making, and provide an accessible medium for reflection and dialogue. These conditions are widely acknowledged as essential for inclusive participation (Belda Medina, 2024; Jewitt, 2008). Research on participatory and democratic engagement warns that participation can become tokenistic when differences in power and capability are overlooked. Comics help address this by broadening who can understand, contribute, and be heard.

Understanding comics as social innovation is therefore analytically valuable. It positions the medium as a change practice that expands access, enhances recognition, and strengthens agency beyond formal policy mechanisms (Belda Medina, 2024; Jewitt and Kress, 2003). The design-based research that follows will test these claims across EU SIDE pilot sites (EU SIDE Consortium, n.d.), assessing how comics function both as socially innovative artefacts and as enabling tools within broader innovation processes.

If social innovation asks us to rethink how change happens, comics remind us that change also begins with how we tell our stories—and who gets to tell them.

5 DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Collaborative Problem-Solving in Primary Technology Education: An Interactional Analysis of Model Construction Tasks Across Cognitive Load

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Abstract

This study examined collaborative problem-solving among primary school students during hands-on activities in technology education. Participants were 24 students from two Australian primary schools, all operating within Piaget's concrete operational stage of cognitive development, who worked in small groups to construct one of three mechanical models: a windmill (low cognitive load), a tower crane (moderate cognitive load), or a boat (high cognitive load). These model construction tasks required students to engage in group work involving shared planning, coordination of actions, and negotiation of responsibilities.

Adopting a qualitative observational design informed by interactional analysis, the study examined students' interaction patterns as they engaged with technological materials and processes. Group interactions were video-recorded and analysed using Rusk and Rønning's Joint-Individual and Open-Closed analytical framework to examine how students balanced joint decision-making with individual contributions during collaborative problem-solving. Analysis also examined how task structure shaped participation and how student roles emerged and shifted throughout the construction process.

Findings showed that students assumed a range of fluid student roles, including builder, organiser, guide, leader, and bystander, often transitioning between roles in response to task demands and peer interactions. While all groups demonstrated moments of effective group work, recurring challenges constrained collaborative problem-solving, including unequal participation, dominance by more confident students, difficulties articulating ideas, and limited strategies for negotiating disagreement. Task characteristics significantly influenced these patterns. The open-ended, high-load task supported creativity and exploration but increased the likelihood of fragmented efforts, whereas the closed, low-load task promoted focus and task completion while limiting opportunities for joint decision-making.

Overall, the study highlights how task design shapes collaborative problem-solving, student roles, and group work in primary school technology education, offering insights for the design of hands-on model construction activities that better support equitable participation and coordinated collaboration.

Key Words: Primary School Students, Technology Education, Collaborative Problem-solving, Model Construction, Group Work, Student Roles

1 INTRODUCTION

Collaborative problem-solving is widely recognised as a key learning process in contemporary education, particularly in contexts where students work together to plan, negotiate, and construct shared solutions. Rather than viewing learning as an individual cognitive activity, research has consistently shown that understanding is often co-constructed through interaction, including explanation, questioning, negotiation, and coordination of perspectives and resources (Cerovac & Keane, 2025; Dillenbourg, 1999; Mercer, 2000; Vygotsky, 1978). However, collaborative group work does not automatically lead to productive learning. While it can support deeper engagement and shared understanding, it can also result in unequal participation, dominance by particular students, and breakdowns in coordination (Chang & Brickman, 2018).

Research on collaborative problem-solving provides insight into how students manage shared goals, regulate participation, and respond to cognitive and social challenges as they work together (Dillenbourg, 1999; Hadwin et al., 2011). Central to this work is an interest in how interactional processes such as role distribution, decision-making, and conflict management shape the quality of collaboration. Understanding these processes is particularly important for the design of tasks and learning environments that support equitable and effective group work (Rusk & Rønning, 2020).

From a developmental perspective, primary school students in Piaget's concrete operational stage represent an important group for examining collaborative problem-solving. At this stage, students demonstrate increasing capacity for logical reasoning and perspective taking, while remaining strongly oriented towards tangible materials and observable actions (Ackermann, 1985; Bearison & Cassel, 1975). Hands-on construction tasks therefore provide a developmentally appropriate context in which students can externalise ideas through talk, gesture, and manipulation of physical resources. Studying collaboration in these settings offers insight into how students coordinate attention, negotiate meaning, and manage disagreement while working towards shared outcomes.

This focus is particularly relevant within primary technology education, where students frequently engage in hands-on design and construction activities (ACARA, 2025). Model-building tasks require students to coordinate tools and materials, negotiate design decisions, and distribute roles during group work. Learning in these contexts depends not only on individual reasoning, but also on how students collaborate during the construction process. Despite the centrality of group work in primary technology education, there remains limited empirical insight into how task structure shapes students' collaborative problem-solving and role enactment during

model construction. This study addresses this gap by examining how primary school students collaborate during model-building tasks of varying cognitive load.

2 LITERATURE REVIEW

Collaborative problem-solving is widely used in hands-on learning contexts where students work together to plan, coordinate actions, and construct shared solutions. In technology education, such activities often involve material artefacts and tools, requiring students to negotiate goals, distribute responsibilities, explain reasoning, and make joint decisions as work unfolds (Fox-Turnbull, 2024; Ziaeeffard et al., 2017). Learning in these contexts is therefore shaped not only by individual cognitive processes, but also by interactional processes such as communication, turn-taking, and the coordination of perspectives and resources (Dillenbourg, 1999; Mercer, 2000).

Research consistently shows that collaborative problem-solving does not automatically result in productive learning (e.g. Aslan et al., 2025; Barron, 2003; Roschelle & Teasley, 1995). While group work can support engagement and shared understanding, it can also lead to unequal participation, dominance by particular students, and breakdowns in coordination (Cerovac & Keane, 2025; Chang & Brickman, 2018). A growing body of work highlights task design as a critical factor influencing how collaboration unfolds, including whether students engage in joint decision-making or work in parallel with limited interaction (Schneider et al., 2016; Zabolotna et al., 2025). Features such as task openness, material constraints, and cognitive load shape how groups organise their work, manage shared attention, and respond to challenges during problem-solving.

Hands-on construction tasks are particularly relevant for primary school students, whose reasoning is closely tied to concrete materials and observable actions. At this developmental stage, collaborative problem-solving often unfolds through talk, gesture, and manipulation of shared artefacts, making interactional processes highly visible (Ackermann, 1985; Bearison & Cassel, 1975; Yliverronen et al., 2018). In these settings, participation is negotiated not only through verbal interaction but also through access to physical resources, such as tools and components. Control of these resources can influence whose ideas are enacted and how group activity progresses, highlighting the importance of examining participation beyond spoken dialogue alone.

One influential contribution to understanding collaboration in hands-on problem-solving is the work of Rusk and Rønning (2020), who examined how students organise interaction at a micro-level while working on shared STEM construction tasks. Their Joint–Individual and Open–Closed framework captures variation in collaboration based on whether work is undertaken jointly or individually and whether knowledge sharing is open or constrained. This framework provides a lens for analysing how turn-taking, access to artefacts, and epistemic positioning shape collaborative problem-solving, helping to explain why some groups progress productively while others fragment or stall.

Despite the central role of group-based construction activities in primary technology education, there remains limited empirical research examining how task structure influences students’

collaborative problem-solving and the roles they enact during model construction. This study addresses this gap by analysing interaction patterns and student roles as primary school students engage in hands-on model-building tasks of varying cognitive load.

3 METHODOLOGY

This study employed a qualitative interactional analysis to examine how primary school students organised collaboration during a hands-on model construction task. Participants were students in Years 3 and 4 (aged 8–10) from two Australian primary schools. Students worked in small groups of three to construct a physical model using shared resources.

Data were collected as each group engaged in one of three model-building tasks designed to vary in cognitive load (low, moderate, and high). The tasks required students to plan, coordinate actions, and negotiate roles while constructing a shared artefact. All group interactions during the construction phase were observed and recorded for subsequent analysis.

Ethics approval for the study was obtained from the relevant university Human Research Ethics Committee and the Victorian State Government Department of Education. Informed consent was secured from participating schools, parents or guardians, and students prior to data collection. To comply with ethics approval requirements, pseudonyms were used for all student participants. Group interactions were video recorded to capture verbal and non-verbal interaction, including talk, gesture, and access to shared artefacts.

3.1 *Research questions*

The following research questions guided the study:

[RQ1] How do primary school students organise collaborative interactions during hands-on model construction tasks of differing cognitive load, as characterised by Rusk and Rønning's Joint–Individual and Open–Closed framework?

[RQ2] What roles do students assume during collaborative model construction, and how do task structure and interactional openness influence participation, dominance, and bystander behaviour?

3.2 *Participants*

Twenty-four primary school students from two Melbourne (Australia) primary schools serving communities with comparable socio-economic characteristics participated in the study. Students were assigned by their teacher to small groups of three, after which each group was randomly allocated by the research team to one of three model construction tasks. This is shown in Table 1.

During these group construction activities, supervision was provided solely by the researcher (Working With Children Check certified), while the classroom teacher worked with non-participating students in a separate room.

Table 1

Group composition and allocation to model construction tasks

Group	Model	Level of Cognitive Load
1	Windmill	Low
2	Tower Crane	Moderate
3	Tower Crane	Moderate
4	Tower Crane	Moderate
5	Tower Crane	Moderate
6	Boat	High
7	Boat	High
8	Boat	High

The organisation of groups and tasks also reflected practical constraints at the time of data collection. Data collection began during the COVID-19 period, when schools limited access for external research and prioritised student wellbeing and core literacy and numeracy initiatives. As a result, opportunities for participation, particularly in technology education, were constrained, and the distribution of groups across task types reflects these practical limitations rather than a balanced allocation.

3.3 Models

Guided by Rusk and Rønning's (2020) distinction between open and closed epistemic interaction, three model construction tasks were designed to vary systematically in cognitive load and task openness, thereby shaping opportunities for collaborative problem-solving.

The low cognitive load task represented a closed condition, in which students followed fully specified pictorial instructions (Ikea-style). This structure minimised epistemic negotiation, as task steps and outcomes were predetermined. The moderate cognitive load task represented a partially open condition, in which selected steps were omitted, requiring students to infer missing procedures and coordinate actions to progress the construction. The high cognitive load task represented an open condition, in which students were provided only with a design brief. This task required joint interpretation of design possibilities, negotiation of a shared solution, collaborative planning, and ongoing coordination of both knowledge and physical resources.

This progression in cognitive load and task openness was designed to elicit contrasting interactional patterns, consistent with Rusk and Rønning's (2020) argument that task structure influences how learners balance joint and individual contributions during collaborative work. The three tasks are summarised in Table 2.

Table 2

Overview of model construction tasks by cognitive load and task openness

Task 1: Low cognitive load • 55 component parts, excluding two sets of chain links provided • Full set of pictorial instructions provided • 20-minute build time	
Task 2: Moderate cognitive load • 112 component parts provided, with a minimum of 83 required to build the model • Partial set of pictorial instructions provided • 30-minute build time	
Task 3: High cognitive load • 28 component parts provided • additional parts available to students beyond the immediate workspace • 40-minute build time	 Base kit of parts (includes paper and pencil for designing / planning)  Example of additional parts in close proximity to students' workspace

3.4 *Data collection*

Student interactions during model construction were video-recorded to capture both verbal and non-verbal forms of collaboration, including talk, gesture, and shared manipulation of materials. Video data provided a detailed record of how students coordinated actions, negotiated roles, and participated in collaborative problem-solving.

3.5 *Data analysis*

The video recordings were analysed inductively to identify student roles enacted during group work. Through repeated viewing of the data and iterative coding of interactional behaviours, recurring patterns of participation became visible. While the analysis was informed by prior research on young children's participation roles (e.g. Yliverronen et al., 2018), the roles in the present study were not predefined. Rather, the categories of builder, organiser, guide, bystander, and, where evident, leader were developed from patterns observed in our data. Because students often shifted roles over the course of the activity, each student was assigned a primary role, based on the role most frequently enacted, alongside any additional roles observed.

The analysis was informed by sociocultural perspectives on peer collaboration and by prior research examining young children's participation in design contexts, particularly their identification of recurring interactional roles based on patterns of verbal and embodied contribution. In addition, the analysis drew on Rusk and Rønning's (2020) Joint–Individual and Open–Closed framework, which examined the organisation of epistemic authority and participation during collaborative STEM activity. These perspectives provided a lens for interpreting how the identified roles were enacted within broader patterns of epistemic openness and authority in group interaction.

Drawing on this framework, the Joint–Individual and Open–Closed categorisations were derived through analytic comparison of coded interactional episodes. Episodes were classified as joint when students coordinated actions and decisions through shared talk or mutual engagement with materials, and as individual when work proceeded in parallel with limited integration of contributions. Interaction was classified as open when students proposed, took up, contested, or revised ideas with one another, and oriented to each other's knowledge in ways that sustained epistemic negotiation. Interaction was classified as closed when epistemic stances limited such negotiation (e.g. when students asserted strong knowing or unknowing positions without elaboration), or when contributions were not substantively taken up by peers. These determinations were based on patterns of role negotiation, turn-taking, access to materials, and how students responded to each other's contributions across episodes.

Building on this analysis, the video data were coded using the analytic framework focused on two dimensions of collaboration central to this study: role negotiation and interaction patterns. These dimensions captured how students organised participation, balanced joint and individual contributions, and coordinated work during model construction. The coding framework and associated descriptors are summarised in Table 3.

Table 3*Dimensions of collaboration and epistemic openness in model construction tasks*

Sub-dimension	Analytic focus	Code	Indicative Example
Role negotiation	How participation roles are established, maintained, and transformed	Role claiming	“I’ll build the base”
		Role acceptance	Nodding
		Role contestation	“I was doing that”
		Role switching	Guide becomes builder
Interaction patterns	How students coordinate action and meaning through talk and embodied activity	Verbal coordination	“Can you place the gear there”
		Gestural communication	Figure pointing
		Parallel work	Independent building
		Distributed participation	Turn-taking
		Unequal participation	One student dominates

Across the three model construction tasks ranging from a fully specified windmill model to a partially specified tower crane and an open-ended boat design the primary analytic focus was the degree of epistemic openness within group activity. Epistemic openness was examined through how students negotiated interactional roles (e.g. builder, organiser, guide), participated in decision-making, and coordinated contributions during collaborative problem-solving.

Particular attention was given to moments in which ideas were proposed, accepted, resisted, or rejected, as well as instances where one student’s contributions became authoritative in guiding group activity. These interactional features served as indicators of how epistemic authority was established and enacted within groups, especially in the high cognitive load task where procedural guidance was absent.

Conceptualising collaboration along this analytic dimension enabled systematic comparison of interaction patterns across tasks that differed in instructional explicitness and design freedom. The analytic framework used to examine epistemic openness and interactional organisation is summarised in Table 3.

3.6 Generative AI disclosure

In accordance with conference guidelines, generative AI tools were used only in a supportive capacity for copy editing and language refinement. All text content, analytical work, interpretations, and conclusions were produced exclusively by the human authors.

4 RESULTS AND FINDINGS

The results address the research questions by examining how collaborative interaction varied across model construction tasks of low, moderate, and high cognitive load. Drawing on Rusk and Rønning's Joint-Individual and Open-Closed framework, analysis focused on role enactment, role negotiation, and interaction patterns. All eight groups were analysed; selected groups are presented as illustrative exemplars of dominant interactional patterns observed within each cognitive load condition. A summary of roles and interaction patterns across all groups is provided in Table 4.

Table 4

Group-level interaction patterns across cognitive load conditions (Joint-Individual; Open-Closed)

Group	Cognitive Load	Dominant Roles	Role Negotiation	Interaction Pattern
1	Low	Builder, Organiser, Bystander	Early role acceptance	Joint-Closed
2	Moderate	Builder, Guide	Role contestation and switching	Partially Open
3	Moderate	Builder, Guide, Bystander	Limited renegotiation	Joint-Closed
4	Moderate	Builder, Guide, Bystander	Limited renegotiation	Joint-Closed
5	Moderate	Builder, Guide, Motivator	Role switching over time	Partially Open
6	High	Parallel Builders	No role negotiation	Individual-Open
7	High	Builder, Bystander	Role contestation	Individual-Closed
8	High	Builder, Bystander	Limited renegotiation	Joint-Closed

4.1 *Low cognitive load: Stable roles and closed interaction*

In the low cognitive load condition, collaboration in the single participating group was characterised by early role stabilisation and closed epistemic positioning. In this instance, one student assumed epistemic authority and control of the model, directing peers' contributions while retaining access to materials. This positioning was made explicit through directives such as, "You guys help me find the pieces and I'll build". Other group members adopted supporting or bystander roles, which were rarely renegotiated. Although brief challenges to authority occurred, these did not result in sustained joint decision-making. Interaction remained joint but closed, supporting efficient task progression while limiting opportunities for epistemic negotiation.

4.2 *Moderate cognitive load: Negotiated authority and partial openness*

In the moderate cognitive load condition, interaction was more variable, with evidence of contested and shifting epistemic authority. Groups 2 and 5 demonstrated episodes of role claiming and negotiation as students responded to incomplete instructions. In Group 5, epistemic authority shifted when one student's explanation regarding missing procedural steps was explicitly accepted by peers, who responded, "I trust you". Such moments enabled continued progress and partial coordination. However, these open configurations were often unstable, and interaction frequently oscillated between joint engagement and unequal participation.

4.3 *High cognitive load: Openness without coordination*

In the high cognitive load condition, increased task openness did not consistently result in joint collaboration. Group 6 exemplified an individual–open interaction pattern, in which students worked in parallel and pursued unintegrated ideas. Attempts to initiate collective planning, such as "How about we make a plan?", were repeatedly unacknowledged. As a result, epistemic authority remained diffuse rather than shared, and opportunities for collaborative problem-solving were limited despite high design freedom.

4.4 *High cognitive load: Dominance and closed interaction*

A contrasting pattern was observed in Group 7, where collaboration was characterised by individual–closed epistemic positioning. One student established and maintained authority through verbal directives and physical control of materials, explicitly restricting peers' participation with statements such as, "Wait, don't touch anything!". Although others attempted to contribute ideas or assert knowledge, these efforts did not lead to shared decision-making or role renegotiation. Despite the task's openness, interaction remained closed and asymmetrical.

Together, these findings indicate that while increasing cognitive load affords greater epistemic openness, collaborative problem-solving in primary model construction tasks remains interactionally achieved rather than guaranteed by task design alone.

5 DISCUSSION AND CONCLUSION

This study examined how primary school students organised collaboration during hands-on model construction tasks of differing cognitive load, focusing on interactional processes rather than task outcomes. Using a qualitative interactional analysis informed by Rusk and Rønning's Joint-Individual and Open-Closed framework, the findings show that collaborative problem-solving was shaped less by task complexity alone and more by how epistemic authority, participation, and access to resources were organised within groups.

How do primary school students organise collaborative interactions during hands-on model construction tasks of differing cognitive load?

In relation to the first research question, collaborative interactions across all three tasks were frequently characterised by early role stabilisation and limited epistemic negotiation. Even as cognitive load increased, groups often organised activity through parallel work or through the dominance of a single student. As a result, interaction patterns frequently remained closed, despite the greater epistemic openness afforded by the high cognitive load task. These findings indicate that increasing cognitive load does not, in itself, guarantee joint engagement or inclusive collaboration.

These observations align with prior research indicating that collaborative learning does not automatically result in productive interaction (Barron, 2003; Chang & Brickman, 2018). While open-ended design tasks are often assumed to promote joint decision-making and shared problem-solving (Hennessy & Murphy, 1999), the present study suggests that task openness alone is insufficient. Extending Rusk and Rønning's (2020) work, our findings demonstrate that epistemic openness at the task level does not necessarily translate into open interactional configurations. Instead, collaboration depended on how students organised authority, participation, and access to materials in the moment.

What roles do students assume during collaborative model construction, and how do task structure and interactional openness influence participation and dominance?

With respect to the second research question, students enacted a small set of recurring roles most notably builder, organiser, guide, leader, and bystander which were typically claimed early and rarely renegotiated. Role switching and explicit contestation were uncommon, and bystander positions often persisted across the activity. In the high cognitive load task, the absence of shared planning and workload distribution further constrained opportunities for students to adopt or shift roles, limiting the emergence of collective design-oriented collaboration.

Although the higher cognitive load model-building task was designed to afford sustained negotiation, iterative testing, and collective problem-solving, the interactional analysis demonstrated that these practices were only intermittently enacted within groups. For instance, while some episodes showed proposal and revision of ideas (Group 5), other groups worked in parallel (Group 6) or limited negotiation through dominant control of materials (Group 7).

Consistent with an interactional perspective, the findings suggest that students operating within the concrete operational stage still require explicit scaffolding of collaborative and epistemic practices for task openness to translate into productive joint activity. In contrast, lower cognitive load tasks supported efficient task completion but offered fewer opportunities for extended design dialogue or adaptive collaboration.

Extending Rusk and Rønning's work, this study demonstrates that task complexity qualitatively reshapes how students relate to one another, to material resources, and to the design process itself. Collaboration emerged as a socially organised and dynamic process rather than a stable group attribute, enacted through talk, gesture, and control of shared materials. Together, these findings highlight the importance of epistemic openness, sensitivity to others' knowledge, and equitable access to resources, and point to the need for more deliberate scaffolding of collaborative practices in primary technology education. By integrating micro-level interactional analysis with Rusk and Rønning's epistemic framework, this study also provides empirical insight into how collaborative configurations are interactionally produced in primary technology classrooms, complicating simplified assumptions that increasing task complexity will inherently foster deeper collaboration.

In conclusion, this study shows that collaborative problem-solving in primary technology education is not determined by task complexity alone but is interactionally achieved through how students negotiate roles, share epistemic authority, and coordinate access to materials during hands-on model construction. While higher cognitive load tasks afford greater epistemic openness, these affordances do not automatically translate into inclusive or joint collaboration without explicit support for collaborative practices. By applying Rusk and Rønning's interactional framework to primary school model-building tasks, this study contributes empirical insight into how task design and social interaction intersect in shaping students' collaborative engagement. These findings underscore the importance of deliberately scaffolding collaborative and epistemic practices in primary technology classrooms to support meaningful participation during hands-on design activities.

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Ally Rather Than Mere Utility: Reimagining the Teacher and Generative Artificial Intelligence Relationship in Design Education

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Abstract

Advances in Generative Artificial Intelligence (GenAI) are reshaping how design ideas are generated, explored, and justified in Design and Technology (D&T) education. While research on GenAI is expanding rapidly, limited attention has been given to how human and technological actors co-shape creative processes in authentic design contexts, or how these tools reshape pedagogical practice and professional judgement. This qualitative case study investigates how pre-service and in-service D&T teachers engaged with GenAI-enabled tools—Fusion 360 generative design and ChatGPT 1.5—within makerspace-based design activities. Drawing on interviews, classroom observations, stimulated recall, and artefact analysis, the study examines how GenAI becomes pedagogically meaningful within iterative workflows characterised by constraint, comparison, and decision-making.

Findings show a shift from instrumental use toward dialogic, reflective engagement, where AI-generated outputs functioned as provocations rather than solutions. Teachers actively mediated GenAI through critique, justification, and ethical discussion, redistributing—but not relinquishing—pedagogical agency. Conceptualised through a sociomaterial and posthuman lens as orchestrated co-agency, these practices demonstrate how design learning emerges through negotiated relations among teachers, students, AI systems, and material constraints. The study contributes empirical insights into GenAI-mediated design pedagogy and offers implications for curriculum, assessment, and teacher education.

Keywords: Generative Artificial Intelligence, Design, Case Study, Co-Creation, Posthumanism, Teacher Agency

1 INTRODUCTION

Generative Artificial Intelligence (GenAI) is increasingly embedded within Design and Technology (D&T) education through tools for modelling, ideation, and optimisation that shape how design problems are explored and resolved (Veliz Reyes et al., 2024; Deng et al., 2025).

While much discourse frames GenAI in terms of efficiency and automation, such accounts offer limited insight into how these systems interact with the epistemic foundations of design education—where knowledge is produced through iteration, justification, and engagement with constraint (Lindström, 2022; Smith & Iversen, 2022). The central pedagogical question is not whether GenAI can generate ideas, but how teachers integrate and mediate its participation in design learning.

Existing research has largely focused on student use, ethical risk, or tool capability, often positioning teachers as regulators (Kasneci et al., 2023; Selwyn, 2022; Shute et al., 2023). In D&T classrooms, however, teachers play a more active role of designing tasks, framing constraints, orchestrating dialogue, and judging the quality and legitimacy of design decisions (Blikstein, 2013). Yet empirical research remains limited on how GenAI operates as a collaborator in iterative classroom practice, particularly in reshaping the roles, agency, and creative decision-making of teachers and students when it moves beyond a tool for cognitive offloading (Lodge et al., 2023). This study addresses that gap by investigating how teachers engage with Fusion 360 generative design and ChatGPT 1.5 in makerspace-based contexts. Adopting a sociomaterial and posthuman orientation, teaching is conceptualised as emerging through relations among human and non-human actors. The concept of *orchestrated co-agency* is introduced to describe how pedagogical agency is distributed yet actively coordinated across teachers, students, AI systems, and material constraints (Fenwick et al., 2015; Orlikowski, 2007).

2 LITERATURE REVIEW

2.1 *Conceptual Framing: GenAI, Design Knowledge, and Orchestrated Co-Agency*

D&T education is characterised by knowledge emerging through making, iteration, and justification under constraint (Lindström, 2022). Tools shape not only how ideas are expressed but what can be imagined and valued (Blikstein, 2013). The integration of GenAI therefore raises questions about how design knowledge is constituted.

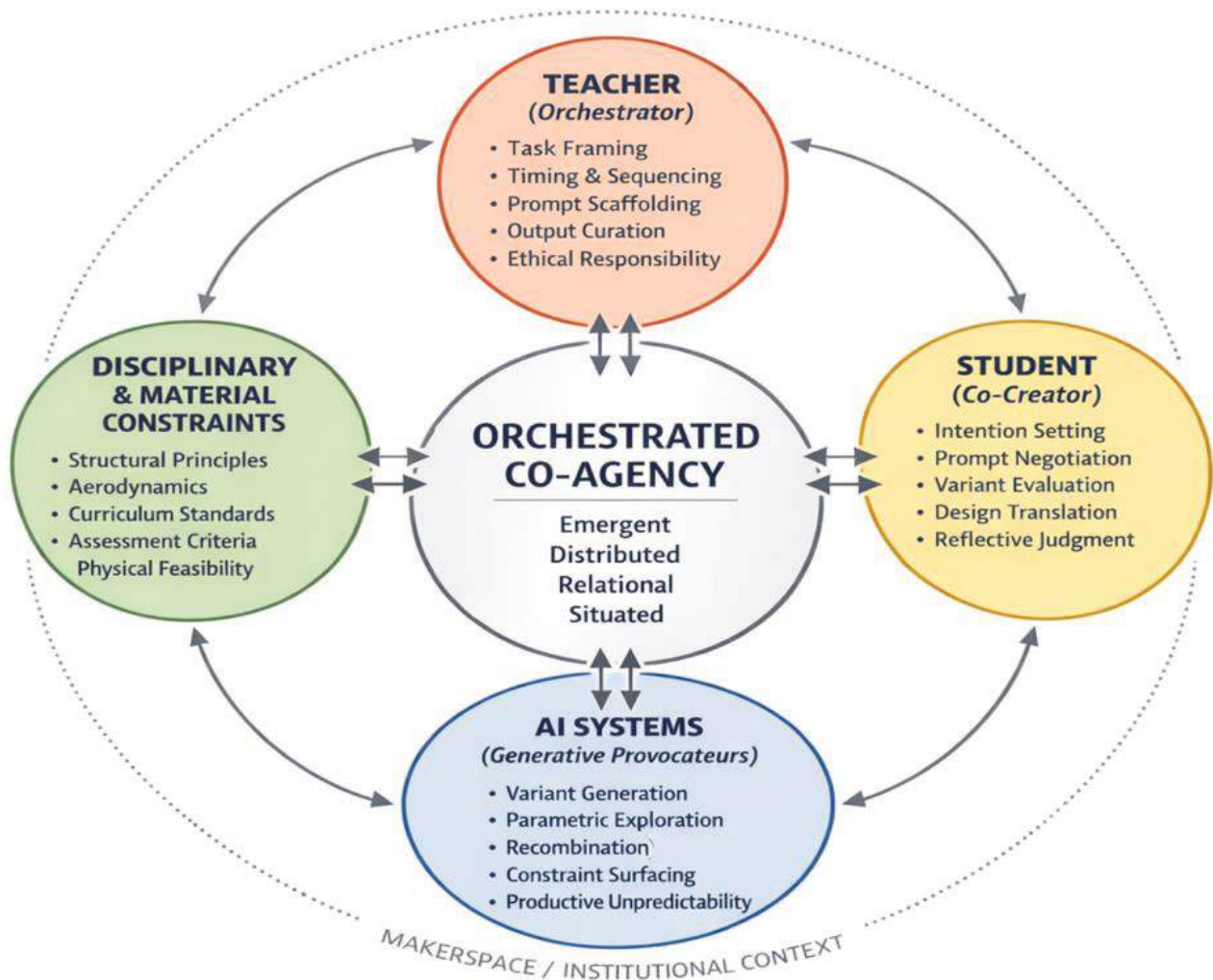
Recent literature increasingly frames GenAI as a creative collaborator capable of generating alternatives (Bommasani et al., 2022; Kasneci et al., 2023), alongside concerns about bias, hallucination, and over-reliance (Bender et al., 2021; Selwyn, 2022). However, the pedagogical work required to integrate GenAI into disciplinary learning remains underexplored. Teachers in D&T classrooms play a central mediating role by framing design tasks, establish constraints, modelling judgement, and establishing criteria for evaluating design decisions (Priestley et al., 2015). When GenAI enters the design process, it introduces a non-human participant whose contributions must be acknowledge, interpreted and disciplined in relation to curricular goals and material constraints.

Understanding teaching with GenAI therefore requires an analytic lens that foregrounds relations among people, technologies, and materials (Orlikowski, 2007). To analyse this mediation, the concept of **Orchestrated Co-Agency** is introduced. Drawing on sociomaterial theory (Orlikowski, 2007), posthumanism (Haraway, 2008), and actor-network theory (Latour, 2005), it describes distributed agency emerging through interactions among teachers, students, AI systems, and constraints. While agency is distributed, it is pedagogically orchestrated. Orchestration

emphasises teachers' role in structuring, timing, and constraining AI contributions (Dillenbourg 2013), while co-agency recognises GenAI's capacity to contribute meaningfully without displacing human judgement (Tholander & Jonsson, 2023). Arrows indicate the circulation of agency across these elements, emphasising that creativity and decision-making emerge through iterative negotiation rather than residing with any single actor.

Figure 1

Orchestrated Co-Agency in Design Education



To examine the interplay between the bounded system, this study is guided by the following research questions explained and analysed through the Orchestrated Co-Agency framework:

RQ1: How do teachers engage with Fusion 360 GenAI and ChatGPT 1.5 in design tasks?

RQ2: How do teachers interpret agency, creativity and authorship in these interactions?

Table 1*Descriptive and Analytical Framework Derived from the Orchestrated Co-Agency Model*

Model Component	Role in Design Process	Observable Indicators	Practices/	Analytical Focus in This Study
Orchestrated Co-Agency (Central Dynamic)	Emergent relational agency produced through iterative interaction among teachers, students, AI systems and design constraints.	Cycles of prompting, interpretation, critique, redesign, and material testing within the design process.		How agency circulates across actors and how creativity, authorship and pedagogical responsibilities are negotiated.
Teacher (Orchestrator)	Frames and regulates the design process by structuring tasks, scaffolding AI use, and aligning outputs with curricular goals.	Task framing, prompting guidance, timing AI engagement, curating or rejecting AI outputs, modelling evaluative judgement, linking AI suggestions to disciplinary knowledge.		How teachers position GenAI (tool vs collaborator), how they guide prompting, and how they regulate creativity and decision-making.
Student (Intention-Setter and Co-Creator)	Students articulate design intentions, negotiate prompts, evaluate AI-generated possibilities, and translate outputs into sketches and CAD models.	Prompt creation and refinement, interpretation of AI suggestions, sketching and modelling adaptations, evaluation of variant designs, reflection on authorship and creativity.		How students engage with AI-generated ideas, how they integrate them into design thinking, and how they perceive creative ownership.
AI Systems (Generative Provocateurs)	Produce variant design possibilities that stimulate ideation and reshape design trajectories.	Generation of alternative forms, parametric variations, conceptual prompts, structural suggestions, unexpected design possibilities		How AI outputs influence design exploration, provoke reflection, and alter the trajectory of design development.

Disciplinary Norms and Material Constraints	Stabilise and filter design possibilities through disciplinary knowledge, assessment criteria, and physical feasibility.	Structural evaluation, aerodynamic considerations, manufacturability, CAD constraints, material limitations, curriculum expectations.	How disciplinary knowledge and material realities shape acceptance, modification, or rejection of AI-generated ideas.

3 METHODOLOGY

3.1 *Research Design*

A qualitative exploratory case study was employed to examine how pre-service and in-service teachers engaged with GenAI in a constrained drone arm design task. This approach enabled analysis of situated practice and emergent meaning-making (Yin, 2009; Crowe, 2011). Consistent with a sociomaterial perspective, the study traced how agency and design reasoning emerged through interactions among teachers, students, AI systems, and material constraints (Fenwick et al., 2015).

3.2 *Site selection, sampling and participants*

The study was conducted in an Advanced Manufacturing course at Adelaide University. A purposive sample of 60 participants who all provided written consent included 45 pre-service and 15 in-service teachers from diverse school contexts. Participants varied in experience and GenAI familiarity, but all had engaged with AI tools in practice. All provided written consent

3.3 *Design Collection, Analysis and Validation*

Data were collected over a 12-week period through questionnaires, interviews, observations, stimulated recall, artefact analysis, and participant journals, with design tasks situated within participants' existing curricular and professional contexts to maintain ecological validity (Tracy, 2018). Analysis was conducted using reflexive thematic analysis (Braun & Clarke, 2021), guided by the Orchestrated Co-Agency framework. Coding was organised across four dimensions: teacher orchestration, student co-creation, AI generativity, and disciplinary-material constraints. Trustworthiness was ensured through a comprehensive audit trail of observations, notes, sketches, images, and logs (Korstjens & Moser, 2018), alongside participant verification and cross-case comparison to enhance credibility while preserving contextual specificity (Yilmaz, 2013).

3.4 *Design tasks and process*

The design process unfolded across multiple representational modes, including sketching, CAD modelling, Fusion 360 generative design, and interactive dialogue with ChatGPT 1.5. Students began with hand drawn sketches and outputs were evaluated collaboratively, with "promising"

designs selected for Fusion360 generative variation based on parameters such as torque, material and mounting constraints.

Figure 2

Example of students' hand drawn concepts

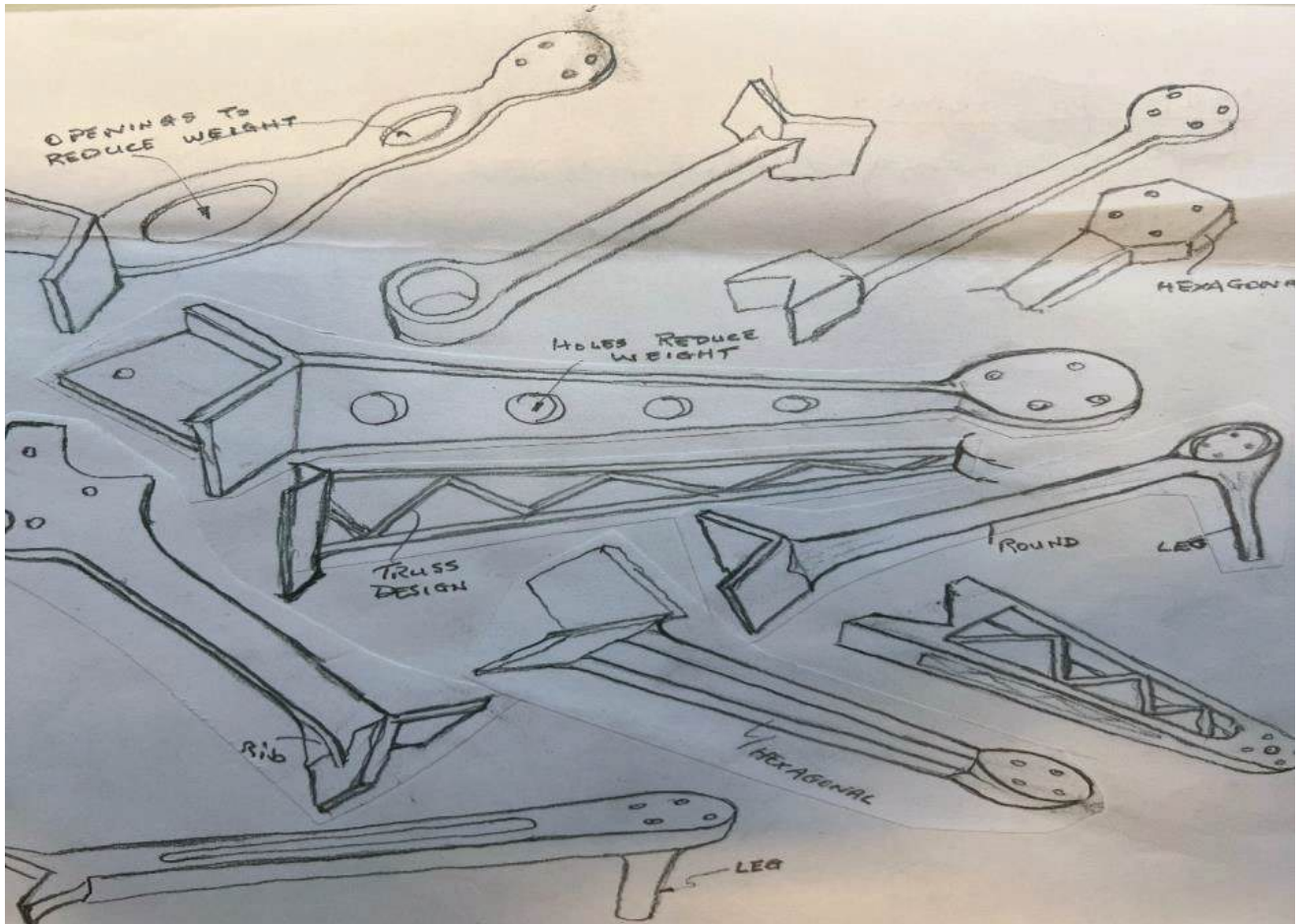


Figure 3

Parameters for fixed mounting geometry to design the drone arm

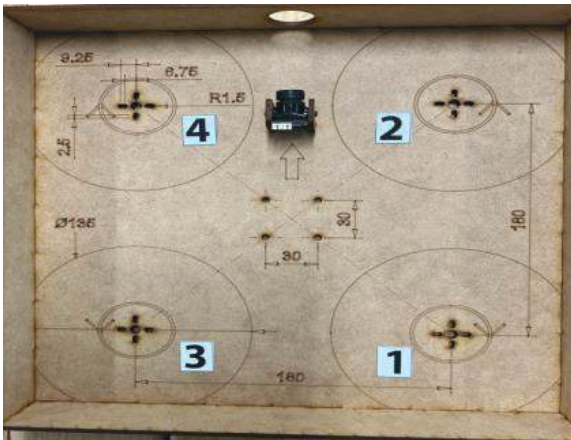


Figure 4

Layout of electronics system

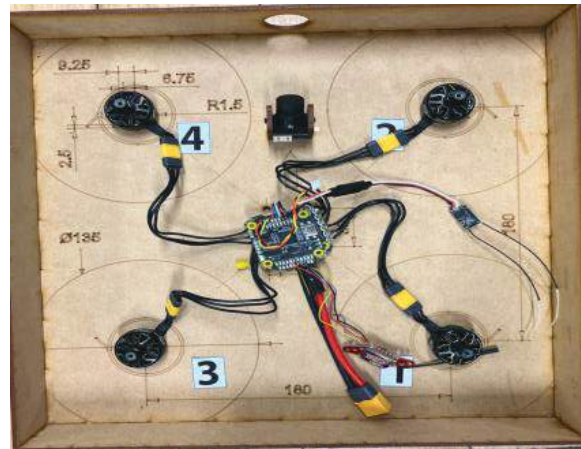


Figure 5

Layout of drone arms with electronics fitted

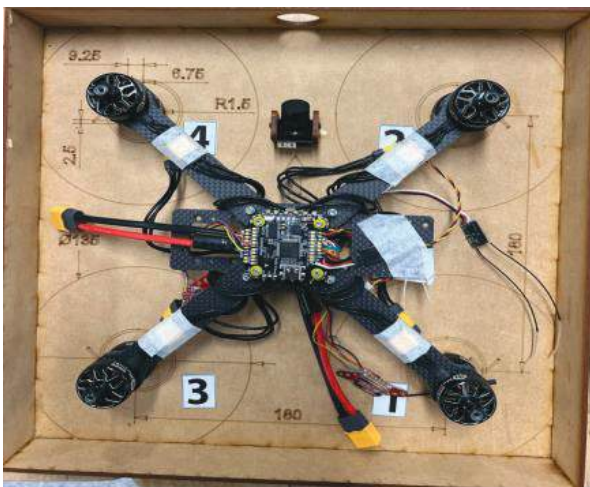


Figure 6

Fusion 360 GenAI fixed mounting geometry with measurements taken from figure 3.

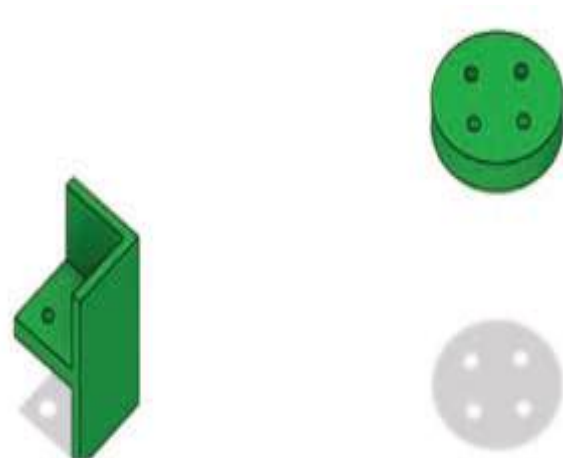
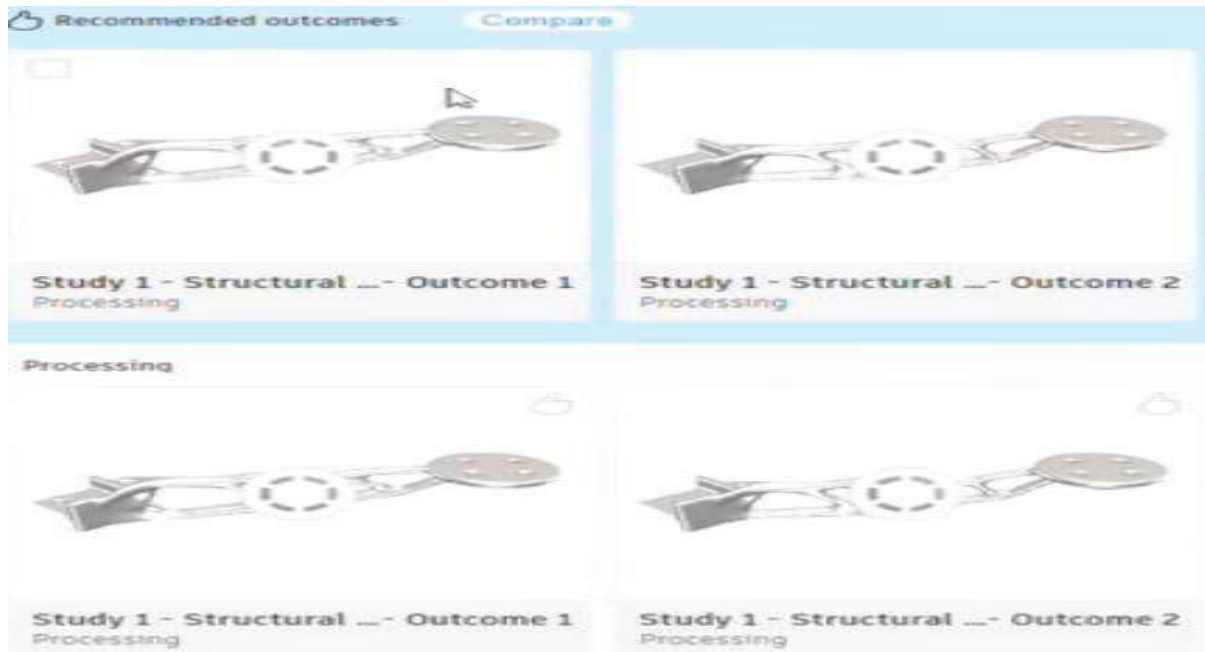


Figure 7

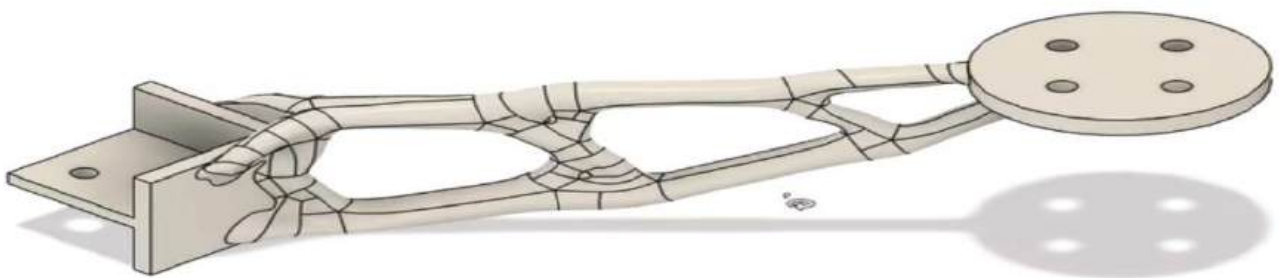
Fusion 360 generative design outputs produced under shared parameters View the process here <https://youtu.be/uNHMq-Xzpi0>



Multiple design variants were used as comparative artefacts to prompt discussion of structural logic, load paths, and manufacturability, rather than as final design solutions.

Figure 8

Most promising outcome From Fusion 360 GenAI

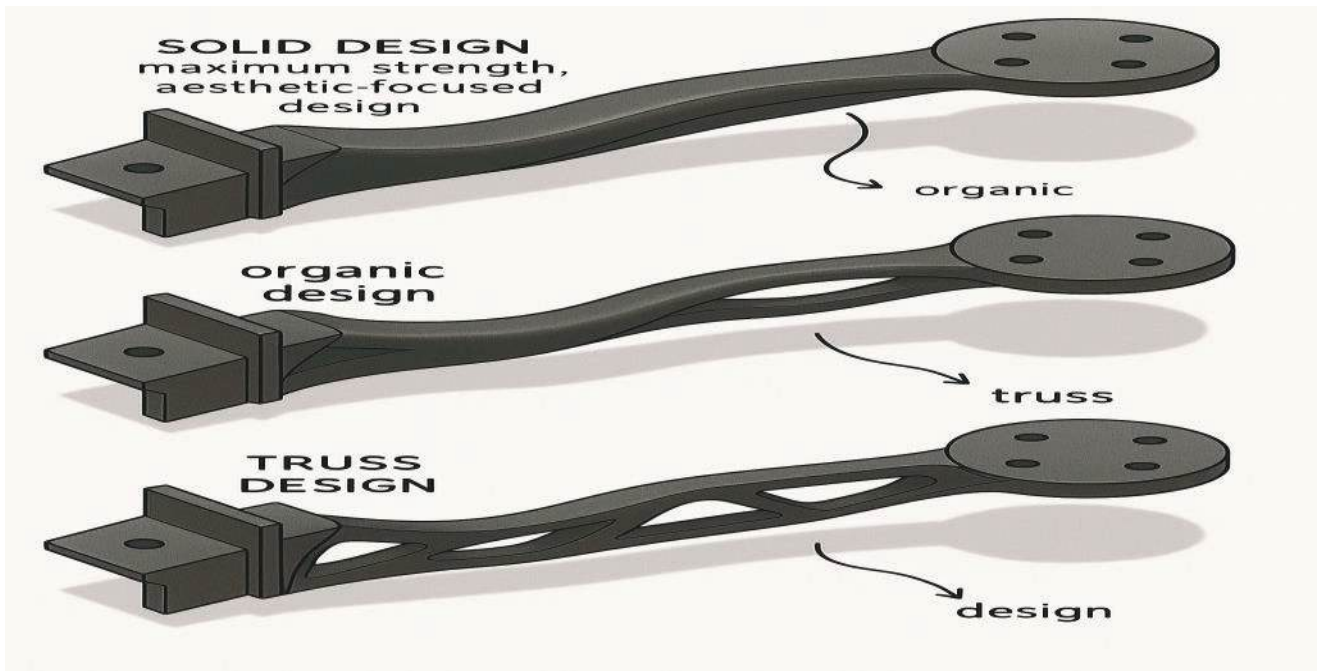


ChatGPT was introduced as a tool for “intellectual sparring,” prompting critique and reflection. The text-to-image generated interpretations of the drone arm design were not final but served as provocations for critique and redesign, prompting discussion of aesthetics, functionality, and implicit assumptions embedded in AI-generated representations. Teachers and students collaboratively evaluated outputs based on structural integrity, feasibility, and design intent. Importantly, teachers and students co-constructed prompts, negotiated constraints, and critically evaluated AI-generated responses. Authority was not delegated to GenAI but through

orchestrated interactions, deciding when to accept, modify, or reject outputs. By designing tasks that required translation between human intention, machine generation, and material testing, the study created conditions under which orchestrated co-agency could be empirically observed rather than assumed.

Figure 9

ChatGPT-generated design interpretations.



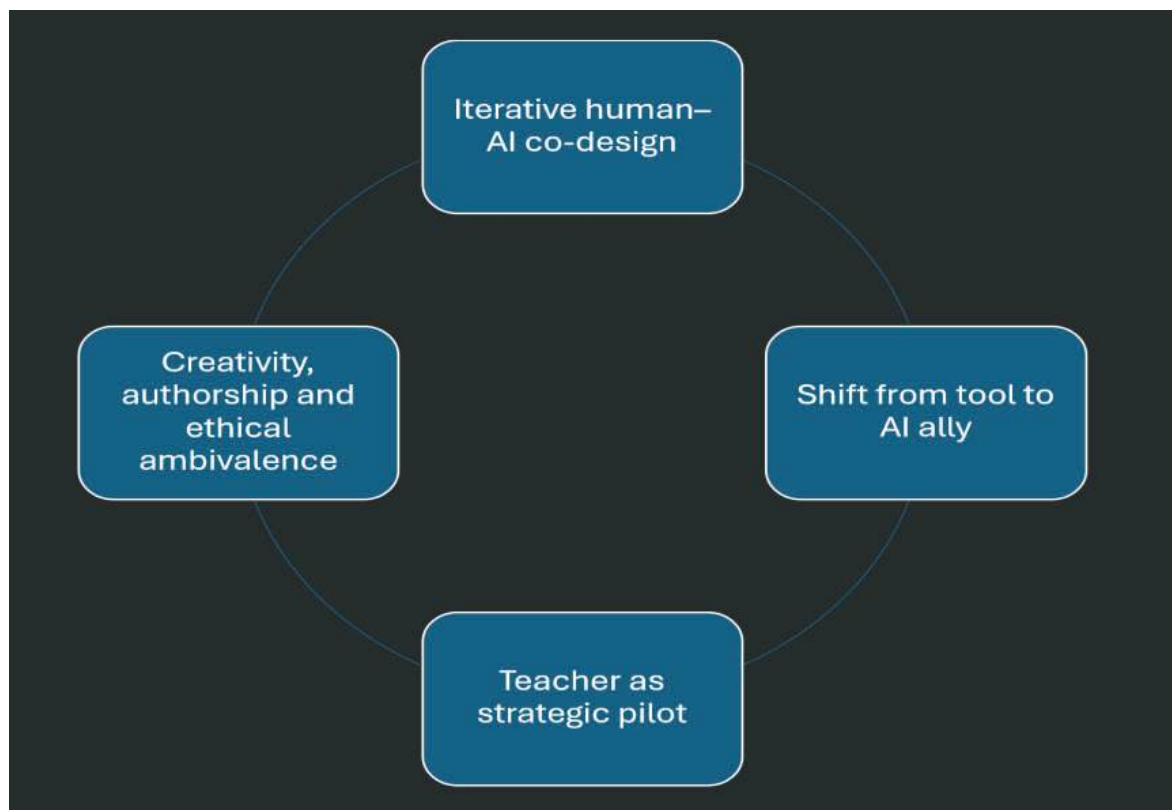
All figures shown were used analytically to illustrate pedagogically consequential moments of comparison, selection, and justification rather than to document technical proficiency (Lindström, 2022; Davis & Linn, 2000). ChatGPT text-to-image generated interpretations of the drone arm design were not final but served as provocations for critique and redesign, prompting discussion of aesthetics, functionality, and implicit assumptions embedded in AI-generated representations.

4 RESULTS AND DISCUSSION

This section presents findings from interviews, observations, and stimulated recall, examining how pre-service and in-service D&T teachers engaged with GenAI in design activities. Analysis focuses on how pedagogical meaning and agency emerged through teachers' orchestration of human–AI relations in practice. The four emerging codes illustrate how orchestrated co-agency was enacted in practice.

Figure 10

Key Findings



4.1 Iterative Human/GenAI Co-Design

Across cases, GenAI participation was fluid and context dependent. Teachers positioned it variably—as generator, provocateur, or constraint—based on pedagogical intent rather than technical affordances. Initially, teachers used GenAI instrumentally to “speed things up” or “take the grunt work out of modelling”. Engagement was largely transactional, with prompts issued quickly and outputs judged for surface-level correctness reflecting productivity-oriented GenAI use (Selwyn, 2022; Shute et al., 2023). However, as students developed prompting skills, design engagement deepened. AI-generated outputs expanded the design space and prompted discussion around design principles of structural logic and manufacturability. AI-generated outputs were mobilised to expand the design space and provoke comparison among alternatives. Some comments from teachers emphasised comparison and critique:

“It was like laying ideas side by side so we could argue with the machine’.

“The GenAI designs weren’t the answer – they were something to push against. This made students to ask, ‘Why does this look like this?’ and ‘What aspects of the design answered the brief best?’

“It wasn’t about choosing the best design the GenAI gave, it was about asking why it chose that.”

These comments echo findings in design education research suggesting that exposure to alternatives reduces design fixation (Kim et al., 2023; Tan 2023).

4.2 *Shift from Tool to Ally*

Over time, a marked shift occurred in both teachers’ language and practice. Teachers shifted from viewing GenAI as a tool to engaging with it as a collaborator. Interaction became dialogic, involving iterative prompting, questioning, and refinement. Design sessions increasingly featured teachers and students discussing how to frame, revise prompts, pose follow-up questions, and compare multiple AI-generated alternatives before making design decisions. Several participants explicitly linked the quality of GenAI response to the quality of their own prompts. Comments from one pre-service and experienced teacher reflected this:

“At first, I treated it like a command line—tell it what I wanted and see what came back. But I realised quickly that if I didn’t think carefully about my questions, the output was shallow.”

Human/GenAI interactions were thus embedded within cycles of questioning, response and reconsideration. Agency became distributed across prompts, outputs, and judgement. Rather than transferring authority to AI, this shift intensified teacher responsibility. One teacher said:

“It forced me to slow down. I couldn’t just rush to an answer—I had to think about what I was really asking and why.”

These findings align with emerging research indicating that effective engagement with large language models depends on users’ questioning strategies and conceptual clarity (Kasneci et al. 2023; Knoth et al. 2024). GenAI was no longer merely executing commands but shaping the direction of prompting and design inquiry.

4.3 *Teachers as Strategic Pilots*

Teacher mediation emerged a central feature of orchestrated co-agency. Teachers actively interpreted, constrained, and legitimised GenAI contributions against disciplinary norms, feasibility, and curriculum goals. In some cases, teachers intervened quickly; in others, they allowed students to pursue flawed AI suggestions as opportunities for critique. As two participants explained:

“Sometimes I let them run with a bad AI idea for a bit—because figuring out why it doesn’t work is more valuable than me shutting it down straight away.”

“We didn’t try to give them a neat answer. The point was getting them to sit with the discomfort and talk it through.”

Teachers also guided students in articulating reasons for selecting or rejecting GenAI outputs through justification journals and annotated screenshots to support this process. One participant noted:

“If they choose an AI-generated design, they must explain why. If they reject it, they also must explain why. Either way, the decision must be theirs.”

These practices reinforced teacher authority while supporting student reasoning. Consistent with sociomaterial and AI in education scholarship (Latour, 2005; Barad, 2007; Selwyn, 2019; Luckin et al. 2016), teachers do not relinquish authority to GenAI but enact it through ongoing mediation, validating, framing and ethically positioning AI outputs – thereby orchestrating a form of distributed yet accountable co-agency in design practice.

4.4 *Agency, Ambivalence and Ethical Reflexivity*

Despite recognising GenAI’s creative potential, teachers expressed persistent ambivalence regarding authorship, originality, and over-reliance which can result in erosion of critical thinking. Some teacher reflections were as follows:

“It’s empowering, but it’s also unsettling. You start wondering—if the AI keeps suggesting better ideas than the students, where does that leave their thinking?”

“There is a fine line between accessibility and dependence. If one started relying too heavily on GenAI outputs, the critical thinking fades”.

Authorship emerged as particularly sensitive. Several teachers expressed discomfort when students claimed ownership of designs heavily influenced by GenAI. As three participants reflected:

“We are not designing alone anymore; we are designing with GenAI and that loop needs to be visible and accountable.”

“If the form came from the AI, the parameters from the teacher and the final choice from the student – who is the author?”

“I found myself questioning whether the design was mine or the GenAI’s. Who is the author?”

Concerns about reliability reinforced the need for critical evaluation especially where ChatGPT provided confident but incorrect information or where Fusion 360 generative products appeared disconnected from real-world manufacturing constraints. A pre-service teacher commented:

“Some of the Fusion 360 results looked amazing, but when we talked it through, we realised they’d be a nightmare to actually make.”

These findings align with research indicating that educators' engagement with generative AI is frequently characterised by simultaneous enthusiasm and concern, as teachers recognise its creative and pedagogical possibilities while remaining wary of its implications for authorship, academic integrity, and the erosion of critical thinking skills (James et al., 2025; Ghimire et al., 2024; Oliveira, et al., 2026). Rather than rejecting GenAI, teachers embedded ethical reflection into practice. Students documented how AI outputs were used, shifting ethics from compliance to accountability. Ethical reasoning became integral to design reasoning and orchestrated co-agency (Floridi et al., 2018; Williamson & Eynon, 2020).

5 IMPLICATIONS FOR DESIGN AND TECHNOLOGY EDUCATION

Findings suggest curriculum and assessment must adapt to AI-mediated design as tasks emphasising iteration, comparison, and justification align well with GenAI-rich environments (Lindström, 2022; Smith & Iversen, 2022). Administratively, policy should support infrastructure, guidelines and communities of practice that enable safe, ethical and pedagogically meaningful integration of GenAI across diverse school contexts.

Similarly, assessment should prioritise documentation, justification, and reflective commentary documentation and reasoning over final products, making AI participation visible without resorting to surveillance (Biesta et al., 2015).

For teacher education, the key challenge is not technical training but developing orchestration capability. Teacher and student education need to develop prompt engineering literacy skills, orchestration skills and ethical reflexivity to manage human, AI and material interactions constrained by curriculum needs (Holmes, et al., 2022). The limitations of instrumental training models focused solely on tool use are exposed bare here.

6 CONCLUSION

This study examined how D&T teachers engaged with GenAI in makerspace contexts, moving beyond instrumental framings to foreground relational agency and pedagogical judgement. Teachers did not simply adopt or resist GenAI; they actively configured its role within design processes. The concept of *orchestrated co-agency* captures how agency is distributed yet coordinated across human and non-human actors.

The findings indicate that GenAI did not replace teacher authority but reconfigured it. Teachers remained responsible for design legitimacy, ethical judgement and learning outcomes (Biesta et al., 2015; Barad, 2007). By positioning GenAI as a pedagogical participant rather than a solution, this study highlights the centrality of teacher judgement in sustaining meaningful and ethical design education in AI-rich environments (Dillenbourg, 2013; Goodyear & Dimitriadis, 2013).

By conceptualising these practices as orchestrated co-agency, this paper contributes an empirically grounded framework for understanding pedagogy in AI-rich design environments.

7 DISCLOSURE STATEMENT

No artificial intelligence (AI) tools were used in the preparation of this manuscript. All writing, data analysis, and interpretation were conducted entirely by the authors without assistance from AI technologies

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The Use of a User in Design Projects

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Abstract

This study examines how user representation is embodied in students' physical models in technology education design projects, and how this relates to the models' function, structure, and overall design.

Given that physical models are widely used in technology education, previous research has paid limited attention to how users become materialised in students' models. Drawing on research that conceptualises modelling as a generative and epistemic activity, this study addresses this gap by analysing 45 physical models produced in a technology course for student teachers. The models were created in an individual design assignment based on a children's book. Two versions of the assignment were used: one requiring student to design a technological solution represented in a model for a specific user within the book, and another using the book purely as inspiration for designing a solution. The models were analysed using an extended analytical framework that included graded categories of user representation model design character and structural representation.

Findings show that user representation decisively shaped the character and overall design of the models. Models with clear user influence displayed explicit structural reasoning and integrated overall designs, whereas models lacking user representation tended to remain exploratory or centred on isolated functions. Importantly, user representation also emerged when not explicitly required, indicating that users functioned as interpretive resources in students' design reasoning. The study contributes empirical and analytical insight into how user-related reasoning becomes embodied in physical models and highlights the need for further research and more robust analytical frameworks for examining physical models in technology education.

Key Words: Design Projects, Physical Models, User Perspective

1 INTRODUCTION

Physical models are mentioned in several countries' curricula for technology, where they serve as key tools for problem solving, communication, and technological development (Norström & Hallström, 2023; Citrohn, 2018). In school design projects, physical models function both as

representations of intended solutions and as epistemic artefacts that support externalisation, testing, and communication of solutions (Citrohn et al., 2023).

Although the use of models is common in technology education, little attention has been given to how users are represented within models. Research in information technology and human-computer interaction shows that users are often constructed through designers' assumptions and that there is a persistent gap between user-centred design ideals and practice (Hyysalo & Johnson, 2015; Oygür, 2018; Mäkinen et al., 2019; Wilkinson & De Angeli, 2014; Marti & Bannon, 2009). Yet little is known about how user representations are embodied in physical models in technology education. From a philosophical perspective, technological artefacts have a dual nature: they are physical objects shaped by human intentions and purposes (Kroes, 2002; Kroes & Meijers, 2006). Thus, a technological model must be understood in relation to its intended user, underscoring the importance of examining how the user influences the model.

In technology education design projects may have a specific user, a user implied through narratives, or a user constructed by students as part of their design reasoning. How students interpret or construct users can therefore shape their modelling practices and the relationship between model and intended solution. Previous research shows that a user influences students' reasoning about function, structure and materials (Citrohn, 2025) and that models designed for a specific user differ from those focused mainly on technical functions (Boström & Citrohn, 2023). However, few studies have examined how such user-related reasoning becomes materialised in students' physical models, or how models differ when users are assigned or self-constructed. In order to address this gap this study by analyses physical models created in a design assignment based on children's books, in which one version required an explicit user and the other used the book only as inspiration. This setting makes it possible to investigate both whether students work with a user and how user representation becomes embodied in their physical models.

The purpose of the study is to examine how user representation is embodied in physical models developed in design processes, and to analyse how these embodiments relate to the models' function, structure, and level of integration. Accordingly, the study is guided by the following research question:

In what ways is user representation embodied in physical models in design processes, and how does this relate to the models' function, structure, and overall design?

2 LITERATURE REVIEW

In Swedish technology education, design projects involving physical models are common, particularly in compulsory school, where design processes including modelling are explicitly stated in the curriculum (Skolverket, 2022). In these projects, models function as representations through which students develop, refine and communicate their solutions. Models enable students to externalise, test and communicate ideas about function, structure and material (Citrohn et al., 2023).

2.1 *Technical artefacts, function and use*

As technological artefacts, models link physical structure to human intentions and contexts of use. Kroes (2002) argues, when discussing function, one always refers to a context of use and to the user for whom the artefact (model or solution) is intended. With regard to context, Kroes (2002) introduces an important distinction between designer context and user context. In the designer context, a solution's function may fit the design specifications, yet in the user context the same solution may fail to satisfy users' needs, expectations, or constraints. Therefore, designers must consider the user context alongside the designer context (Kroes, 2002). The user context is simply not external to technical artefacts; it is constitutive of what makes them meaningful. This highlights the importance of examining user representations in students' solutions and physical models.

2.2 *Physical models and prototypes in design processes*

Models and prototypes function as generative, exploratory and communicative artefacts that enable designers to investigate functions, test structural principles and consider use situations. They typically evolve from simple constructions focusing on isolated functions toward more integrated, product-oriented representations (Isa & Liem, 2014), a progression that is also relevant in educational settings where design problems are loosely defined (Citrohn, 2025). As models develop, usability and handling often gain prominence, making the user more visible even when not initially specified. At the same time, research highlights conceptual ambiguity in how models are analysed, creating a need for analytical tools that distinguish intentions, representations, structures and outcomes in students' modelling work (Green et al., 2014).

2.3 *Physical models in technology education*

As material representations, models shape students' reasoning by highlighting certain functional or structural aspects while downplaying others. Models may be categorised by their properties or by the purposes they serve in the design process (Müller, 2009). In educational design projects, students may engage both the designer's and the user's perspective, and the model's specific design reflects considerations of intended use and intentionality (Nia & de Vries, 2017). An imagined user often becomes essential for expressing design intentions; without one, modelling risks reducing the task to craft or isolated function work rather than technological design (Kimbell, 1996). Depending on how a design assignment is framed, students' models may emphasise form, isolated functions or structural principles (Boström & Citrohn, 2023; Citrohn, 2025). From the perspective of the philosophy of modelling, models are tools constructed to answer specific questions (Rost & Knuuttila, 2022). User representation therefore provides epistemic direction by helping define what the model is intended to investigate. Despite this, how user-related reasoning becomes materially expressed in students' physical models remains an underexplored aspect within technology education.

2.4 *Positioning the study*

This study examines how user representation is embodied in students' physical models in a technology course for student teachers. Drawing on philosophical accounts of technical artefacts as intentional objects, research on models in design processes, and the need for analytical

frameworks, the study investigates how users influence functions, structure and material of students' models. By analysing physical models as epistemic artefacts and focusing on user representation as an analytical dimension, the study contributes to a deeper understanding of how design assignments shape modelling practices and technological knowledge in educational contexts. In doing so, the study explores how user-centred reasoning, the design and representation of intended solutions in physical models, and didactic relations intersect in technology education. The present study also responds to the gap identified by Norström and Hallström (2023), who show that educational modelling practices rarely make explicit the epistemic stages of simplification, validation and verification. By examining user representation in physical models, the present study extends their call for analytical frameworks capable of connecting modelling decisions to intentionality and context.

3 METHODOLOGY

This study adopts a qualitative comparative design aimed at examining how the inclusion of an explicit user and context in design assignments influences physical models and ideas about intended technological solutions in a technology education context. The analysis focuses on students' physical models developed through design activities.

3.1 *Participants and educational context*

The participants were student teachers preparing to teach grades 1–3 (children 7 to 10 years of age) in Swedish schools, enrolled in a Technology Education course. A majority of the students had limited knowledge of constructing, materials and tools. The course included workshops on material properties and structural strength, as well as seminars addressing the nature of technology, technological development and design processes. Students' modelling work were conducted in a university technology workshop with access to a variety of tools and materials; also, students were allowed to bring additional materials from home. The students had about 9 hours to design and complete their models.

3.2 *The design assignment*

The design assignment was based on children's books which were selected and analysed by the students earlier in the course. Two versions of the assignment were used: in the first version, students were instructed to select a character from their book and design a technological solution adapted to that character. In the second version students were instructed to develop a technological solution inspired by the content of their children's book. Apart from the inclusion of an explicit user the versions were otherwise identical. In both versions, students were asked to design and construct a physical model which was supposed to be used when demonstrating their intended solution. When demonstrating the solution, the model was supported by sketches and an oral presentation.

3.3 *Empirical material and analysis*

The empirical material consists of 45 physical models produced by the student teachers, together with their descriptions of the intended functions. The first 27 models (M1 - M27) are related to

the first version of the assignment while the last 18 models (M28 – M45) are related to the second version. The models were treated as the primary units of analysis but were complemented by student’s oral presentation and sketches. The analytical framework builds on previous research analysing physical models as epistemic artefacts used to explore ideas, functions, structures and materials (Citrohn, 2025). In the present study, this framework was extended by introducing *user representation* as a distinct analytical dimension. The analysis was guided by an analytical matrix comprising categories for *user representation*, *structure representation*, and *model category*. Central to the analysis was a graded coding of user representation, capturing the extent to which the user influenced the functional, structural and material characteristics of the models (Table 2).

Each model was analysed individually. Descriptive data were first recorded, followed by analytical coding. Care was taken to distinguish between features explicitly shown in the physical model and aspects that were only verbally described during demonstration. Finally, each model was categorised according to its overall character (e.g. form-oriented, function-oriented or product-oriented), enabling systematic comparisons between models developed in assignments with and without an explicit user. Models were categorised using four model categories (K1–K4), corresponding to a progression from exploratory models to prototype models (Table 1). The categories build on established distinctions between simple, advanced, presentation and prototype models (Isa & Liem, 2014) adapted here for the analysis of students’ physical models in educational design projects.

Table 1

Categories of physical models in educational design projects

K1: Exploratory model	K2: Function model	K3: Presentation model	K4: Prototype model
A simple, idea-oriented model for exploring initial concepts without attention to technical accuracy or structural realism. Often built in easily adaptable materials.	A more precise model focused on demonstrating specific functions. Often constructed in durable materials and centred on isolated mechanisms or principles.	A model developed for presenting the intended solution. The user influences included functions, and components are combined into a coherent whole with attention to usability and handling.	An integrated model resembling a prototype. Display strong user representation and brings together function, structure, and material in a cohesive product-oriented model.

The two versions of the design assignment differed in whether a specific user was explicitly supposed to be used in the assignment. However, user representation was not treated as a direct outcome of assignment design. Instead, the analysis focused on whether and how a user was constructed and represented in the physical models. Thus, models developed in the version without an explicitly defined user could still be coded as containing user representation if students themselves introduced a user during the design process. In this way, user representation was

analysed as an emergent feature of students' designing and modelling practices rather than as a predefined condition of the assignment.

Table 2

Analytical categories used in the study

Dimension	Code	Description
User representation	U0	No user represented in the model
	U1	User mentioned when demonstrating but not influencing the model
	U2	User influences specific functions
	U3	User influences both function and structure
	U4	User permeates design (function, structure, material, use)
Structure representation	S0	No structural aspects represented
	S1	Structural aspects partially represented
	S2	Structural aspects clearly represented
Model category	K1	Exploratory model
	K2	Function model
	K3	Presentation model
	K4	Prototype model

3.4 Disclosure section

Generative AI was used as a tool for sound boarding ideas, translation and copy editing.

4 RESULTS

The analysis of the physical models reveals systematic relationships between user representation, model character, and knowledge expressed through modelling. Rather than reflecting assignment instructions alone, these patterns highlight how students actively constructed and worked with the user of the intended solution as part of their design process.

4.1 User representation beyond assignment design

Although the assignment differed in whether the students were instructed to use a user, user representation emerged across both sets of models. Many students assigned to version 2 of the assignment introduced a hypothetical user during the design process and used this constructed

user to inform decisions about the intended solution's function, structure, and form. This finding indicates that user representation cannot be understood solely as a consequence of instructional framing. Instead, the user often functioned as a design resource that students mobilised in order to make sense of the design problem and structure their modelling activity.

4.2 *User representation and model character*

A clear pattern was identified between the degree of user representation (U) and model category (K). Models with low or absent user representation (U0–U1) were predominantly categorised as exploratory or function-oriented models (K1–K2). These models typically focused on isolated technical ideas or single mechanisms, for example rolling wheels, lifting devices, or motor-driven solutions. Even when technically advanced functions were present, the lack of a clearly articulated user limited the development of integrated, product-oriented models. In contrast, models characterised by higher levels of user representation (U3–U4) were often categorised as presentation models (K3). In these models, students' intentions became visible not only in how they designed functions, but also in how they actively considered the user. The models showed deliberate attention to usability, safety, stability, and handling, indicating that students sought to integrate the user into the design in a coherent and purposeful way. For example, the models contained safety features as safety rails, mechanisms that could be operated by the user and extra stable constructions for heavy users. These aspects were frequently made explicit in the models, suggesting that the user played a central role in how students organised and communicated their design ideas. Only a small number of models approached a prototype-like character (K4). These models combined strong user representation with an integration of function, structure, and material, indicating that prototype-oriented modelling emerges when the user becomes a dominant organising principle in the design process.

4.3 *Structure as a materialisation of user-related reasoning*

Structural aspects were closely connected to user representation. Models with limited or no user representation rarely showed clear structural considerations (S0–S1), whereas models with strong user representation almost exclusively displayed explicit structural representation (S2). In these cases, structure was used to adapt the solution to the user, for example by addressing weight, stability, safety, or reach. This suggests that structure as a mediating dimension through which user-related reasoning becomes materialised in the physical model. Rather than being an independent technical concern, structural modelling gained prominence when students reasoned about how their intended technological solution would be used by a specific user.

4.4 *Summary of results*

Taken together, the results show that user representation plays a decisive role in students' modelling practices, regardless of whether the user was explicitly defined in the assignment. While the presence of a user does not guarantee functional accuracy or material realism, it consistently shapes what students choose to model and how different aspects of technology contribute to the overall design of the solution. Models in which a user was actively constructed were more likely to express structural reasoning, integrated solutions, and intentions about a final product, whereas models without a clear user tended to remain exploratory or focused on isolated technological functions.

5 DISCUSSION AND CONCLUSION

The findings show that user representation influenced how students' models developed, clarifying how modelling mediates relationships between function, structure and use. When the user was represented, functional and structural choices aligned with intended use, while models without a user tended to remain exploratory or focused on isolated functions. These results support models as epistemic artefacts—tools that guide reasoning rather than depict reality (Rost & Knuuttila, 2022). Specifying a user provides epistemic direction by defining the questions a model addresses, which helps explain why user-embodied models progressed toward presentation- and prototype models, whereas models lacking a user often remained exploratory or function-focused.

The study extends earlier work on the generative and integrative role of physical models (Isa & Liem, 2014) by showing that user representation can drive the shift from simple models to more coherent prototypes. When user considerations strongly shape the design, models tend to become more integrated and structurally deliberate. In line with Green et al. (2014), the study also demonstrates how an analytical framework can systematically compare different dimensions of modelling. Methodologically, it shows how relationships between students' intentions, representations, and material artefacts can be operationalised. The findings further connect to Norström and Hallström (2023), who argue that key epistemic stages in modelling often remain implicit. This may account for the variation observed in students' approaches. Their six-step framework highlights the need for clearer scaffolding, and this study suggests that user representation constitutes an additional, and currently underdeveloped, epistemic dimension.

The present study refines research on model dimensions in technology education (Citrohn, 2025; Boström & Citrohn, 2023) by adding the user representation as a decisive dimension alongside function, structure and materials. Even in assignments without an explicit user, students introduced their own users to make the design problem meaningful, suggesting that user-centred reasoning may be a natural part of students' modelling practices to make sense of open-ended design projects. Yet the variability across models indicates that user representation does not arise automatically and that explicit scaffolding may be needed to help students connect user needs to functional and structural decisions.

In conclusion, this study shows that user representation significantly shapes the development and character of physical models in educational design processes. User-related reasoning appears to support more coherent and well-developed models, while its absence is associated with exploratory or function models. The study identifies user representation as a key analytical and pedagogical dimension in technology education. Further research is needed to investigate how user-centred modelling can be supported and how analytical frameworks for categorising and interpreting students' models can be further developed. These frameworks are essential for clarifying how modelling mediates the relationships between intention, function, structure, material, and use — core components of technological knowledge in education.

This study involves student teachers which introduces limitations regarding generalisability, as their reflective and theoretical framing differs from that of pupils. Nevertheless, the study highlights the pedagogical potential of making user representation explicit in technology education, both as a driver of model development and as a means for supporting students in integrating function, structure and use.

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Fashion, Sustainability and Textiles Education in England: A Scoping Review, Curriculum Analysis and Evidence Base for Reform

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Abstract

Textiles education in England sits at a critical juncture. With the National Curriculum review already signalling an explicit requirement for sustainability to be embedded across subjects, including Design and Technology, the question of whether teachers are equipped to deliver this is key. The recent review by the Textile Skills Centre (2024) review found that whilst secondary textiles teachers are enthusiastic about sustainability, many lack the subject knowledge and confidence to embed it meaningfully within fashion and textiles teaching. This paper locates itself at the intersection of this professional gap and the policy moment created by the curriculum review. Drawing on a scoping review of literature on sustainable fashion education, alongside a qualitative content analysis of current National Curriculum programmes of study for Design and Technology at Key Stage 3 and 4, this paper identifies the key opportunities and barriers to delivering quality, sustainable fashion and textiles education in English secondary schools. The literature review reveals that textiles education has significant, underexploited potential as a vehicle for ESD, whilst the curriculum analysis, structured using the twelve competency areas of the GreenComp framework demonstrates that the current programmes of study fail to articulate sustainability as a core expectation. Several GreenComp competencies, particularly those related to envisioning sustainable futures and acting for sustainability, are largely absent, leaving provision dependent on individual teacher initiative. We argue that this combination of an unprepared workforce, an unspecified curriculum, and an imminent policy window, makes the case for targeted action. Frameworks drawn from the sustainable fashion education literature offer practical starting points for curriculum redesign and professional development. As the curriculum review progresses, this paper provides an evidence base to support textiles educators, curriculum designers, and policy makers in ensuring that sustainability becomes a consistent and meaningful feature of textiles education across English secondary schools.

Key Words: Sustainable Fashion Education, Textiles Education, Curriculum Review, English Secondary Schools, Education for Sustainable Development

1 INTRODUCTION

Fashion is one of the world's most environmentally damaging industries. Textile production generates approximately 1.2 billion tonnes of greenhouse gas emissions annually and, by some projections, sector emissions are expected to rise by over 60 per cent by 2030 (United Nations Climate Change (UNFCCC), 2018). Within fast fashion, 85% of all textiles produced globally are sent to landfill each year, and the washing of synthetic garments releases an estimated 500,000 tonnes of microfibres into the world's oceans (Maiti, 2025). These environmental statistics describe an industry that secondary-age (11-16) pupils interact with daily as consumers. If education is to equip young people with the knowledge and agency to respond to global environmental challenges, the classroom ought to be one of the important sites of that work.

Within the Design and Technology (D&T) curriculum, no strand is more directly implicated in this crisis than textiles. Unlike other D&T material areas, textiles education places pupils in direct, embodied contact with the very materials, processes, and consumption decisions that drive fashion's environmental footprint: fibre choice, dyeing and finishing, construction, care, repair, and disposal. This tangibility makes textiles a uniquely powerful vehicle for Education for Sustainable Development (ESD) as abstract concepts such as lifecycle analysis, circular design, and material responsibility become concrete and manipulable in the textiles classroom in ways that are difficult to replicate elsewhere in the curriculum (Hardy, 2015). Fashion also carries rich cultural and historical dimensions, by connecting to labour rights, global supply chains, identity, and consumption, that support the kind of critical inquiry McLain et al. (2019) identify as central to D&T literacy. The Textiles Skills Centre (2024) found that 60% of secondary pupils reported applying their textiles learning outside school, frequently in ways related to repair, reuse, and waste reduction, suggesting that well-designed textiles education can cultivate what Borg et al. (2012) call *sustainability agency*: the disposition and capability to act sustainably in everyday life.

Textiles also occupies a distinctive position within the secondary curriculum that distinguishes it from other D&T strands. At Key Stage 3 (KS3 – 11-14), it sits within D&T; at Key Stage 4 (KS4 – 14-16), it increasingly migrates to Art and Design (The Textiles Skills Centre, 2024). This dual curricular identity creates challenges for sustainability provision: the pedagogical expectations, assessment frameworks, and subject cultures of D&T and Art and Design differ significantly, and textiles teachers must navigate both. No equivalent structural tension exists for food technology, electronics, or product design. This makes the case for textiles-specific curriculum analysis, rather than if findings about D&T apply uniformly across its constituent strands.

England is currently undergoing a significant curriculum review through the Curriculum and Assessment Review Panel, and recent reports signal an explicit aspiration to embed sustainability across subjects, including D&T (Department for Education 2025). Yet ambition and provision are not the same thing. Rushton and Walsh (2025), in a survey of 870 teachers across England, found that sustainability in the national curriculum is more often *inferred* than explicitly mandated, and that a content-heavy curriculum actively inhibits consistent delivery. D&T teachers made up only a small fraction of that sample, but the structural finding is significant.

The most substantial recent evidence on this comes from the Textiles Skills Centre's (2024) comprehensive review of textiles education in English schools, *Unravelling the Fabric of Textiles Education — Where Next?* The report documents considerable teacher enthusiasm for sustainability as a curriculum theme but finds that only a quarter of those interviewed give it significant emphasis in practice. Teachers also report inadequate training in contemporary industrial processes, new materials, and creative sustainability approaches, and limited access to high-quality curriculum resources. The result is a profession that recognises the importance of sustainable fashion education but lacks the subject knowledge, pedagogical tools, and curriculum infrastructure to deliver it consistently.

Addressing this gap requires, as a first step, bringing together the available evidence in one place. While prior research has examined ESD integration across subjects broadly (Rushton & Walsh, 2025; Borg et al., 2012; Taylor et al., 2019) and D&T curriculum reform conceptually (Hardy, 2015; McLain et al., 2019), no study has combined a scoping review of the available literature on sustainable fashion and textiles education with a close reading of England's National Curriculum programmes of study in the context of a live curriculum review. This paper does so for the first time. In addition, this paper is part of a larger funded curriculum development project (The All Saints Education Trust), with the explicit aim of translating these findings into practical resources for textiles teachers and curriculum designers.

2 LITERATURE REVIEW

The following literature review is drawn from a wider scoping literature review. The initial strategy for the review focused on identifying literature related to ESD within the secondary education curriculum to scope out current research in the area. From this the search has narrowed to examine published research related to the teaching of D&T subjects, in particular textiles and existing work related to the teaching of sustainability within the subject area, including perspectives from both school teachers and their students towards the uptake of sustainability within applied pedagogical approaches. The scoping review used Google Scholar, Emerald and Scopus to identify relevant literature published from 2015 onwards, with a leaning towards review type publications as these were helpful in fleshing out the breadth of existing research and to highlight areas where knowledge was lacking. While we have included internationally focused publications in our search criteria, our primary goal in this paper is to focus on reviewing the literature related to English practice, this enabled us to highlight gaps which our work responds to. The textiles aspect of D&T, which is the primary focus of this research presents an important opportunity for imparting sustainability knowledge, particularly given the textile sector's need to address longstanding environmentally damaging practices (Wood, Redfern and Verran, 2022). A keyword search of reports and research that focus on ESD in textile education at secondary level revealed limitation in research that addressed pedagogical approaches and impacts of learning. Davies and Hail's (2015) research found evidence of sustainability focused pedagogical approaches being used by Textile Technology teachers through two profiled schools in the East Midlands. While their findings revealed positive examples of sustainable fashion education at secondary level, there is a pressing need to understand what is currently happening within the subject area, particularly given curriculum changes at national level.

Aside from Davies and Hail's (2015) work there is an evident gap in research that examines the practical application of sustainable fashion education within the curriculum at secondary level. On a practical level there are teaching resources for textile teachers to draw from, for example Oxfam's (no date) sustainable fashion guide for teachers which is packed full of information about the harmful impacts of fashion on the environment alongside practical activities to engage young people in problem solving skills to support sustainable fashion education. How far these types of resources support the teachers' curriculum development is unclear, and as they are outside of the curriculum they require the teachers to be actively searching for them which may apply pressure on already restrained time for professional development. In addition, this paper responds to the concerning decline in textiles as a valued subject at secondary level. Solomka's 2019 literature review on issues surrounding the uptake of GCSE textiles at secondary level, was a reaction to it becoming an unpopular subject, particularly due to what pupils found to be a lack of creativity in the classroom.

The following section presents a summary of the authors' critical reflection of more recent studies with a view to drawing out the challenges for implementing sustainable fashion education from the perspective of teachers and within the requirements of the National Curriculum. This paper highlights the gaps in knowledge that our empirical study seeks to address.

2.1 *Education for Sustainable Development in Schools*

ESD is broadly understood to be an approach to learning that equips individuals with the knowledge, skills, values, and attitudes to make informed decisions and take responsible action in the face of complex environmental, social, and economic challenges (UNESCO, 2017). Within schools, ESD has increasingly been recognised as a cross-curricular imperative rather than a discrete subject, though this raises significant challenges around curriculum coherence, teacher expertise, and assessment (Scott, 2015).

The drive to further embed ESD within curriculums emphasises the importance of sustainable competences for achieving the transformation of learners, these include knowledge, skills, behaviours and attitudes, alongside social skills, values and emotions (Kioupi and Voulvoulis, 2019). Sposad and Rieckmann's (2024) global review of sustainable competencies within secondary education found that key competencies of critical thinking, systems and action competence were integral to supporting secondary pupils in addressing sustainability. Sposad and Rieckmann's review responded to a noted gap in the knowledge of appropriate frameworks for developing sustainable competencies to support secondary education (2024). In their conclusions they found that cooperative and participatory learning were transformative pedagogical approaches within secondary education.

Bianchi, Pisiotis & Cabrera (2022) offer the GreenComp framework as a tool for sharing a vision for suitable competences to be used within education. The framework is designed to guide learners and educators in developing the knowledge, skills and attitudes needed for sustainable living and action. The framework can be used across all age groups and settings, with a focus on promoting critical thinking, agency and responsibility. Its four competency areas: embodying sustainable values, embracing complexity in sustainability, envisioning sustainable futures, and acting for sustainability, provide a structured vocabulary that is increasingly influential in

European curriculum policy. However, GreenComp represents a competency-based orientation making assumptions that sustainability can be meaningfully broken down into learnable, assessable components, an assumption that not all ESD scholars accept (Mezirow, 1991, Olsson, Gericke & Boeve-de Paw, 2022).

2.2 *Sustainable Fashion and Textiles Education: Opportunities*

ESD is salience within the context of sustainable fashion education. The fashion industry is widely acknowledged as one of the most environmentally and socially damaging industries globally (Ellen MacArthur Foundation, 2017), making it both an urgent site for intervention and a rich pedagogical context for exploring sustainability. The concept of the circular economy (designing out waste, keeping materials in use, and regenerating natural systems) is increasingly central to industry thinking (WRAP, 2020) and offers a compelling framework for textiles education.

Experiential learning is consistently evidenced as a particularly effective approach to sustainability education (Agirreazkuenaga and Martinez, 2021). The National Association for Environmental Education commissioned a 2024 report to examine examples of best practice for teachers to support sustainability within the curriculum and identified the significance of activities that support experiential learning (NAEE.org, 2024). Alongside this must be the acknowledgement that project-based learning has the capacity to increase student engagement in knowledge development, alongside problem-solving and critical thinking (Girgin, 2021; Jäggly et al.'s 2024; Manna et al. 2022.) These findings emphasise the value of practice based learning approaches that can support teachers in the embedding of sustainability within their curriculums.

2.3 *Sustainable Fashion and Textiles Education: Barriers*

Despite these opportunities, significant barriers exist. Teacher subject knowledge is widely identified as the primary constraint. In the Textiles Skills Centre (2024) survey, teachers expressed enthusiasm for sustainability but acknowledged uncertainty about how to embed it systematically, particularly in relation to more technical dimensions such as fibre science, manufacturing processes, and lifecycle thinking. This aligns with broader research on ESD implementation, which consistently identifies teacher confidence and professional development as key enablers (Stevenson, 2007).

In England climate change and sustainability are predominantly taught as part of Secondary Science and geography (Dawson et al. 2022). In 2022, the UK Government published a non-statutory strategy, 'Sustainability and Climate Change' in the education and children's services system' (DFE, 2022), this stated a commitment to giving every teacher and school leader access to world class training and development opportunities, which included climate change and sustainability for science teachers' professional development. This report had little evidence of what that commitment might entail and certainly did not consider teachers of disciplines beyond science and geography (Dawson et al. 2022). There is further evidence to suggest that teachers feel that they do not have enough knowledge or support to teach sustainability (Reboot the Future, 2023). These findings emphasise a distinct gap in the professional development of secondary

education teachers for embedding sustainability within their teaching practice and highlights an opportunity for developing innovative teaching tools that can support teachers in this area.

The tendency to focus sustainability within the curriculums of science and geography at secondary level raises questions as to how the topic is approached within the pedagogical approaches for D&T. Rushton and Walsh (2025) highlight significant barriers to climate change and sustainability education. Their research recognised that sustainable education still manages to come through at the classroom level due to the enthusiasm and passions of individual teachers and supportive leadership at the school level. Significant to their findings was the identification of specific enablers including the personal interests and beliefs of teachers, alongside the motivation of students to learn, and the accessibility of high-quality resources, which is of specific interest to this study.

Other research supports that time allocation, an overcrowded curriculum, and assessment frameworks created barriers. Textiles Skills Centre (2024) survey reported an average of just 53 hours of textiles education across KS3, often delivered on a termly rotation. This limited time makes it difficult to develop the depth of understanding required for meaningful sustainability learning, which benefits from repeated engagement, iterative enquiry, and opportunities for reflection. How much time topics are given with the curriculum is aligned to KS4 D&T (examination) specifications which have been criticised for being insufficiently textiles-specific and for privileging product design and manufacturing knowledge over the contextual, ethical, and environmental dimensions that sustainability education requires (Textiles Skills Centre, 2024). A point also supported by Taylor Quinn, Taylor (2019) who argues that the overcrowded curriculum and a lack of exam questions about sustainability competences create barriers.

In summary the literature reveals that while ESD is a requirement of the Secondary Education curriculum, there are identified barriers for teachers to implement it into their pedagogies. How the teaching of ESD is manifested through D&T subjects and in particular textiles is vague and needs investigation to ensure its value as a subject. There are clearly opportunities to support the professional development of teachers through informed tool kits that can enhance learning for the students by embracing creative approaches towards ESD. The paper will next take an analytical approach to unpicking how ESD is documented through the National Curriculum.

3 CURRICULUM ANALYSIS

This section presents a qualitative content analysis of the National Curriculum programmes of study for D&T at KS3 and KS4, available to textiles teachers in England. Content analysis was chosen as the methodological approach because it allows for the systematic, replicable examination of textual documents to surface both what is said and what is not said about sustainability (Krippendorff, 2019).

The analysis proceeded in two stages. First, documents were coded for explicit sustainability content, defined (following the Cambridge Online Dictionary) as content that is "clear and exact," leaving no ambiguity about sustainability intent. This included direct references to terms such as *sustainability*, *environmental impact*, *circular economy*, *ethical sourcing*, or *lifecycle*

assessment. Second, documents were examined for implicit sustainability opportunities, defined as content that is "suggested but not communicated directly" (Cambridge Online Dictionary). Examples include references to *materials and their properties*, *design decisions*, or *the needs of users and society*, each of which creates pedagogical space for sustainability without mandating it.

Each curriculum element was then rated against the twelve competency areas of the GreenComp framework (Bianchi Pisiotis and Cabrera, 2022) using a four-point classification scheme:

- **Strong:** The competency is explicitly named, required, or directly assessable within the document. *Example:* The KS4 D&T specification requirement to consider "ecological and social footprint" in design decisions was coded Strong for GreenComp competency 1.1 (Valuing Sustainability), as it constitutes a direct, assessable mandate.
- **Partial:** The competency is implicit or suggested, present in the language or framing of the document but not foregrounded as a sustainability expectation. *Example:* The KS3 instruction to consider "the way materials and components are combined and finished" was coded Partial for 2.1 (Systems Thinking), as it opens a route to systems thinking without requiring it.
- **Weak:** A tenuous or very incidental connection to the competency exists, requiring significant interpretive effort or teacher initiative to activate. *Example:* The KS3 phrase "the wider world" in D&T was coded Weak for 1.2 (Supporting Fairness) as it implies some awareness of context but offers no steer toward equity or fairness as explicit concepts.
- **Absent:** No connection (explicit or implicit - could be identified). *Example:* Neither KS3 nor KS4 D&T documents contain any language that could be linked to competencies 4.1 (Political Agency) or 4.2 (Collective Action), which were therefore coded Absent.

These coding decisions were made by the lead researcher, with a selection reviewed against an independently coded sample to confirm consistency of application. Where the same curriculum language appeared across documents, coding was applied uniformly to support comparison between key stages.

The analysis was structured to enable three comparative moves: (1) tracking the trajectory of sustainability provision from KS3 to KS4; and (2) identifying gaps where GreenComp competencies are systematically unaddressed at either stage. Findings are summarised in Table 1 and discussed in the following section.

Table 1*D&T Coverage Overview and Trajectory KS3 → KS4*

GreenComp	KS3	KS4	Trajectory KS3 → KS4
1. Embodying sustainable values			
1.1 Valuing Sustainability	Partial	Strong	Strengthens: moves from implicit impact awareness to explicit sustainability and ethics terminology
1.2 Supporting Fairness	Weak	Partial	Marginal: social footprint is named at KS4 but inter-generational fairness remains absent
1.3 Promoting Nature	Partial	Weak	Weakens: partially present at KS3 through links to Science/Geography at KS3; narrows to a design constraint at KS4
2. Embracing complexity in sustainability			
2.1 Systems Thinking	Partial	Strong	Strengthens significantly: named explicitly at KS4 as a design strategy
2.2 Critical Thinking	Partial	Strong	Strengthens: moves from awareness of impact to critical evaluation of technologies
2.3 Problem Framing	Partial	Strong	Strengthens: real-world contextual challenges at KS4 require engagement with sustainability
3. Envisioning sustainable futures			
3.1 Futures Literacy	Absent	Weak	Remains absent: future scenarios mentioned once at KS4 but not developed
3.2 Adaptability	Absent	Absent	Absent at both — adaptability not addressed
3.3 Exploratory Thinking	Weak	Partial	Marginal: cross-disciplinary links present but not framed around sustainability

4. Acting for sustainability.			
4.1 Political Agency	Absent	Absent	Absent at both: no political dimensions addressed at either stage
4.2 Collective Action	Absent	Absent	Absent at both: no stakeholder consultation and collective action for change
4.3 Individual Initiative	Absent	Absent	Absent at both: no individual design agency and sustainability initiative

4 DISCUSSION

The evidence reviewed in this paper points to a clear and urgent conclusion: for sustainable fashion and textiles education to fulfil its potential as a vehicle for ESD, both the curriculum and the teaching profession must be substantially better prepared. The Textiles Skills Centre (2024) report, combined with the findings of the curriculum review panel (DfE 2025), together paint a picture of a subject with significant untapped potential constrained by real structural and professional obstacles. The curriculum analysis presented here sharpens this picture further.

Beyond examinations, broader accountability structures further constrain what transformative sustainability education can look like in practice. School performance metrics — including Progress 8, examination league tables, and Ofsted inspection frameworks — incentivise a narrow focus on measurable, time-bounded outcomes. This creates what Ball (2003) terms a *performativity culture*, in which teachers must continually demonstrate value through quantifiable results, leaving little institutional space for the kind of sustained, reflective, and values-oriented pedagogy that ESD requires. For textiles and D&T teachers — who already navigate reduced timetable allocations, subject marginalisation, and uncertainty about whether their subject will appear in a revised curriculum — these accountability pressures compound existing professional vulnerabilities. Transformative learning (Mezirow, 1991), which the ESD literature identifies as central to genuine sustainability education, requires time, trust, and pedagogical risk-taking: conditions that current accountability systems rarely protect or reward.

The GreenComp framework offers a practical tool for addressing this deficit. Its twelve competences provide a structured vocabulary for curriculum designers and CPD developers to map what is currently present, what is absent, and where textiles education is specifically well placed to intervene. The framework's emphasis on experiential and project-based pedagogies (Bianchi, Pisiotis & Cabrera, 2022) aligns closely with the practice-led nature of textiles teaching, suggesting that the subject is not merely a context in which to deliver ESD but an inherently suitable method for developing it.

In conclusion, while the literature reviewed for this paper is not exhaustive, and focuses on England, this paper's significance lies in bringing together, the evidence base on barriers and opportunities to sustainable fashion and textiles education. Critically, this analysis suggests that curriculum ambition alone is insufficient: without corresponding reform to examination specifications, assessment criteria, and accountability frameworks, even a well-designed revised curriculum risks being undermined in practice. As the curriculum review progresses, it is essential that textiles educators, curriculum designers, and policymakers work together to ensure the revised National Curriculum creates genuine and explicit space for sustainability learning. Further empirical research is needed to test and refine the frameworks identified here. The authors intend to address this through a forthcoming empirical study engaging textiles teachers directly in the co-design of sustainability-focused curriculum resources.

5 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Descriptions of concept 'Research within Design' in STEM design projects

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Abstract

Design projects within STEM education often involve research, with students actively experimenting and testing to generate new insights. Even more often, the acquisition of existing knowledge necessary for designing takes place. In fact a previous study showed a discrepancy between what students indicate that research in design should be and what they actually recognize in their own design practice; actually often research consisting of looking up existing facts and knowledge. Students can articulate what research is and should be in design, but they do not recognize this in their own design practice and identify knowledge acquisition as research. This discrepancy suggests a lack of in-depth understanding of the concept of research in a design project. Therefore, this study examines teachers' descriptions of research that should be conducted within design projects. This is crucial because teacher-developed project descriptions form the foundation for design-based learning in the first three years of STEM subject Research and Design (R&D) project education (grades K7-9) at Technasia. The main goal is to determine based on these descriptions what is expected of students in a design assignment when it comes to research, to map the methods and tools used, and to determine at which stage of the design process research is considered. Twelve descriptions of design projects, one per school, from twelve different Technasium schools, selected by their teachers, are analysed for the required research implementation within the design assignment. Preliminary results indicate that most requested research takes place in the first phases of the design process during exploring and formulating the design problem. The required level of research suggests an informal, exploratory approach, trial and error, leading to little or no need for reliability and validity of the requested research.

STEM, Design based learning (DBL), Design projects, Design and Technology Education, Research and Design (R&D)

1. PROJECT-BASED STEM DESIGN EDUCATION

Design-based learning (DBL) is a key principle of project-based STEM education. This approach involves learning through design processes and context-specific design projects. Drawing upon scientific inquiry, design, engineering, mathematical reasoning, and technology, DBL is used to solve real-world problems (Zheng et al., 2020). Rather than transmitting ready-made knowledge, DBL focuses on actively constructing coherent knowledge and action (Oo, Kadyirov, Kadyjrova & Józsa, 2024). As there are no standard textbooks, it is the unique projects that form the foundation of learning. Consequently, the curriculum remains dynamic, with teachers coaching students through the design process.

At Dutch Technasium schools, the STEM Research and Design (R&D) subject involves students working in teams on realistic research or design projects set by external partners (Technasium, 2025). Each project focuses on a different technical discipline, with students acting as technical specialists. Projects for younger students (grades K7–9, aged 12–15) are created by teachers in collaboration with companies, institutions and technical experts (e.g. architects and software developers). These project descriptions generally follow a fixed structure according to Technasium guidelines and contain, general information, details of the assignment, assignment sub-steps, a description of the expert's professional role and assessment.

Although design-based learning focuses on design, research and design are intertwined. To explain this relationship, it is first necessary to clarify the definitions of "research" and "design".

1.1 *Research*

There are many different definitions of research, and while there are similarities, there does not seem to be a single, all-encompassing definition that is endorsed by everyone involved in research. Grover (2015) emphasises that the main purpose of research is to obtain new knowledge about reality through carefully chosen methods, whereas Creswell (2008) states that 'research is a process of steps used to gather and analyse information to enhance our understanding of a topic or issue'.

1.1.1 *Purpose of Research*

In addition to the many definitions of research, there are also various approaches to it. For example, research is often categorised as either fundamental (scientific) or applied. The former aims to generate knowledge, while the latter uses knowledge to solve practical problems. Both types of research must follow a structured, verifiable approach. According to Stokes (1997), there are four categories of research based on two binary dimensions. The first dimension is the search for fundamental knowledge about the world around us and the second is how this knowledge can be applied. Stokes distinguishes four quadrants, providing the following examples of researchers: fundamental research with little application (Bohr); applied, problem-solving research (Edison); use-oriented research combining knowledge and relevance (Pasteur); and creative, practical experimentation through trial and error, where chance leads to new insights (no example scientist). This model helps to distinguish between different perspectives in science, engineering and technology.

1.1.2. Characteristics of Research

Creswell and Poth (2014) explain that theory development and literature research lay the groundwork for research questions and analyses. Subsequently, Verschuren and Doorewaard (2015) emphasise that research must be systematic, well-structured, and follow a clear, planned and reproducible method. All decisions made during the research process must be explicitly stated and substantiated, enabling readers to understand the rationale behind them. Creswell and Creswell (2018) stress that this transparency is essential to ensure the verifiability and reliability of research, which in turn are important for research credibility (Booth et al., 2016). Conclusions must be based on systematically collected valid data in both applied and scientific research (e.g. observations, interviews and documents). In summary, research can be characterised by the following key features: it is systematic and transparent; it is based on valid data collection; it is verifiable and reproducible; and it is founded on a theoretical basis with clear relevance.

1.1.3. Mode of Knowledge Acquisition

Building upon Creswell and Creswell's (2018) descriptions of quantitative, qualitative and mixed methods, as well as Pedaste et al.'s (2015) inquiry-based learning steps, the methodological options have been organised into three progressive levels of knowledge acquisition. Each level represents an increasing degree of analytical complexity, learning autonomy and search for factual knowledge, whether existing or self-discovered. This composite framework is solely used here to structure the analysis and does not claim to represent the taxonomies of Creswell or Pedaste. One possible classification consists of three constructive ways of acquiring knowledge, which are explained below:

- (i) Based on existing knowledge.
Curiosity-driven/basic exploration: The collection of factual and non-factual information without in-depth analysis. This is an informal search for understanding based on existing information. Examples include Googling, visiting websites, learning by experimenting with materials and tools, summarising articles, making simple observations and conducting experiments.
- (ii) Partially Structured Knowledge Inquiry
Situated between (i) and (iii), this involves students collecting existing knowledge in a more methodical and structured manner or seeking new, self-discovered factual knowledge using a clear guiding question, interviews, repeated observations, triangulation or identifying relationships between variables. However, this does not yet constitute a fully systematic approach resulting in reliable, reproducible findings.
- (iii) Based on new facts that have been discovered independently.
Systematic/advanced: This is the search for new factual knowledge that builds upon a systematic approach and offers transparent, reliable and reproducible results. This approach constitutes a fully systematic approach resulting in reliable, reproducible findings.

1.2 Design

As with research, there are many definitions of design. Of particular interest is the definition provided by the Accreditation Board for Engineering and Technology (ABET) (2015), which

describes technical design as the process of creating a system, component, or process to address a specific need and solve technical problems. Moore et al (2014) states that, although the focus differs by discipline, design processes are central to engineering practice. Ralph and Wand (2009) describe ICT design as an activity, whereas Van Dooren et al. (2013) view architectural design as a complex, personal and creative skill. Cross (2006) characterises industrial design as 'the conceiving and realizing of new things'. Despite these differences, common principles emerge; design is context-driven, iterative and creative (IDEO, 2023; Klapwijk & Stables, 2023). In essence, design aims to develop or improve products and services (De Vries, 2005).

1.2.1. Design process

One model that is often used in Dutch primary and secondary design education to clarify the design process is the visualisation of the design phases according to the 'Guide to Inquiry-Based and Design-Based Learning' by Klapwijk and Holla (2018). This design cycle model consists of six phases and provides teachers and students with guidelines. Design process phases by Klapwijk, R., & Holla, E. (2018):

- (i) Exploring and Formulating the Problem
- (ii) Generating and Selecting Ideas
- (iii) Developing and Selecting Concepts
- (iv) Prototyping
- (v) Testing and Optimizing
- (vi) Presenting

1.3 Research and Design

In addition to being difficult to define, the processes of research and design closely resemble each other. Both begin with the problem analyses, knowledge acquisition and knowledge implementation, leading to solutions, conclusions, evaluation, and reflection. Creswell and Creswell (2018) describe research as a systematic process for gathering and analysing information to promote understanding. Lawson (2006) and Cross (2006), highlight that design is also an iterative process that encompasses analysis, synthesis and evaluation. The essential difference lies in the end goal. Research aims to generate new, reliable knowledge characterised by transparency, reproducibility, and objectivity. According to Creswell (2018), 'research is a systematic process aimed at increasing understanding of a subject or problem'. Design, on the other hand, focuses on creating a solution to a specific problem and is characterised by contextuality, creativity and often subjectivity. Lawson (2006) states that designers work with 'design intelligence' to create solutions that do not yet exist. Design thinking (Brown, 2009; IDEO, 2015) places emphasis on empathy, ideation and prototyping, whereas research focuses on generating hypotheses and evidence.

2. RESEARCH WITHIN DESIGN PROJECTS

This study focuses on conducting research within design, as research plays a variety of roles in the design process. For example, it is often an integral part of the design process, such as investigating material properties, collecting user data, testing usability or conducting empirical research. Frankel and Racine (2010) describe the role of research in design as 'research for design',

which they define as research that makes design possible. Conversely, design also encompasses looking up existing knowledge, such as exploring previous studies, analysing trends and consolidating relevant information. This is crucial for making design decisions, as well as for collecting and synthesising existing insights.

Despite this distinction, teachers and professionals often classify both activities as 'research in design', creating an interesting paradox. Why is collecting and analysing existing knowledge considered 'true' research in design? The ambiguity surrounding the nature of research in design education forms the basis of this study. It highlights the need to distinguish more clearly between research, which aims to acquire new knowledge, and looking up, which involves synthesising existing knowledge for practical use. Previous pilot research (de Haan et al., 2025) revealed a gap in students' reasoning regarding research and knowledge acquisition in design. While students can articulate what research in design is and should be, they do not recognise it in their own design practice. This discrepancy suggests a lack of in-depth understanding of the concept. Consequently, this study examines how teachers describe the research that should be conducted within design projects.

3. DATA COLLECTION AND ANALYSIS METHODS

The study analysed research descriptions requested by teachers within design projects. The content of these descriptions and their implications are investigated systematically. The main objectives were to identify the research required by teachers within design projects, to map the methods mentioned in assignments and to determine the stage of the design process at which research is considered and the mode and type of research involved.

Using conceptual content analysis, the descriptions of various written design projects from lower secondary education (grades K7–9) submitted by twelve Technasium schools in the Netherlands were examined for a request for research. Parts of the written design project were coded when 'research' was requested. Additionally, text fragments mentioning direct implications for research, such as 'testing a design for use', were coded. The research description, methods and activities (e.g. surveys, interviews or user analysis) were thematically coded and categorised if mentioned. All text fragments were categorised, resulting in various code groups and subgroups.

Furthermore, the descriptions were placed within the design phases based on the six-phase model of the design cycle (Klapwijk & Holla, 2018). The study also examined how acquiring the necessary knowledge is classified, as described in the three constructive modes of knowledge acquisition.

Table 1

Twelve Analysed Design projects

Project title	Class	Design Assignment
Repurpose design	K-7	Design a reusable product from hard-to-sell waste streams. Create a 'making-of' video and promotional materials.

Natural North!	K-8	Create a working model for one concept: a self-sufficient vertical herb garden, high-tech scarecrow, chicken feeder or smart snail killer.
Village farm	K-7	Design a mobile shelter and a rotation plan to ensure the well-being and natural behavior of the sheep, donkeys and goats. Also design a visitor walking route providing continuous visibility.
4D Experience at the Museum	K-7 to K-9	Design an interactive exhibition that engages at least two senses and tells an object's story, offering visitors a new experience while forming part of a coherent whole.
A healthier canteen	K-7 to K-9	Investigate the current canteen situation. Propose a new design that makes the food offers significantly healthier for students.
Fast Fashion	K-7 to K-9	Design a campaign component highlighting the clothing industry's negative impact and fitting within an info campaign including a video, pop-up store and card game.
Underwater	K-7 to K-9	Provide a model and before-and-after photos of a redesigned municipal site to show how it is used to reduce flooding or create water storage.
Plastic waste in a river	K-8	Design a plastic-filter system for a river in a foreign country.
On the radar	K-7 to K-9	Design a user interface for one value proposition, then develop and test a new one.
Designing an interchange (hub)	K-7 to K-9	Design a city interchange (hub) that improves future traffic and transportation flows.
Developing an attractive solar park	K-8	Design a solar park that meets residents' needs by generating energy while also fulfilling at least one additional community function
Mist nets for a green wall.	K-8	Design a pilot to green a 5-hectare Moroccan desert using mist nets to harvest water for agriculture and tree-planting.

4. RESULTS

4.1 *Requested research within design project assignments*

Nine of the twelve participating schools (75%) requested research, or variants such as preliminary or user research. Eight of these nine schools also requested research via research methods or activities. Of these nine schools, a total of 37 requests for research were made within the design project (n=37). All nine schools requested research in the project component, in which the assignment is divided into sub-steps.

When schools requested research, they asked 'research' seven times without further specification. When further specification was provided, it concerned exploratory research (six times), target group research (two times) and research results, such as a research poster (two times). Other types of research mentioned once included comparative research, source research, a research plan, a research question and a research report.

The most requested research activities were testing (six times) and analysis (four times), followed by methods such as interviews (two times), experiments (two times) and site visits (one time).

4.2 *Requested research within the design process phases*

The results obtained were categorized into six design phases:

- (i) **Exploring and Formulating the Problem**
Research was required in 45.9% of the descriptions (n = 37) in the first phase of the design process. The various actions required in this phase varied from project to project. For example, the following was requested for the project '4D experience at the museum': 'During your research, answer at least the following questions: In what year was the museum object created or discovered? Who created or discovered the object? Etc.'
- (ii) **Generating and Selecting Ideas**
In the second phase of the design process, 21.6% of project descriptions required research. For instance, a project concerning a healthy canteen required comparative research. 'During your research, make a list of the existing canteen products that are good and those that could be improved. Use this information to generate new ideas for your recommendations.'
- (iii) **Developing and Selecting Concepts**
In the third phase of the design process, 8.2% of project descriptions required research. The following question was asked in the 'Project Repurpose Design': 'Interview at least three potential users about your ideas.'
- (iv) **Prototyping**
No research was required during the fourth design phase.
- (v) **Testing and Optimizing**
In this phase, 18.9% of projects required research. For instance, the project on water harvesting in the desert using mist nets required research. 'The client has

asked you to conduct research using the test setup to determine the water yield of both concepts.'

(vi) Presenting

In the sixth design phase (presentation), 5.4% of project descriptions requested that preliminary research results be presented in the form of posters or reports.

4.3 *Mode of the research asked*

A large share of the research tasks outlined in the project documentation fall under mode (i), which involves searching for existing information, carrying out simple observations, or conducting basic experiments. In total, 65.7% ($n = 37$) of the required research falls into this category. This work is not scientific research aimed at generating new knowledge; rather, its primary purpose is to gather information needed for the design process. A semi-scientific approach (mode II) was required for 34.3% of projects. Systematic or advanced scientific research (mode III), intended to produce new factual insights, was not required.

5. DISCUSSION

According to the results, nine of the twelve participating schools requested research activities within the design project. The research is requested using terms such as 'research' or 'initial exploratory research', and via research methods (analysis) or research activities (testing). Research activities are primarily requested in the early stages of the design process, as a means of acquiring the necessary knowledge, or as a process of trial and error. Secondarily in the later stages of the design process, in the testing and optimization phase. The descriptions do not specify how this research should be structured, nor whether validity and reliability must be guaranteed. This is relevant because, in response to the open question in an earlier pilot study (de Haan et al. 2025) regarding the required research mode in a design assignment, 12 of the 16 teachers chose the partially structured mode (ii), which involves students collecting existing knowledge in a more methodical and structured manner or seeking new, self-discovered factual knowledge using a clear guiding question, interviews, repeated observations, triangulation or identifying relationships between variables. This suggests research that goes beyond (i) curiosity-driven or basic exploratory knowledge acquisition. However, their own project descriptions, as described in the current study, show that in 65.7% ($n=37$) of cases, a curiosity-driven approach (i) a basic exploratory approach were requested. Why do they usually ask for these more basic methods of knowledge acquisition in the written project descriptions and effectively focus only on existing knowledge, while previous research has shown that teachers prefer a partially structured mode? This question aligns with the findings of the already mentioned previous research, which shows that students understand research in theory, but in practical examples primarily describe the trial-and-error method and the search for existing information. It is therefore important to further investigate what level of validity and reliability teachers expect from students in their research, how their descriptions and intentions correspond, how students interpret this, and what causes the discrepancy between students' theoretical knowledge of research and the practical research examples they cite. The following research steps, based on focus group interviews with teachers and students, are aimed at clarifying these agreements and gaining a better understanding.

6. DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were (minimally/marginally) used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Understanding the Invisible: Fostering Students' Structure-Behaviour Reasoning with Multi-Level Thought by Using Design

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Abstract

In design education the relationship between a prototype's structure and its behaviour is an important one. In traditional fields such as mechanics and engineering, for example bridges or steam engines, both the structures and their structure-derived behaviour are observable. This visibility facilitates reasoning how this structure relates to behaviour and function. In more contemporary fields of technology like, ICT, nanotechnology and chemical engineering, however, the observable (macro-level) behaviour of a design often results from structural features at a non-observable scale. Consequently reasoning about structure and behaviour in these domains requires so-called multi-level thinking: using representations of micro level structures to explain or predict a macro-level phenomenon. Secondary school students often struggle with such structure-behaviour reasoning (SBR), particularly when it involves connecting invisible micro-level structures with observed behaviour. Likewise, teachers face the challenge of teaching 'the invisible' and assessing students' proficiency in SBR. Chemical design activities can provide for valuable opportunities to address this challenge. By linking the molecular-level structure with the observed behaviour and design requirements, such activities can foster students' SBR. In this research study we identified and characterized changes in students' level of SBR in written answers to a prompt question before and after engagement in a chemical design activity. First, the students' written answers were converted into reasoning diagrams. Then, these diagrams visualised students' modes of reasoning and enabled categorization in one of the five levels. A small scale pilot test (N=16) revealed an increase in the level of sophistication of students' written explanations with a modest effect size. Currently a large-scale data collection and analysis is in progress. At the conference we will present the results from the complete data set.

Key Words: Structure-Behaviour Reasoning, Multi-level Thought, Chemical Design Education, Conceptual Understanding

1 INTRODUCTION

In the last decade design practices have become more prevalent as part of international science curricula and standards (NGSS Lead States, 2013; CvTE, 2025). Design is defined by the ABET (2023) as “the process of devising a system, component or process to meet desired needs and specifications within constraints” (pg3). Implementation of design activities in secondary science classrooms provides several opportunities. First, students learn about design processes, apply design skills, and engage in ways of design thinking (Lammi & Becker, 2013). Second, design is a practical, hands-on, student-centred approach, thereby contributing to the development of students’ practical and investigative skills (Gabel, 1999). Finally, design is an iterative, creative, decision-making process in which the basic science, mathematics, and engineering sciences are applied to convert resources into solutions (ABET, 2023). Therefore, design practices can serve to bridge the gap between separate science disciplines and open the way to more integrative STEM (Science, Technology, Engineering and Mathematics) education (Fan & Yu, 2017). In the design process reasoning about the relationship between the structure and the behaviour of a prototype is an important one (Gero, 1990). Students’ use this reasoning to make choices about their process or their next prototype. In chemistry, one of the science disciplines in STEM, this structure-behaviour reasoning (SBR) is also present and is even considered an important, crosscutting concept (Den Otter et al., 2024; Talanquer, 2018). Chemical phenomena on the observable macro level can be explained or predicted by exploring the structure of the substances. However, in chemistry the structures are mainly at a non-observable molecular level, the micro level. This means that SBR requires multi-level thought (Johnstone, 1991). Secondary chemistry students struggle to master this type of reasoning and teachers experience difficulties in effectively teaching this. Since design activities require the same type of reasoning and are also a part of several science curricula and standards we aim to explore the benefits of chemical design activities to foster students SBR.

2 LITERATURE REVIEW

When students are engaged in a design activity they employ a variety of thought processes. They evaluate, analyse and synthesize (Aranda et al., 2020). These processes are also embedded in the FBS framework linking the structure of a design to its behaviour (Gero, 1990). Students’ reasoning during these processes have been investigated in the context of engineering design lessons (Aranda et al., 2020) or technology design lessons (Hultmark et al., 2024). Students mainly use means-end reasoning in evaluation and cause-effect reasoning during planning and ideation. However, insight in students’ use of multi-level thought in the content of reasoning is topic of our recent project. A previous study in the context of a chemical design activity showed that students’ SBR occurred during the processes of evaluation, synthesis and analysis when students gave meaning to their observations (De Lavoie et al., 2023). In these phases of the design activity students’ reasoning became noticeable for the teachers as well as opportunities to guide students’ reasoning. Sheoratan and colleagues (2023) found that when chemistry content was topic of conversation teachers’ verbal support entailed mainly giving feedback and asking questions. A recent study showed that use of metaphors and explicit drawing on the worksheets additionally were used to guide students reasoning with multi-level thought while engaged in the design process (De Lavoie et al., in manuscript). Multi-level thought as mentioned in the

introduction entails switching between the observable macro level behaviour and the non-observable micro-level structures to explain or predict this behaviour (Johnstone, 1991). Structure-behaviour reasoning with multi-level thought is hard for students to master (Chi et al., 2012; Talanquer, 2018). Also teachers struggle to effectively teach this type of reasoning (Kararo et al., 2019). One effort to guide students' structure-behaviour reasoning with multi-level thought is by use of the perspective for structure-behaviour reasoning (Den Otter et al., 2024). This perspective connects macro level entities like 'behaviour', 'organisation' or 'substance' with micro level entities like 'particles', 'bonds and interaction' (figure 1).

Figure 1

The perspective for structure-behaviour reasoning (adapted from Den Otter et al., 2024)



Besides guiding students' reasoning by asking perspective questions, this perspective can also be used to assess students answers by looking at the entities used and the connection between them (Den Otter et al., 2022). A similar way of assessing students' reasoning is described by Moreira and colleagues (2019). Students answers to a prompt question were converted into a reasoning diagram containing the entities, properties and actions in the answer and the connections between them. The reasoning diagrams were categorised by their level of sophistication and in a pre- post-test design even a shift in level of sophistication could be observed. For our study's purpose we adopt the method of Moreira and colleagues (2019) augmented with the perspective for structure-behaviour reasoning (Den Otter et al., 2024) to develop and subsequently use an assessment instrument. This will be briefly described in the methodology section. We then use this instrument to characterise changes in SBR in students' written answers to prompt question before and after engagement in a chemical design activity. Our study was formally guided by the following research question:

In what way does secondary school students' structure-behaviour reasoning in written explanations change as a result of being engaged in a chemical design activity.

3 METHODOLOGY

In this section we will describe the participants, the design activity as context for our study, and the specific instruction given to the teachers to foster students' SBR during the activity. After that we will describe the pre-post-test instrument used to characterise students' structure-behaviour reasoning before and after engagement in the chemical design activity. Since this instrument is not published yet we will first briefly describe the development and testing of the SBR instrument.

This description contains the prompt question, conversion of the students' written explanations into reasoning diagrams and subsequent scaling of the diagrams. Finally we will describe the method of analysis of the students' answers to the prompt question before and after engagement in the design activity.

3.1 *Context and participants*

This study took place in a 10th grade secondary chemistry class taught by the first author of this paper. All students (N=20) participated in a chemical design activity scheduled in four time-tabled lessons of 45 minutes. Each lesson had an accompanying worksheet. The goal of the activity was to design a bubble soap fluid that produces easy-to-blow and long-lasting bubbles. The first lesson contained the introduction to the design process, the design requirements and the basic substances: water and soap. Also students performed an experiment to guide their reasoning about the organisation of soap molecules in water. In the second lesson students generated ideas for soap-water ratios and tested their first prototypes. The worksheets helped students to provide explanations for their observations and had room for drawings on micro level. In the third lesson students generated ideas about an extra substance to better meet the design requirements. For each idea students provided an argumentation on micro level why this substance should improve the behaviour of the design. In the fourth lesson, in a second iteration, students tested and evaluated their improved bubble soap fluids. The worksheets again guided the evaluative reasoning and had room to provide drawings of the structures on micro level.

All students in our study were fully informed about the purpose of our research, the way in which data was, anonymised, used and stored. Subsequently all students that agreed to cooperate gave their written consent.

3.2 *Development of the SBR instrument*

The development of our pre- post-test research instrument largely followed the methodology described by Moreira and colleagues (2019), tailored towards our study's context. Our prompt question was chosen because it is an example of a textbook question about explaining a phenomenon by using SBR with multi-level thought. We asked students to provide a written answer to the question and additionally a drawing clarifying the written response. The English version of the prompt question was:

Alex is cooking when he accidentally spills olive oil over his new shirt. He immediately tries to wash it out with water but that does not work. Then he tries to wash it out with a mixture of water and soap. Now he observes that the olive oil is washed out of his shirt.

Question:

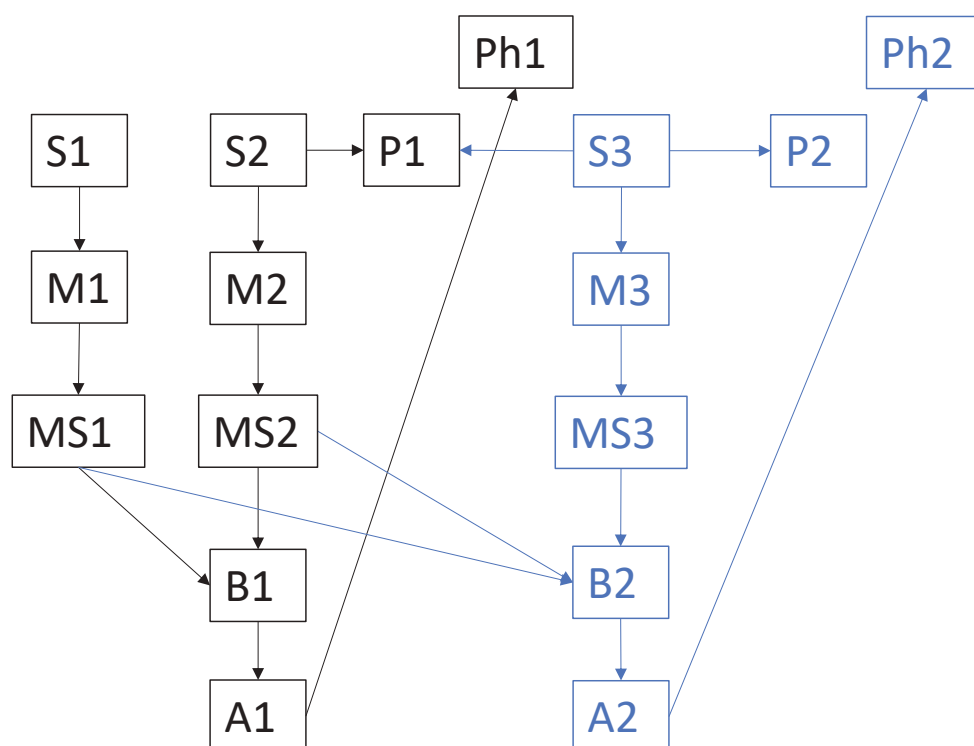
Explain explicitly how water is not able to remove the olive oil out of the shirt but a mixture of water and soap is able to remove the olive oil out of the shirt. Use an additional drawing on micro-level to support your explanation.

Additionally this question contains the same substances as used in the project: Water, soap and a hydrophobic substance. However students are now asked to apply these concepts in another context using the same type of reasoning.

In the development of the instrument first three teachers provided the ‘perfect’ answer to our question. These answers were discussed until consensus was reached about the ‘top-level’ answer providing for content validity. This answer was converted into a reasoning diagram shown in figure 2.

Figure 2

Expert reasoning diagram corresponding to the ‘top-level answer’. S1= water; M1= water molecules; MS1= OH-bonds; S2= oil; P1= hydrophobic; M2= oil molecules; MS2= no OH groups; B1= bonds/interaction; A1= compounds will not mix; A2= compounds do mix; S3= soap; P2= hydrophilic; M3= soap molecules; MS3= head and tail; B2= bond/interaction formed; Ph1= oil not removed from shirt; Ph2= oil is removed form shirt



Next 38 students in 10th grade secondary chemistry education were asked to provide an answer to the prompt question after the topic of mixing molecular compounds was covered in regular chemistry classes. These answers were converted in reasoning diagrams. These reasoning diagrams were inductively coded and categorised in 4 major levels of reasoning using the proposed levels of reasoning by Talanquer (2018) as an analytical lens. Table 1 provides an overview of the distribution of answers over the identified levels. An overview of the characterisation of the levels is provided in figure 3. Since the actions are mainly described on a

level between the micro- and macro level these actions A1 and A2 are placed between the two levels in the student reasoning diagrams.

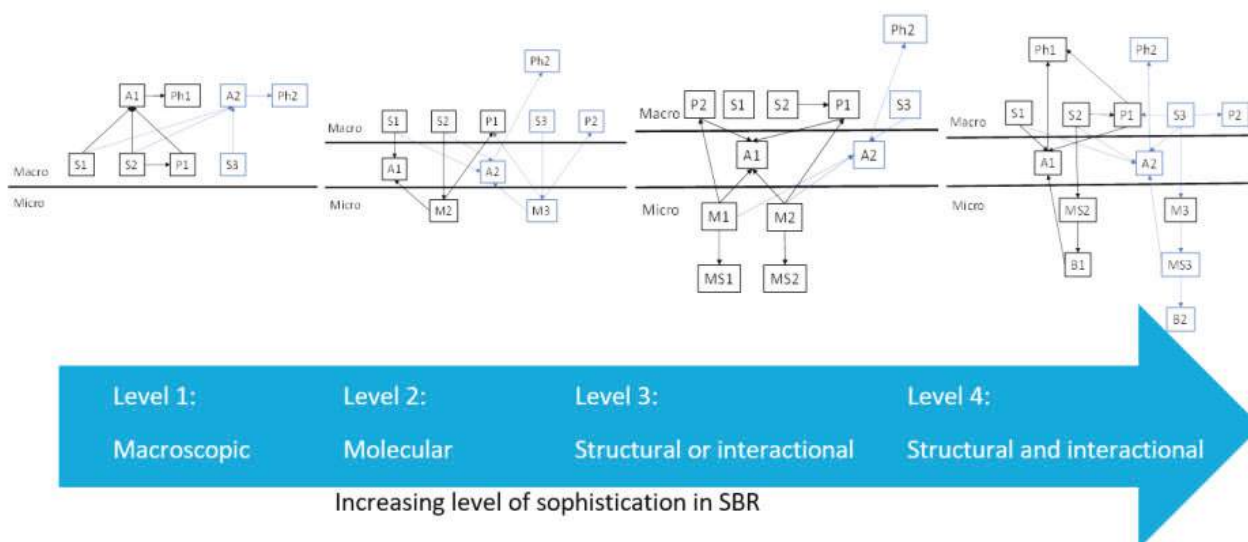
Table 1

Distribution of the 38 answers over the four levels of sophistication in SBR found

Total	Level 1	Level 2	Level 3	Level 4
38	1	13	18	6

Figure 3

Overview of the four characterised levels of SBR used to subsequently scale our studies results before and after the design activity



In this categorisation Level 1 answers use only entities on observable level. Level 2 answers use macro level phenomena and entities in relation to molecules on non-observable level. The level 3 answers use structural features of the molecules or interactions between molecules to explain phenomena but lack a direct link between molecular features responsible for the bonds and interactions. This direct link is present in level 4 answers.

3.3 Data collection

The students in this study, as described in section 3.1 provided an answer to the prompt question directly before starting with the design activity. Directly after the final lesson of the design activity students were again asked to answer the same prompt question. The pre-tests were provided with a number corresponding to the students. The post-tests were consequently numbered, coupled with the pre-test and subsequently a-personalised. Two out of twenty students were not present

at the pre-test and 2 were not present during the post-test lesson. We chose to only use the coupled pre- and post-tests so a total of 16 student answers were analysed.

3.4 Data analysis

The student answers were converted into reasoning diagrams and categorised as level 1, level 2, level 3 or level 4. The first and the third author categorised the answers independently from each other. After comparison, the scores of two post-test answers did not align. After discussion between the two researchers consensus was reached about the final scoring of all 32 answers. Finally the scores before and after were compared using IBM SPSS Statistics software version 28. First a Kolmogorov-Smirnov test was used as a test for normal distribution. In case of normal distributed data, a paired-samples t-test will be executed. In case of non-normal distributed data a Wilcoxon Signed Rank test will be executed as a non-parametric test for difference.

3.5 AI disclosure statement

Nowhere in the process of data collection, data processing, data analysis and writing of this paper AI tools or LLMs were used.

4 RESULTS

We now show the results of the analysis of students' level of SBR in the written answers given to the prompt question before and after engagement in the chemical design activity. Table 2 and figure 4 provide an overview of the amount of students' answers in the pre- and post-tests for each level of reasoning.

Table 2

Overview of students' shifts in levels of sophistication of the answer to the prompt question before and after the design activity

Level 1	n	level 2	n	level 3	n	level 4	n
1 – 1	1	2 → 1	1	3 → 1	0	4 → 1	0
1 → 2	5	2 – 2	5	3 → 2	1	4 → 2	0
1 → 3	2	2 → 3	1	3 – 3	0	4 → 3	0
1 → 4	0	2 → 4	0	3 → 4	0	4 – 4	0

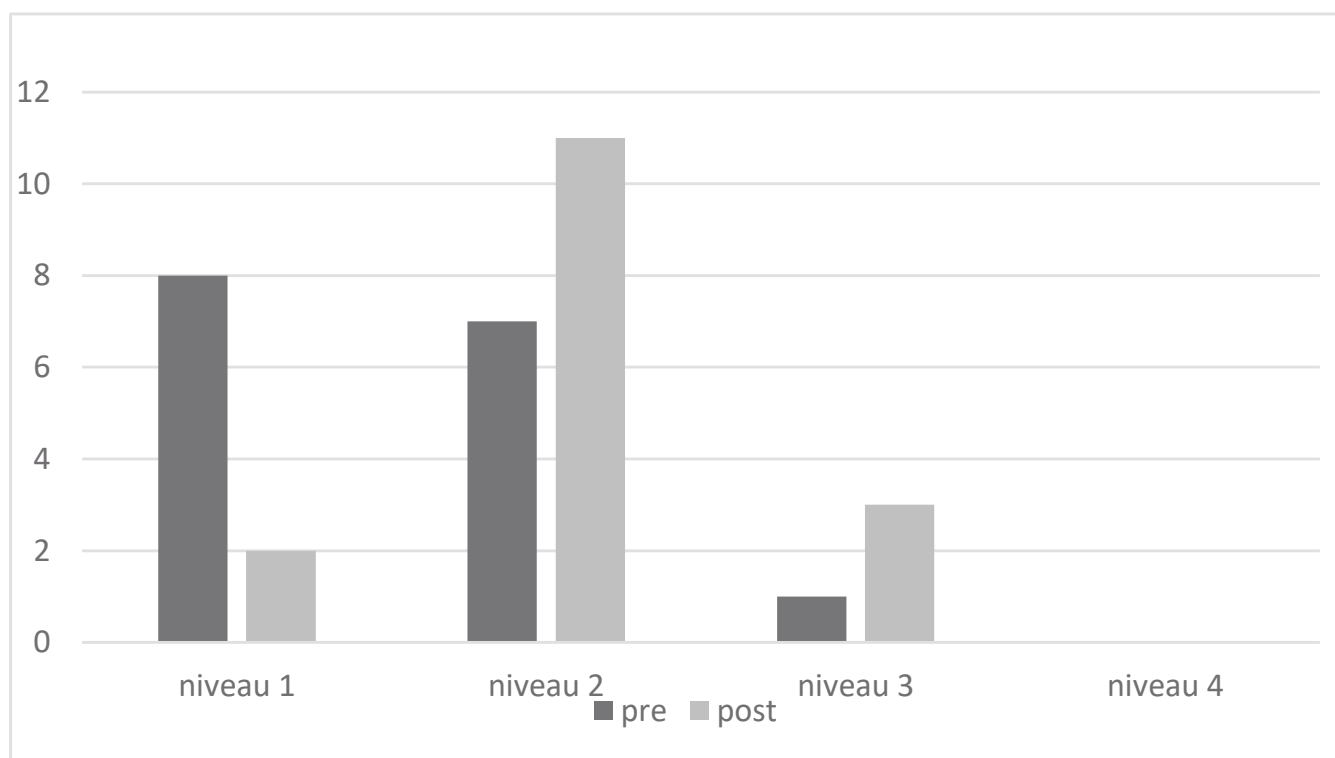
For the whole group of students the scores show on average a shift from mainly level 1 – 2 types of reasoning towards more level 2 and level 3 types of reasoning. The amount of students with an answer on the least sophisticated level, using only macroscopic entities to explain the

phenomenon, decreased. An increase was observed for the use of molecular and structural or interactional entities in the written answers' reasoning.

The Kolmogorov-Smirnov test for normality revealed that the pre-test scores $D(16) = 0.31$, $p < .001$, and post-test scores, $D(16) = 0.36$, $p < .001$, were both significantly non-normal. Subsequently the Related-Samples Wilcoxon Signed Rank Test was used to test the null hypothesis: the median of differences between the scores pre and post equals 0. The results indicated a rejection of the null hypothesis. This indicated that these students scored significantly higher on the post-test (Mdn = 1.99) than on the pre-test (Mdn = 1.50), $z = 1.999$, $p < .05$.

Figure 4

Graphic overview of the number of students' scores per level ['niveau'] of reasoning before and after engagement in the design activity. Niveau 1 -macroscopic, niveau 2 – molecular, niveau 3 – structural or interactional, niveau 4 – structural and interactional



As an example of the observed change in reasoning we will use the work of student_12. The excerpt below shows his initial answer to the prompt question.

“Alex cannot wash the olive oil out of his shirt because olive oil is hydrophobic so it repels water. And soap provides for a connection between the water and the oil. It is an emulsifier.”

The generated reasoning diagram for this answer is shown in figure 5.

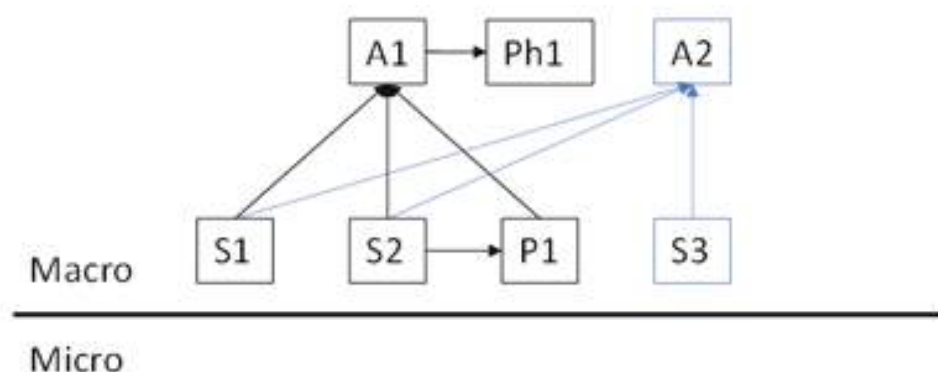
The answer shows only entities on a macroscopic level. In this answer the student uses the word connection, but this refers to connecting substances on a macro level. In our analysis we focus only on the explicit reasoning.

The answer of this student after engagement in the design activity was categorized as level 3 – structural reasoning.

“Alex can wash the olive oil out of his shirt because the hydrophobic parts of the soap bind with the oil and the O-H-groups (hydrophilic parts) bind with the water and that is why it forms a connection. The soap is so-to-speak the connection between the water and the oil. Explanation of the drawing: the hydrophobic tails are going into to oil and the hydrophilic heads are going into the water.”

Figure 5

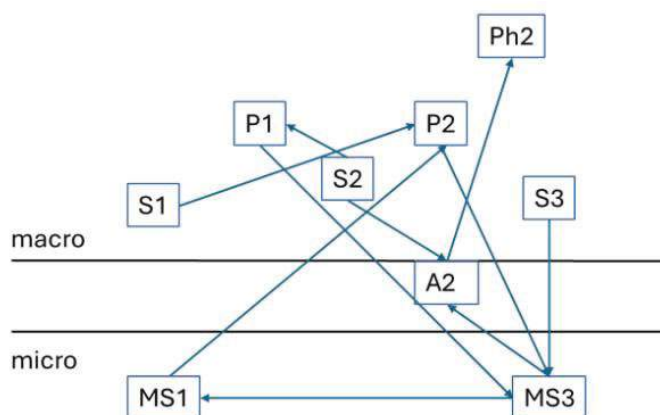
The corresponding reasoning diagram for student_12_pre answer, categorised as macroscopic reasoning



The corresponding reasoning diagram for the post-test is shown in figure 6. Here the term ‘binding’ is used to connect the structural entities of soap molecules with substances on macro level. Again this is a result of only coding the explicit reasoning. When a student means ‘water molecules’ this should be explicitly stated in the answer. Therefore, “bind” in this answer was coded as action A2 “to form an aggregate”.

Figure 6

Reasoning diagram of student_12_post categorised as level 3 for connecting molecular structural components of a substance to the properties to explain the action and phenomenon



5 DISCUSSION

Our findings show that the level of sophistication of students' SBR on average increased after engagement in the design activity. In answers to the prompt question before the project students employed mostly macroscopic level reasoning and molecular reasoning. After the project we saw a shift in the answers towards more sophisticated reasoning using micro level molecules and structures or bonds to explain the phenomenon. Although this result seems promising, research with a larger sample size is needed to gain significant insight and conclusions about the gains. This data collection will take place in several chemistry classrooms with a number of different teachers to rule out any teacher effect. Furthermore, the use of a control group is advised to correct for possible instrument effects. We observed no level 4 types of reasoning, where students used the molecular structures, bonds and interactions between the molecules to come to a concluding answer. This might have been caused by several reasons of which sample size might be considered the biggest reason. However, reaching higher orders of structure-behaviour reasoning takes a lot of time and effort (Talanquer, 2018). The lesson material stimulates the use of these entities during evaluation and ideation. Teachers' emphasis on these entities in higher order reasoning might play a role. To guide students towards a level 4 type of reasoning this might subsequently imply a more specific instruction for teachers beforehand about possible interventions in teacher-student interaction during the design activity.

It is important to note that our analysis only focussed on the levels of reasoning between entities on macro- or micro level. It might be possible that students' give a wrong answer to the question but employ a high level of reasoning to warrant their claim.

Although this research is conducted in the chemistry classroom, the identified levels of reasoning about structure-behaviour relationships are applicable to other contexts like electro-physics. A system then consists of particles at micro-level. Even when structures are at non-observable level,

nanoscale technology or quantum dots for example, our insights in levels of sophistication can be used to identify the depth of SBR. Relevant reasoning steps for the structure of any design at non-observable level are then the particles, the bonds and interactions between the parts and the organisation of the parts. Correct representations of the microlevel structures and subsequent reasoning about the relationship between this structure and the behaviour of the design can be guided by our findings. Clearly, this then asks for further investigation on the transferability and usability of our findings as a framework to guide SBR in other STEM fields.

6 CONCLUSION

We set this study to investigate students' structure-behaviour reasoning in written explanations before and after engagement in a design activity. Although we describe a small scale pilot study, the results indicate an increase in the level of sophistication in students' SBR. The method of analysing the students answers by generation of reasoning diagrams seems helpful in reaching intercoder agreement and subsequent categorisation of the answers. At the conference we will present the complete data set with more excerpts of observed change. With that we will be able to present a more detailed description of the gain in students' reasoning skills and the opportunity to use design activities to foster students structure-behaviour reasoning with multi-level thought.

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Investigating the Theoretical Grounding of Questionnaires to Study Technology and Engineering Career Choice

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Abstract

The shortage of qualified professionals in engineering and technology has become a critical concern. Research to understand factors influencing students' career decisions has primarily focused on attitudes questionnaires. To address resulting limitations, role identity is emerging as a significant construct influencing study and career choice and persistence. The current research develops and tests an analysis framework, coherent with established theories, to evaluate instruments measuring attitudes and related constructs to investigate study and career choice. By applying this framework to seven paradigmatic instruments, several insights emerged. First, the framework proved useful for cross-disciplinary comparison and detecting gaps, but requires further refinement regarding depth in components and directional nuances. Second, the analysis revealed a lack of terminological clarity across instruments and substantial differences in how engineering and technology knowledge is operationalized. Future work should involve item-level analysis of a broader selection of instruments to ensure individual items map accurately onto intended theoretical dimensions, ensuring that the instruments are accurately measuring the specific constructs they are intended to assess and reducing conceptual ambiguities.

Key Words: Attitudes Towards Technology, Attitudes Towards Engineering, Engineering and Technology Study Career Choice, Role Identity

1 INTRODUCTION

The persistent shortage of qualified professionals in engineering and technology (E&T) has become a critical concern for economies worldwide (e.g., European Commission, 2023). This imbalance underscores the importance of understanding the factors that influence students' decisions to pursue studies and careers in these domains. Research on aspirations has frequently employed attitudes questionnaires to capture students' perceptions, interests, and intentions, particularly in science and technology education (Ankiewicz, 2016; Osborne et al., 2003; Toma & Lederman, 2022), whereas engineering remains comparatively underexplored. (Kennedy et al., 2020). For technology, the most noted study of students' attitudes towards technology has been The Pupils' Attitudes Towards Technology (PATT) instrument, and its related questionnaires

(Ankiewicz, 2019). Nevertheless, some criticisms have recently emerged pointing to the need for a more holistic approach to measuring students' attitudes toward technology, including the behavioural component and reintroducing the cognitive component of attitudes, which has gradually disappeared in PATT-based approaches (Ankiewicz, 2025; Svenningsson et al., 2022)

Acknowledging that understanding study and career choice (SCC) requires robust and theoretically informed measurement tools, there is a pressing need to critically examine the instruments commonly used to assess attitudes and related constructs in the context of engineering and technology education. Without a clear link between questionnaire design and the established SCC theories, research risks producing fragmented or misleading insights.

In this regard, in the broader STEM domain, role identity (e.g., science identity, physics identity, engineering identity) is emerging as a construct with significant influence on SCC and persistence (Destin & Williams, 2020; Simpson & Bouhafa, 2020; Vincent-Ruz & Schunn, 2018). However, among S-T-E-M identities, technology identity is the least investigated field (Simpson & Bouhafa, 2020). Our perspective is that this framework could complement the attitudes' approach giving answer to the abovementioned gaps.

With the aim of contributing to critically evaluating the tools used to measure students' study and career choice in technology and incorporating engineering as a field of study, the present work seeks to:

- (i) Develop an analysis framework, coherent with current SCC theories, for evaluating questionnaires that claim to measure attitudes or other constructs influencing SCC
- (ii) Test and validate the framework by analysing paradigmatic tools used to measure attitudes or other constructs influencing technology and engineering SCC and propose refinements
- (iii) To provide insights on these paradigmatic tools regarding the link between their design and the underlying theories of SCC

2 LITERATURE REVIEW

This section reviews the theoretical foundations regarding attitudes and related constructs influencing study and career choices. It draws on literature in the fields of technology and engineering education but extends to frameworks used in STEM or more general fields. The four key identified research perspectives are: (1) attitudes, (2) identity, (3) understanding of the nature of the discipline, and (4) study and career choice theories. Together, these perspectives inform the (preliminary) analysis framework presented at the end of this section.

2.1 *Attitudes*

Definitions of attitudes differ in literature, although there is convergence of the idea that attitudes are a “psychological tendency to evaluate an object in terms of favorable or unfavorable attribute dimensions such as good/bad or positive/negative” (Ajzen, 2001; van Aalderen-Smeets et al.,

2012). Traditionally, also in PATT, attitudes are conceptualized as comprising **cognitive**, **affective**, and **behavioral** dimensions (Ardies et al., 2013; Svenningsson et al., 2022). In PATT, underlying components are proposed, but these are not defined and it is not argued why these components are making up each dimension. A reworked framework, focussing on teachers' attitudes towards science, provides inspiration. It keeps the affective dimension, but replaces cognition with **cognitive beliefs**, and adds **control** as a new dimension. These three dimensions together influence **behavioral intention** (i.e., career aspirations) and ultimately behavior (i.e., SCC) (van Aalderen-Smeets & van der Molen, 2012). Based on a review of attitudes towards science literature, the authors further categorize these dimensions in components:

- **Perceived importance** (Cognitive belief) = “the extent to which people consider [the topic of interest] relevant for their personal lives, for society, for prosperity, or for health”
- **Perceived difficulty** (Cognitive belief) = “beliefs of individuals regarding the general difficulty of [the topic of interest] relative to other fields of study”
- **Gender beliefs** (Cognitive belief) = “beliefs about gender roles and the different abilities of men and women in [the topic of interest]”
- **Enjoyment** (Affect) = “positive feelings of pleasure and joy related to [the topic of interest] in daily life or as a part of leisure time”
- **Anxiety** (Affect) = “fear of or aversion related to [the topic of interest] in general or in daily life”
- **Self-efficacy** (Control) = “perceived level of capability or confidence that an individual has for performing a particular behaviour that may contain difficult and stressful elements”, based on (Bandura, 1997).

These components are also largely covered in PATT; the only component present in PATT and missing in this framework is **interest**, which is in the cognitive and affective dimension (Ardies et al., 2013; Svenningsson et al., 2020).

2.2 *Identity*

Role identity is typically conceptualized as comprising three dimensions: (1) **performance/competence**, (2) **recognition by self and others**, and (3) **interest** (Carlone & Johnson, 2007; Hazari et al., 2010). While some authors conceptualize identity as consisting of these interrelated components that work together to form one's role identity (Carlone & Johnson, 2007; Hazari et al., 2010), others (Dou & Cian, 2022) measure identity as a unidimensional, single item (“I see myself as a [science] person”), that is influenced by the mentioned factors. Grimalt-Álvarez et al. (2022) adopts this approach, and additionally includes the factor ‘Aspirations’, although as discussed before, this could also be considered as a behavioural intention, resulting from attitudes and identity perceptions. In literature, the dimensions are defined as follows:

- **Performance/competence** = “social performances of relevant [...] practices” and “knowledge and understanding of [...] content” (Carlone & Johnson, 2007). Hazari et

al. (2010) emphasise “belief in ability to perform required [...] tasks” (performance) and “belief in ability to understand [...] content”. Note that Hazari’s interpretation in fact corresponds to the self-efficacy component mentioned above.

- **Recognition** = “recognizing oneself and getting recognized by others as a [science] person” (Carlone & Johnson, 2007).
- According to Paul et al. (2020) and based on Hazari et al. (2010), **interest** “reflects one’s desire or curiosity to think about or understand a subject”.
- **Aspirations** = “expressions of people’s hopes or ambitions regarding further STEM studies and career (Archer et al., 2020)”, from (Grimalt-Álvaro et al., 2022).

Together, these perspectives add depth to the understanding of motivational factors beyond attitudes alone.

2.3 *Understanding the Nature of the Discipline*

Finally, students’ understanding of the nature of the discipline is critical for informed SCC (Capobianco et al., 2012). Empirical studies confirm that students across age groups hold uninformed, limited or stereotypical conception of engineers and engineering (Karatas et al., 2011; Knight & Cunningham, 2004; Köycü & de Vries, 2016). The same goes when measuring component relating to students’ E&T career choice. Instruments should either include a description of these field, or probe students’ knowledge about E&T. Using of the term E and/or T without controlling for students’ understanding blurs the interpretability of the instruments’ outcome. Frameworks such as **Nature of Technology** (NoT) and **Nature of Engineering** (NoE) provide guidance on the cognitive aspects of what students should know about these disciplines (Barak et al., 2024, Doyle, 2025).

2.4 *Study and Career Choice Theories*

Numerous theories have been proposed to explain study and career choice, including Expectancy-Value Theory (EVT) (Eccles & Wigfield, 2020), Social Cognitive Career Theory (SCCT) (Lent et al., 1994), RIASEC personality theory (Holland, 1997), and developmental theories such as those by Gottfredson and Super (Gottfredson, 1981). In addition to components already identified in previously discussed frameworks (self-efficacy, ...), these frameworks emphasize factors on the **personal** (personality, values and outcome expectations, ...) and **environmental** level (role models, support, ...). A recent synthesis highlights the relevance of these theories for understanding technology and engineering attractiveness and provides a preliminary integration of their key components (Wint et al., 2025). These theories offer essential guidance for interpreting constructs measured by questionnaires and for assessing whether instruments align with theoretical expectations.

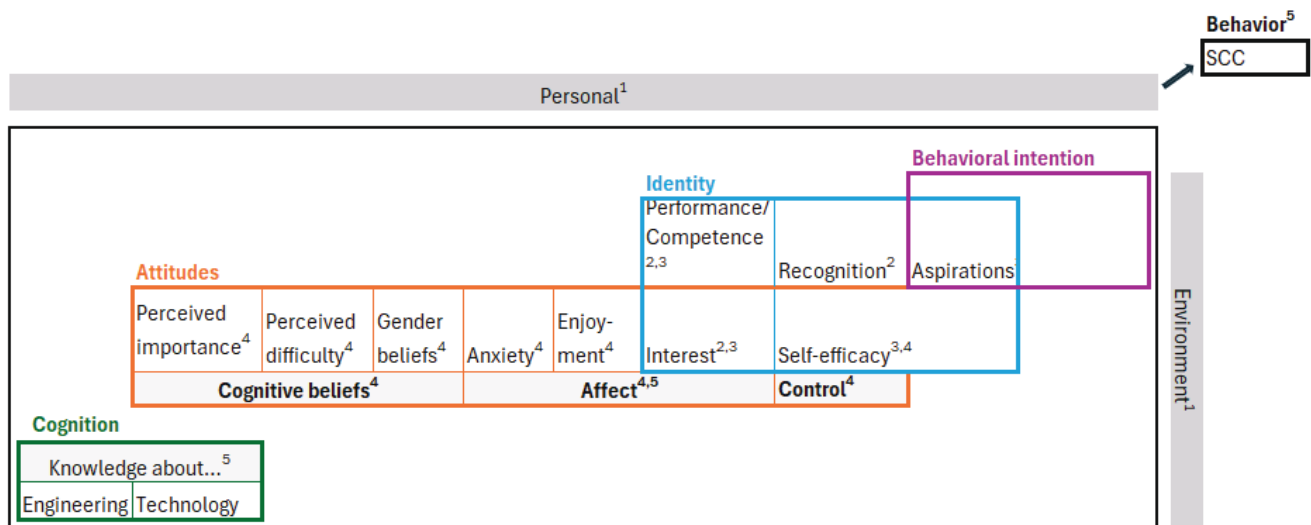
2.5 *Toward an Analysis framework*

The insights from these four perspectives - attitudes, identity, disciplinary understanding and SCC theories - form the basis for a preliminary analytical framework, see Fig. 1, to evaluate

questionnaires claiming to measure components related to SCC. While all perspectives have been linked to SCC, it is unclear in literature which (bi)directional relations exists between components. However, some overlaps can be identified as presented in the proposed framework. This framework serves as a basis for our evaluation of the appropriateness, comprehensiveness and theory-informedness of instruments that claim to study components influencing engineering and technology SCC.

Figure 1.

Analysis framework developed based on SCC theories¹, identity frameworks (Carlone & Johnson, 2007; Hazari, 2010)² and (Grimalt-Álvarez, 2022)³, attitudes frameworks (van Aalderen-Smeets & van der Molen, 2012)⁴, NoT and NoE frameworks⁵.



3 METHODOLOGY

To validate the proposed framework, instruments were selected based on three primary criteria: prevalence of use in the field, disciplinary specificity (appropriateness for E&T) and alignment with the presented frameworks from Sec. 2. This (non-exhaustive) selection was informed by a (ongoing) systematic literature review, and includes seven instruments: PATT-SQ (Ardies et al., 2013), PATT-SQ-SE (Svenningsson et al., 2022), TEAS (Cook, 2009), HBT (Järvinen, 2015), RIS-E (Paul et al., 2020), EIDS (Capobianco et al., 2012), and STEM-CIS (Kier, 2014).

Two researchers independently applied the framework to these instruments to identify which dimensions and/or components were present in each. The analysis focused on the dimension and component descriptions provided in the original article rather than individual items. This high-level approach was chosen to ensure consistency, as preliminary analysis revealed item classification issues (e.g., classifying an item as "knowledge" vs. "competence"), keeping an item-level analysis for future work. Additionally, we extracted the question types used to assess the knowledge dimension.

For the writing of the text, MS Copilot was used as a language assistant to review or improve texts, without adding new content.

4 RESULTS AND DISCUSSION

Results are presented in Tab. 1, which are now critically discussed with respect to research objectives 2 and 3.

We first discuss the applicability, validity and refinement of the analysis framework (objective 2). Overall, the framework has proven useful to analyse and critically evaluate the diverse selection of instruments. It provides a shared vocabulary to align perspectives, detect overlap and supports systematic identification of gaps. That said, one important limitation emerged: there is no explicit reference to outcome expectations as conceptualized in instruments like STEM-CIS (Kier et al., 2014), that builds on expectancy-value theory (Eccles & Wigfield, 2020). We need to rethink the role of this component. A plausible revision is to treat outcome expectations as a mediator, influencing interest and self-efficacy, consistent with arguments of Kier et al. (2014). This observation warrants more precision about the components to include in the personal and environmental dimension, based on SCC theories, and about the (bi)directional relations among all framework components. While the presented framework was not developed to represent all possible influence on SCC antecedents at personal level, it currently lacks depth in components from SCC theories and directional nuances, leading to interpretive ambiguity and a lack of coverage.

The evaluation of the instruments (objective 3) leads to four observations:

- (i) **Coverage and alignment.** None of the reviewed instruments fully covers all dimensions and components identified in the analysis framework. This is not inherently problematic, but it demands critical reflection on use: are we describing a “state of affairs” (i.e., broad profiling) or evaluating specific intervention effects? For the latter, we must specify which component(s) the intervention is designed to influence and select measures that correspond to those targeted mechanisms. Most available tools concentrate on the overlapping space between identity and attitudes, but do not assess both together, leaving blind spots for a full state of affairs. A promising pathway is to integrate PATT-SQ-SE with RIS-E. Such integration should be theory-led (i.e., anchored in the revised framework’s pathways) rather than a pragmatic aggregation of scales.
- (ii) **Knowledge measurement.** Knowledge is included in some instruments, predominantly via Likert-type items. This approach risks imposing an externally defined understanding of the field onto students. An item-level analysis is therefore essential to check coherence with the NoE and NoT frameworks. For this analysis, refinement of our analysis framework is needed. In turn, the analysis of knowledge-elements in existing instruments is expected to further refine our framework. Compared to most instruments

that rely on Likert-type items, the openended items in PATT-SQ-SE are a notable exception; they enable a more direct assessment of students' declarative and conceptual understanding of Technology. However, scoring these responses is substantially more labour-intensive, and drawing reliable conclusions requires a well-developed and validated scoring rubric to ensure consistency and interpretive validity.

(iii) **Conceptual and terminology clarity.** Across instruments, there is a recurring lack of conceptual clarity and terminological consistency. Using the proposed markers (-, ~, *), we make three observations:

- a. Instruments flagged with * lack granular definitions or subscales aligned to theory. In the case of HBT, no components underlying the broad attitudes dimension are used
- b. Semantic drift – different term, same concept: Instruments may use different terms to refer to the same concepts, which is indicated with the marker – in Table 1. For example, TEAS employs the term 'problem solving difficulty', but in fact – based on the component description – measures 'self-efficacy'. Similar examples are: 'multidisciplinary' (TEAS) or 'occupational identity' (EIDS) to denote 'knowledge of E&T', 'career interest' (TEAS) or 'personal goals' (STEM-CIS) to denote 'aspirations'. Furthermore, the PATT-based instruments use the attitudes component 'tediousness' or 'boredom', to measure the opposite of 'enjoyment' (indicated with ~ in Table 1). This observation calls for explicit definition of components and dimensions used in instruments, which is lacking in e.g., TEAS.

(iv) **Semantic drift – same term, different concept.** Instruments may use terms that allude to a certain concept, but in fact measure a different concept. For example, the HBT contains 'activity know-how of technology', which seems to refer to 'competence'. However, the description "how pupils considered they would be able to ..." shows that in fact it measures 'self-efficacy'. The conflation of the terms 'competence' and 'self-efficacy' could be originating from literature, as Carlone and Johnson (2007) and Hazari et al. (2010) in fact refer to different underlying concepts when discussing 'competence'. This lack of terminological rigour is reflected in the conception of resulting instruments and warrants – again - reliance on dimension or component descriptions to position these in the analysis framework.

Table 1

*Summary of selected instruments using the analysis framework. Symbols denoting correspondence between instrument and framework dimensions/components: x=exact, -=different naming, *=not specified, ~=reverse-coded.*

Perspective	Dimensions	Component	PATT-SQ	PATT-SQ-SE	TEAS	HBT	STEM-CIS	EIDS	RIS-E
Knowledge about	Engineering				- (Likert)			- (Likert)	
	Technology			x (OE)	- (Likert)	x (Likert)			
Attitudes	Cognitive beliefs	Perceived difficulty	x	x	x	*			
		Perceived importance	x	x	x				
		Gender beliefs	x	x	x				
	Affect	Anxiety							
		Enjoyment	~x	~x					
Attitude/identity		Interest	x	x	x		x		x
Attitude/identity	Control	Self-efficacy			-	-	x	-	-
Identity		Performance/Competence				x			
		Recognition							x
Identity/behavioral intention		Aspirations	x	x	-		-	x	
SCC theories	Personal						x		
	Environment						x		
Points for discussion					definitions missing	attitudes not split up in components	outcome expectations missing in analytical framework		recognition by self and others

5 CONCLUSION

A key limitation of the present study lies in the self-selection of instruments, which was largely shaped by the authors' prior familiarity with specific instruments and further informed with a preliminary selection of articles from an ongoing systematic literature review. While this pragmatic choice allowed for efficient data collection and interpretation, it inevitably constrained the breadth of the analysis and may have introduced unintentional bias in the selection of constructs and measurement approaches. As a result, the findings should be interpreted as indicative rather than exhaustive.

Despite this limitation, the study makes several valuable contributions. First, it proposes a comprehensive analysis framework for instruments addressing SCC in E&T that brings together multiple dimensions relevant to the study of students' attitudes, identities, and engagement, extending the scope to the field of engineering. This broadened focus allows for cross-disciplinary comparison and reveals three important gaps in current measurement practices. The first gap concerns coverage: none of the investigated instruments measures all components included in the analysis framework. Second, existing instruments differ substantially in how (and whether) they capture students' conceptual understanding of engineering and technology (dimension 'knowledge of E&T'). In many cases, knowledge is either treated superficially or operationalized in ways that assume disciplinary understanding that learners may not yet possess. The third gap relates terminological clarity: the coherence between dimension/component names, their descriptions and the items used to measure them. Several instruments do not present

component/dimension definitions or display inconsistencies between their conceptual definitions and the framework we draw from. Inconsistent definitions further lead to different instruments using the same terms for different constructs. Preliminary analysis (not presented) indicates ambiguity between what is actually being measured and how the intended dimension is described.

These insights point to several priorities for future work. The analysis framework itself requires further refinement to ensure conceptual clarity and stronger alignment with established theoretical models. In addition, a more comprehensive, item-level analysis of a broader selection of instruments is needed to examine how well individual items map onto intended dimensions, and where knowledge about the field is measured according to contemporary understandings of the field. Such work will support the development of more coherent, theoretically grounded instruments capable of capturing the full complexity of learners' SCC and its antecedents in engineering and technology education.

6 DISCLOSE ON GENAI USE

GenAI (MS Copilot) was used for copy editing purposes to review or improve texts, without adding new content.

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Mapping Futures: Comparative Analyses of International Design and Technology Education Curricula

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Abstract

South African Technology Education (TE) is designed to equip learners with broad knowledge, skills, and values that they can apply in solving real-world problems, implying substantial potential in its curriculum to prepare learners for their futures beyond school. The same could be true for comparative Design and Technology (D&T) subjects internationally. Although small comparative studies have been conducted across TE, D&T and similar subject curricula, those have been limited in scope and context. The vast potential of international Design and Technology Education (IDTE) to prepare learners for their futures has not yet been explored on a large international scale. One key purpose of this study was, therefore, to explore how learners are being prepared for their futures through IDTE curricula in various countries worldwide. In anticipation of a large international curriculum benchmarking study to address the overarching goal, several pre-determined themes were set for the larger study, but the finer details needed refinement to enhance the validity and reliability of the study. Therefore, an exploratory literature review was conducted to identify patterns in existing studies on learners' future readiness that could contribute themes for the thematic curriculum analyses. The current paper reports on the findings of the exploratory literature review, providing insights regarding themes currently reported in relation to learners' futures, or their 21st-century readiness. Key findings include that context is a key determinant of content and skill preferences in relation to future readiness, and that there exists a gap regarding D&T's contributions to prepare learners for their futures.

Key Words: Curriculum Benchmarking, Future Readiness, International Comparison, Intended Curriculum

1 INTRODUCTION

Technology education (TE) in this paper refers to the school subject Technology (in South Africa), which is also called 'Design and Technology' (D&T) in other countries. It must be noted that TE focuses on knowledge and skills development regarding technological concepts and problem-based learning, which should not be confused with digital technologies, information and

communication technologies (ICT) or ‘computer technologies’. In this regard, the Senior Phase¹ curriculum document defines TE in South Africa as using “*knowledge, skills, values and resources to meet people’s needs and wants by developing practical solutions to problems, taking social and environmental factors into consideration*” (DBE, 2011b, p. 8). From this definition, TE is intended to provide learners with broad knowledge, skills, and values that they should be able to apply in solving real-world problems. Problem-based learning, which supports self-directed learning, promotes higher-order thinking skills and the application of knowledge in practical (or lived) contexts (European Union, 2025, p. 11) and is recognised as a core teaching-learning strategy for TE (Du Toit & Gaothlobogwe, 2017:154). The inclusion of problem solving and ‘social and environmental factors’ in the South African definition of TE, together with overarching curriculum topics such as “Technology, Society and the Environment” (DBE, 2011b, p. 10), also hints at the subject’s potential to contribute to addressing the United Nations’ Sustainable Development Goals (SDGs). The SDGs aim to contribute to improving and positively transforming the real or lived lives of people across the world, highlighting their intention to enable better futures for all (United Nations, 2015, p. 2).

Against this background, there seems to be substantial potential embedded in South African TE to prepare learners for the real world or their futures after school. TE is, however, not unique to South Africa and many countries across the globe offer similar or comparable subjects such as D&T. These other similar subjects probably hold the same potential to contribute to learners’ future readiness. As these subjects are often compulsory, the learning intended in those curricula must continuously be interrogated for its usefulness and relevance in preparing learners for their futures. Yet, this potential has not yet been explored on a large international scale.

This paper reports on one part of a large international study that is currently analysing Design and Technology education national curricula from more than 15 countries and territories. This larger study (i.e. International Design and Technology Education – IDTE) is benchmarking numerous aspects regarding IDTE (see Hardy and Du Toit, 2026 – this conference). The current paper focuses only on the exploratory work that was conducted to determine themes for analysing IDTE’s contribution to learners’ future readiness - one of the aspects within the larger study.

Constructivism underpins the IDTE study, as researchers from the Global South and Global North collaboratively constructed a shared understanding of concepts, codes, and constructs that would be used in the subsequent extensive international study. Preliminary informal discussions when planning the study highlighted that researchers held various, different, or nuanced views regarding the concepts under investigation. It also emerged that the contexts in which Technology or D&T education is facilitated vary more extensively than what was initially anticipated. Clarifying and delineating concepts, ideas, and constructs was therefore critical before commencing the larger study. One of these constructs was future readiness.

Therefore, the question that guided the research reported here was ‘Which main themes are currently reported in relation to school learners’ future readiness?’

¹ In the Senior Phase, learners are around 13-15 years of age.

2 CONCEPT CLARIFICATION

(Design and) Technology are key school subjects in many countries across the world. For example: “Technology education is vital if we are to instil technological literacy in South African learners to prepare them for their future and develop their knowledge and 21st-century skills” (Mulaudzi et al., 2023, p. 129). Furthermore, TE and D&T subjects are intended to stimulate learners to be innovative, critical and creative thinkers and problem-solvers, to support the optimal use of resources and to prepare learners for the world of work (Du Toit & Gaothlobogwe, 2017, p. 149). There is, therefore, clear potential in TE and D&T curricula to prepare learners for the future. But how should the concept of future readiness be understood?

2.1 *Future readiness*

Future readiness encompasses a broad field of research and information. Among other aspects, the development of scales, indices, frameworks, education, and assessment of, or for, future readiness has been explored (Fletcher et al., 2018; Ng & Chua, 2023; Stone & Lewis, 2012). No single accepted definition of the construct ‘future readiness’ exists, but it broadly refers to anticipating change and being prepared for emerging realities (Tan, 2024). She laments that most research on future readiness is dominated by practices and views from the Global North and that research on future readiness in the Global South is lacking. This is an important point as the IDTE study involves countries and territories from both the Global North and South.

Ng and Chua (2023, p. 634) associate future readiness with *future value*, which they define as “the future readiness of learners that will contribute to the future development of society, environment, and lifework”. They emphasise that learning “must be relevant and aligned to new realities that emerge over time” and that these realities are dependent on context, which Tan (2024) affirms. Although we agree with these descriptions, we believe that *existing* realities should not be disregarded as part of future readiness. Our reasoning is underpinned by the idea that current problems do not necessarily disappear in the future, and that what we learn from current realities might very well be transferable or relevant to future realities.

Ab Jalil et al. (2022) posit future readiness as a 21st-century skill. They claim that, together with agility (another 21st-century skill), these skills help prepare learners for a VUCA world. VUCA is an acronym used to describe the volatile, uncertain, complex, and ambiguous circumstances or world experienced globally, and education across all levels should endeavour to prepare learners for a VUCA future (Du Toit et al., 2025). We also view the future as being VUCA, but we disagree with Ab Jalil et al. (2022) that future readiness is a skill. Rather, we assert that several (21st-century) skills and competencies are needed to enhance future readiness. We therefore viewed future readiness as learners’ potential to navigate shifting contexts and unforeseen challenges, rather than merely as the development of a set of skills or competences.

For our research, we viewed learners’ *future* as life after formal schooling, including (but not limited to) the world of work. The Merriam-Webster dictionary (2026) describes *readiness* as “the quality or state of being ready”, including one’s “state of preparation” or “prompt willingness”. We therefore viewed *readiness* as learners’ competence in a combination of

knowledge, skills, and values to efficiently address current and emerging context-specific realities.

3 METHODS

As stated before, this paper reports only on one part of a much larger ongoing international study that explored and benchmarked numerous aspects of IDTE. Therefore, only the methods relevant to this small part of the research are unpacked. Exploratory desk research was conducted to identify potential themes that could be used for analysing those curricula studies as part of IDTE's contribution to learners' future readiness.

A basic literature review using Google Scholar served as an exploratory tool for this introductory investigation. The search was broad to identify the main aspects that needed to be considered to address the research question, and to spark ideas for potential sub-themes, categories or codes that would contribute valuable insights to this goal. The first Google Scholar search ("future readiness" + "technology education" OR "design and technology education" + school + curriculum OR syllabus + "21st-century readiness") yielded only six results, suggesting a potential research gap. After the initial exploratory search on Google Scholar, the same search was repeated using EBSCOhost, which returned 91 items. This search was narrowed to peer-reviewed items published in the last 10 years, resulting in 44 items. The following exclusion criteria were then applied:

- not focused on school-level learners or – education
- focused only on design education, and not Design and or Technology education
- focused only on computer applications or digital technologies (ICTs)
- focused on other subjects' curricula, such as law studies, chemistry and social studies
- focus on leadership or management, rather than curriculum, teachers or learners.

For each result, the title was carefully scrutinised for relevance (level 2), yielding 11 items. This second search confirmed our initial suspicion that there was little, if any, research focusing on future readiness and IDTE. Level 3 analysis involved carefully reading the abstract and keywords of these 11 items and the six initially found by Google Scholar (17 items in total). The researchers identified emerging themes and deliberated their potential relevance to the larger study, as well as to construct a shared understanding of these terms or constructs through intercoder agreement. The broad findings of the investigation up to level 3 analyses are presented in the next section. Keep in mind that this is not a comprehensive literature analysis; rather, it was exploratory to help us identify potential areas for deeper investigation within the larger study.

No artificial intelligence (AI) was used in the development or write-up of this paper, except for Grammarly, a language-editing application. Grammarly was used with care to correct minor language and grammar issues, and each recommendation was considered individually before acceptance to maintain the authors' voice and cadence in our writing.

4 FINDINGS AND DISCUSSION

As could be expected, several studies reporting scales, indices, frameworks, education, and assessment of, or for, future readiness were found (for example, Ab Jalil et al., 2022; Fletcher et al., 2018; Ng & Chua, 2023; Stone & Lewis, 2012; Tan, 2024). As no studies were found that explicitly focused on an international understanding of TE and D&T curricula's impact on learners' future readiness, some of these more generic publications could be explored individually or collectively to analyse the contributions of TE and D&T to learners' future readiness. However, despite the broadness of future readiness as a construct, and to adhere to the research question, five main themes that emerged from the literature reviewed are discussed in this section.

4.1 *21st-century skills for future readiness*

The literature review showed that future readiness has been explored in relation to various school subjects, including Mathematics, STEM subjects (in general), and design education, with many studies highlighting the contributions of various 21st-century skills to this goal. Using the search string (described in the methods section of this paper) did not return a single publication that focused on exploring learners' future readiness in relation to TE or D&T education. Yet, countless scholars have noted the contributions of TE and D&T to the development of learners' 21st-century skills and competencies (e.g. Du Toit & Gaotlhobogwe, Galeboe et al., 2025; Grönman et al., 2025; Hardy, 2022; McLain, 2022; Schooner et al., 2017; Snape, 2017). Despite Schooner et al. (2017) mentioning claims that so-called 21st-century skills have been around for decades or even centuries, many others – including ourselves – believe that these skills are (still) critical for supporting learners to thrive in current and future realities. Therefore, this finding confirms a gap in existing scholarship and underscores the need to conduct research into how IDTE contributes to learners' future readiness, especially regarding the 21st-century skills embedded in them.

4.2 *A need for concept clarification*

During the level 1 analysis, it became apparent that 'design education' (as opposed to 'design and technology education') appeared in many of the titles returned in the literature search. After deliberation and to ensure intercoder agreement, the following delineations were selected and used:

- Design Education is a broad field focused on creative problem-solving, material intelligence and systems thinking, considering user needs, and (especially green) innovation (Design Council, 2024).
- Design and Technology (D&T) Education specifically emphasises the practical application of science and math, focusing on tangible products, materials, manufacturing, and technical knowledge within defined briefs. D&T refers to a subject in which "pupils design, make, prototype and test products that solve real problems within a variety of contexts, considering their own and others' needs, wants and values...which teaches applied creativity and empathy" (Design Council, 2024, p. 9). It "emphasises the interconnected nature of design **and** technology while implying a concept broader than either alone" (Hardy, 2024, p. 5; *emphasis added by authors*).

Showing a similar lack of decisive distinction, Design is a subject separate from TE in South African schools (DBE, 2011a). Yet, one of the aims in the Design curriculum is to “develop knowledge, technical abilities and skills in the conceptualisation, production and context of design” (DBE, 2011a, p. 8). This, and several other references to ‘technical’ skills in the Design curriculum shows how interwoven (and sometimes confusing) design education and D&T or TE can be. The current finding therefore confirms the perpetual misperceptions or misunderstandings that exists regarding the unique contributions of TE and D&T, as it also emerged as an issue in the current literature review. The researchers believe that the continued lack of emphasis (some even call this a lack of recognition) on *technology* in publications highlights the need to explore and report the valuable contributions of subjects such as D&T or TE to learners’ development. When developing themes for the larger IDTE study, the research team could explore how design is incorporated into D&T subjects, but they would have to ensure that *technology* is not marginalised in their investigations.

Similarly, the literature search also returned many results that focused on digital or computer technologies. This reiterates the issue reported for design education, where clarity of which type of technology is investigated should be emphasised, and the value and contribution of D&T or *technology as a subject* should be highlighted and publicised. The larger IDTE study must, therefore, ensure that it differentiates the contributions of technologies (such as digital and computer technologies) and the *technology-based subjects* under investigation to learners’ future readiness. Such an approach will enhance the perceived uniqueness and benefits associated with TE and D&T subjects.

4.3 *Artificial intelligence is a conclusive part of future readiness*

It also emerged that many publications on future readiness include investigations into the roles and contributions of artificial intelligence (AI) in learners’ preparation. This was not surprising given the sudden and extensive expansion of AI since its launch in 2022. However, in line with the authors’ view that future readiness should not exclude current realities, we cautioned the research team in the larger IDTE study not to focus too much or too narrowly on AI. Many problems relevant in TE and D&T education existed before the rise of AI and will continue to be issues into the future, despite the potential of AI to contribute to addressing them (Deane, 2017). AI was, therefore, noted as one of several themes that need to be critically explored as part of IDTE’s contributions to prepare learners for their future.

4.4 *Problem-solving for future readiness*

It emerged that several studies exploring future readiness of learners in other subjects emphasised the value of problem-solving in their investigations. Developing novel solutions to problems are critical in preparing for the future (Ab Jalil et al., 2022). Problem-solving is a core 21st-century skill and forms the foundation of problem-based and project-based teaching-learning strategies. Problem-solving is also a core competency and a central pedagogical principle in TE (Du Toit & Gaothlobogwe, 2017; Grönman et al., 2025; Mulaudzi et al., 2023). In addition, problem-based learning supports self-directed learning and higher-order thinking skills, both of which are key competencies for survival and thriving in a VUCA world (Du Toit et al., 2025). The role and

impact of problem-solving must therefore be a key theme when investigating the contributions of TE and D&T to learners' future readiness.

4.5 Context impacts future readiness

Problem-based learning is often used to apply knowledge in practical (or lived) contexts (European Union, 2025, p. 11). Future realities and problems will often be context-situated, context-dependent, or context-specific (Ng & Chua, 2023; Tan, 2024). In other words, different contexts will mean different views of the future and which knowledge, skills or values are needed to prepare learners for it in a particular context. Therefore, it was unsurprising that context emerged as another key theme to explore in future readiness. Discrepancies in the contexts in which learning takes place are vast. These discrepancies include access to resources, digital competencies, teacher training, socio-political factors and many more. When education and related activities are contextualised, learning becomes more meaningful, and learners' motivation and their engagement in the process are enhanced (Snape, 2017). Furthermore, contextual differences between the Global North and Global South are often compared, which will also be done in the larger IDTE study with regard to the contexts in which TE and D&T are facilitated. It is, therefore, clear that contextual factors will critically impact what is viewed as requirements for learners' future readiness, and to what extent various factors are evident in the technology subject curricula explored.

5 CONCLUSION

The five main themes identified here will also be contextually dependent. For example, digital competence or AI might be more contextually important in the future of learners in countries where digital access is equal and freely available. We conclude that these five themes will serve as high-level ideas to initiate and structure the exploration of IDTE's contribution to learners' future readiness. We also acknowledge that finer sub-foci will emerge across various curricula, based on and reflecting the unique contexts of different countries. Still, the potential of TE and D&T to enhance learners' future readiness is vast, and it must be explored and reported to underscore the value and importance of technology subjects in school education.

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Scaffolding and Questioning in Engineering Design-Oriented STEM: A Qualitative Analysis of High School Technology Teachers' Pedagogical Strategies and Perspectives

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Abstract

Engineering design-oriented STEM courses have been recognized as important approaches for cultivating students' problem-solving and integrative thinking skills. Such instruction requires students to engage in challenging phases of the engineering design process, while teachers coordinate pedagogical actions such as curriculum unit design, scaffolding, and purposeful questioning to support iterative problem-solving. However, teachers' pedagogical perspectives and instructional decision-making in these contexts remain insufficiently examined. This qualitative study investigates high school Technology teachers' educational beliefs, curriculum design models, and the scaffolding and questioning strategies they employ to guide student engagement in engineering design-oriented STEM courses. Fourteen teachers from diverse regions in Taiwan participated in semi-structured online interviews (approximately 60–90 minutes each). The interview protocol, grounded in prior literature, addressed three dimensions: (1) educational beliefs, (2) curriculum design models, and (3) learning scaffolds and questioning strategies. Interview data were transcribed verbatim and analyzed through iterative coding and thematic analysis aligned with these dimensions. Triangulation was conducted through comparison with relevant literature and course documents provided by some participants. The findings reveal a strong consensus among teachers on the importance of systematically guiding students through the engineering design process to develop their ability to apply interdisciplinary knowledge for solving complex problems. Teachers commonly adopt phased curriculum structures, supported by learning portfolios and instructional exemplars, progressing from foundational skill development to student-centered engineering design projects. Instructional emphasis is placed on problem scoping and noticing, as well as predictive analysis, modeling, and evidence-based testing using interdisciplinary knowledge. Throughout the design process, teachers strategically employ diverse and interactive questioning to support students' reasoning and decision making without providing direct solutions, thereby promoting reflective learning and student autonomy. This study offers implications for curriculum design and instructional strategies in engineering design-oriented STEM education.

1 INTRODUCTION

In recent trends in K-12 STEM (Science, Technology, Engineering, and Mathematics) education, engineering design-oriented STEM courses have been widely recognized as important instructional approaches for cultivating students' problem-solving skills, integrative knowledge, and the ability to apply their learning in real-world contexts (Kidd et al., 2025). Under the concept of interdisciplinary integration, engineering design is positioned as a pivotal cognitive and learning process that connects knowledge from science, mathematics, and technology (Kelley & Knowles, 2016; National Research Council [NRC], 2012; Roehrig et al., 2021). In Taiwan, high school technology education has also explicitly emphasized the importance of developing students' engineering design thinking (Ministry of Education, 2018).

STEM project-based courses centered on engineering design typically require students to engage in a series of challenging design processes, including steps such as problem identification, information gathering, idea development, predictive analysis, prototyping, testing, and optimization (NRC, 2012; Purzer, 2018; Simarro & Couso, 2021; Wells, 2016). Throughout this process, students must continuously employ divergent and convergent questioning to connect and apply disciplinary knowledge in order to identify the core problems to be addressed and effective solutions (Dym et al., 2005). However, prior research has shown that for secondary-level students, clearly defining core problems and effectively linking and applying interdisciplinary knowledge during engineering design activities remains a highly challenging task (English, 2016; Hughes & Denson, 2021). Students also tend to overemphasize making and final products, while neglecting problem analysis, predictive reasoning, and evidence-based testing and optimization (Crismond & Adams, 2012; Rees Lewis et al., 2023).

Engineering design-oriented STEM courses at the secondary level frequently adopt learning models such as project-based learning, problem-based learning, and inquiry-based learning. Although these models emphasize a learner-centered approach, the guiding role played by the teacher remains a critical factor in determining whether students can effectively engage in learning and apply disciplinary knowledge to solve design problems (Wells, 2016). Previous research has indicated that appropriate learning scaffolds assist students in maintaining their learning direction, focusing on key problems, and progressively internalizing the knowledge and thinking skills required for professional practice (Hmelo-Silver et al., 2007). During the engineering design process, insufficient scaffolding may hinder students' ability to grasp core problems and apply existing knowledge for predictive analysis, and may compromise the depth and quality of problem-solving when challenges arise during prototyping and testing (Hughes & Denson, 2021).

In engineering design-oriented STEM courses, teachers have commonly employed engineering design journals, portfolios, or structured worksheets as scaffolds to support students' documentation of design decisions and reflection on their learning processes (Hertel et al., 2017; Kelley, 2014). However, learning scaffolds should not be viewed merely as pre-designed

instructional tools; rather, they represent a dynamic support process that requires ongoing adjustment based on students' learning states (van de Pol et al., 2010). In open-ended engineering design contexts, where students' difficulties are often diverse and individualized, effective scaffolding depends largely on teachers' ability to notice students' thinking and learning difficulties in real time.

Research on teacher noticing indicates that teachers' professional expertise is demonstrated not only in their selection of instructional strategies but also in their ability to attend to students' learning performances and provide appropriate responses (Jacobs et al., 2010; van Es & Sherin, 2002). This process typically comprises three interconnected dimensions: attending to students' key behaviors, interpreting students' understanding and difficulties, and deciding how to respond (Jacobs et al., 2010). In engineering design-oriented STEM courses, teacher noticing is particularly critical given the contextualized and evolving challenges students encounter across different design stages.

Among teachers' instructional actions, questioning is one of the most frequently used classroom practices. It guides students to re-examine design goals and constraints and supports reflection on design decisions and knowledge application (Wells, 2016). Walsh and Sattes (2011) argue that high-quality questioning promotes higher-order thinking and identify several types of questions that support deeper learning, including "Probing Questions," which scaffold students' learning and understanding, and "Interpretation Questions," which encourage students to generate preliminary inferences based on given information or evidence. These questioning strategies must be flexibly combined and adapted in response to students' learning states and task demands to effectively support engineering design learning.

However, determining when to intervene, how to question, and how to strike a balance between providing guidance and allowing student autonomy remains a highly professional and context-dependent pedagogical judgment. Although international research (Kidd et al., 2025) has increasingly focused on curriculum design, interdisciplinary integration strategies, and students' performance in engineering design-oriented STEM courses, there remains a lack of in-depth empirical research on how teachers, in authentic classroom contexts, notice students' learning states during the engineering design process based on their educational beliefs and curriculum design thinking, and subsequently guide learning through dynamic scaffolding and questioning strategies.

Therefore, this study aims to investigate the pedagogical perspectives and practices of high school Technology teachers in engineering design-oriented STEM courses. Specifically, the study focuses on teachers' educational beliefs, the curriculum design models they adopt, and the scaffolding and questioning strategies they employ during the engineering design process as informed by their noticing of students' learning states. By doing so, this study seeks to address gaps in existing research regarding teachers' pedagogical decision-making processes and to provide empirical evidence and practical implications for the design and implementation of engineering design-oriented STEM curricula.

2 METHODS

2.1 *Research Methods and Processes*

This study adopted a qualitative research design, employing semi-structured in-depth interviews to explore the pedagogical perspectives and instructional practices of high school Technology teachers in Taiwan within engineering design-oriented STEM courses. The interview protocol, which consisted of 14 questions, was constructed based on the research objectives and relevant literature. The research focused on three dimensions: (1) teachers' educational beliefs regarding engineering design-oriented STEM instruction; (2) the curriculum design models employed by the teachers; and (3) the learning scaffolds and questioning strategies used by teachers during the engineering design process.

The interviews were conducted online in a one-on-one format, with each session lasting approximately 60-90 minutes and being audio-recorded in full. The interview process began with the interview protocol to guide teachers in recalling and describing their educational beliefs, curriculum design, and the use of scaffolding and instructional strategies, followed by probing questions to further explore their perspectives when appropriate. The interviews were conducted by the researcher or by two trained research assistants, who also assisted with verbatim transcription. To ensure research reliability and validity, with participants' consent, the research team also invited teachers to provide relevant course materials from their engineering design-oriented project courses, which were used as supplementary data for triangulation during the analysis.

2.2 *Participants*

A total of 14 high school Technology teachers from various regions in Taiwan were recruited, all of whom possessed practical experience teaching engineering design-oriented STEM project courses. The cohort included both novice and veteran educators: at the time of the interviews, five participants had five years or fewer of teaching experience, while nine were teachers with six years or more of teaching experience. Prior to the interviews, the research purpose, data usage, and confidentiality principles were explained both verbally and in writing, and informed consent was obtained from all participants.

2.3 *Data Collection and Analysis*

In the data analysis process, an initial coding framework was first established based on the research structure, encompassing three primary axes: "Educational Beliefs," "Curriculum Design Models," and "Learning Scaffolding and Questioning Strategies," followed by initial thematic coding and inductive analysis. Subsequently, focusing on the "Scaffolding and Questioning Strategies" axis, the study further examined how teachers noticed students' critical performances and interpreted their understandings and difficulties through the three dimensions of teacher noticing (attending–interpreting–responding) (Jacobs et al., 2010). This was then integrated with the framework proposed by Walsh and Sattes (2011) to investigate the types of questions employed by teachers and analyze their timing of use within engineering design projects. Finally, through iterative comparison and integration, common patterns and variations across respondents

were synthesized to address the research objectives and formulate the study's findings and conclusions.

The researcher used ChatGPT 5.1 and Gemini 3 as supportive tools for ideas soundboarding, translation, and copy editing. Qualitative data analysis was first conducted using NVivo 12 software, including initial thematic coding and inductive analysis of 14 interview transcripts. NotebookLM was subsequently used as an analytical support tool to facilitate reflective comparison, assist in confirming preliminary analytic interpretations, and surface alternative analytical perspectives. The researcher then returned to NVivo 12 to further verify, refine, and confirm the analysis. All AI-suggested content was manually verified against the raw data. All final analytical decisions, interpretations, and manuscript text were produced by the researcher.

3 FINDINGS AND DISCUSSION

3.1 *Educational Beliefs*

Analysis of the Educational Beliefs dimension reveals a clear consensus among the 14 interviewed teachers that project-based learning is an instructional approach centered on real-world problem contexts or thematic issues, in which systematic processes (e.g., the engineering design process) are enacted to address problems. This approach emphasizes interdisciplinary integration and practical application, adopts a learner-centered orientation, and values the cultivation of student autonomy.

A deeper examination of teachers' beliefs in designing engineering design-oriented STEM project courses shows that, despite differences in emphasis across phases, teachers share a common goal of cultivating students' ability to apply interdisciplinary knowledge to solve complex problems. To this end, teachers focus on guiding students to systematically enact each stage of the engineering design process, including identifying "true problems" in project tasks, gathering relevant information, and applying science, mathematics, or technology (e.g., 3D modeling) to design experiments and collect evidence for prediction, analysis, and verification. These instructional beliefs align with Taiwan's recent Technology Education Curriculum Guidelines (Ministry of Education, 2018) and closely resonate with the seven central characteristics of integrated STEM proposed by Roehrig et al. (2021).

At the same time, teachers generally provide students with meaningful autonomy, valuing their agency and engagement throughout the project process. They emphasize collaborative learning based on students' strengths, prioritize the overall learning process over final products, and encourage learning through failure and iterative refinement.

Further synthesis of teachers' views on essential engineering design competencies indicates that problem scoping and predictive analysis are regarded as particularly critical. In addition, information gathering, modeling and testing, and optimization are identified as key design competencies. Skills such as communication, project planning and execution, hands-on technical skills, and process documentation and reflection are viewed as cross-cutting competencies that support learning across the entire curriculum. These findings are consistent with the research

themes and identified aspects of engineering practices synthesized by Kidd et al. (2025) in their review of K–12 STEM education studies.

3.2 *Curriculum Design Models*

The curriculum design models adopted by the teachers can be summarized into several key characteristics. First, in overall curriculum planning, most teachers employ a phased model that begins with foundational knowledge and skill development, followed by autonomous project implementation. During the first one-third to one-half of the semester, teachers arrange small-scale learning units or practice activities to strengthen students' prerequisite knowledge and hands-on skills, laying the groundwork for subsequent project work.

During project implementation, most teachers follow the systematic steps of the engineering design process. However, due to time constraints or differences in student characteristics, some teachers emphasize particular stages. A notable pattern is that most teachers provide a semi-structured, task-specific problem context without a single correct answer, enabling students to more readily identify design requirements and constraints. This approach reduces time spent on early problem identification and shifts instructional emphasis to idea development, modeling, analysis, testing, and optimization. In contrast, a smaller number of teachers offer broader thematic prompts, focusing on guiding students to analyze problem situations and gradually define problems and constraints independently.

Furthermore, many teachers design targeted instructional units for stages such as prototyping, predictive analysis, and experimental validation. These units emphasize completing design drawings and conducting modeling or simulation with simple materials or digital tools prior to fabrication, helping students identify potential design issues and examine solution feasibility. Such practices not only cultivate the use of theory- and data-based reasoning but also foster the habit of designing before making. As emphasized by English (2016) and Roehrig et al. (2021), making explicit connections between engineering design challenges and disciplinary knowledge is both challenging and essential, and students require effective instructional support to successfully integrate these concepts.

3.3 *Learning scaffolding and questioning strategies*

Overall, the learning scaffolds and questioning strategies employed by the interviewed teachers center on supporting students in clearly noticing and defining problems and applying knowledge for analysis and problem-solving. Specifically, when guiding students through the engineering design process, most teachers use self-designed instructional aids, 3D models, or exemplars of prior student work to help students more concretely understand project goals and task requirements.

Furthermore, teachers support systematic thinking and documentation through written learning portfolios or worksheets, which prompt students to complete specific tasks at each stage of the design process. These portfolios are generally aligned with the steps of the engineering design

process but provide only a structural framework for key elements, allowing students considerable autonomy in how they represent and document their design processes.

On the other hand, during project implementation, teachers primarily guide students through questioning in one-on-one or small-group interactions. An analysis of questioning strategies and their timing, informed by the attending–interpreting–responding framework (Jacobs et al., 2010), indicates that teachers mainly monitor students’ learning states through classroom walkthroughs, attending to potential negative behavioral or emotional indicators such as confusion, ineffective group interactions, fear of failure, or passivity. At the same time, most teachers infer students’ knowledge and skill mastery by observing the quality of students’ self-initiated questions, their responses to teachers’ follow-up questions, and the testing status of prototypes. Some teachers additionally rely on progress checkpoints or milestone reviews to identify learning challenges through regular reporting.

The analysis of how teachers interpret students’ performances and difficulties in engineering design-oriented project courses can be summarized into four main dimensions: (1) insufficient practical skills; (2) limited understanding of the engineering design process; (3) difficulty adapting to open-ended problems; and (4) insufficient or weakly connected interdisciplinary knowledge. In response to these challenges, analysis of the interview data shows that teachers’ questioning strategies, ranging from foundational troubleshooting to advanced reasoning and argumentation, exhibit the following key characteristics:

First, teachers primarily utilize iterative follow-up or guided questioning to stimulate students’ thinking, rather than directly explaining problem causes or providing answers. For instance, Teacher J uses step-by-step guided questioning to help students identify why their designed linkage mechanisms fail to operate smoothly. These questioning strategies closely resemble Socratic questioning (Paul & Elder, 2007) and the “Probing Questions” proposed by Walsh and Sattes (2011), and are applied across different stages of the engineering design process. In the early stages of problem scoping and information gathering, probing questions guide students to decompose broad problems into actionable sub-problems and identify relevant information sources. During the middle stages, from solution development to modeling and testing, teachers use such questions to prompt students to identify emerging problems, anticipate potential challenges, and determine appropriate tools or directions for further inquiry, encouraging them to develop tentative solutions before consulting the teacher. Given students’ frequent difficulties in locating usable and credible references, teachers further support information gathering by providing keyword prompts, offering multiple search channels, preselecting relevant resources, and requiring students to evaluate source credibility, thereby improving the quality of collected information. These instructional approaches closely align with the teaching strategies for supporting engineering design learning identified by Crismond and Adams (2012).

Secondly, teacher questioning also emphasizes strengthening interdisciplinary connections to integrate theory and practice. For example, Teacher E guides students to apply the "Ideal Gas Law" and "projectile motion" to calculate the thrust and initial velocity of an air rocket, comparing these values with actual launch data to analyze the discrepancy between theory and practice. The questioning strategies used for this purpose align with “Inference Questions” and “Interpretation Questions” proposed by Walsh and Sattes (2011) and are commonly applied during solution

development, predictive analysis, and testing and refinement, guiding students to engage in “if-then” reasoning. In particular, predictive analysis and modeling-based testing grounded in disciplinary knowledge represent key features that distinguish high school engineering design from middle school creative design (Ministry of Education, 2018). Accordingly, these questions prompt students to justify the feasibility of design solutions using theoretical principles, design experiments and identify key variables, predict the outcomes of design decisions, and construct evidence-based arguments based on test data. Moreover, the engineering design details emphasized by teachers during this guidance process closely resonate with the epistemic features of engineering practices highlighted in Simarro and Couso’s (2021) work.

Finally, throughout the project implementation process, teachers use ongoing interactive questioning to check students’ understanding of current design steps, thereby maintaining project momentum and progress. Teachers also provide timely prompts to draw attention to potential issues before students encounter major setbacks. During the optimization and reflection stages, teachers guide students to systematically refine their designs based on test results, engage in metacognitive reflection on the overall project process, and evaluate final outcomes. This practice aligns with the concepts of “Questions to Check for Student Understanding” and “Reflective Questions” proposed by Walsh and Sattes (2011). Overall, the iterative questioning strategies observed resonate with Wells’s (2016) view of questioning as a central mechanism for eliciting students’ “need-to-know” knowledge and advancing the engineering design process, thereby supporting higher-order cognition.

4 CONCLUSION

This study examined the educational beliefs of 14 high school Technology teachers, the curriculum design models they adopt, and the scaffolding and questioning strategies they use to guide student engagement in engineering design-oriented STEM courses. The findings reveal a shared belief that systematically engaging students in the engineering design process is essential for developing their ability to apply interdisciplinary knowledge to solve complex problems. In line with this belief, teachers commonly employ a phased curriculum structure that progresses from foundational skill development to inquiry-oriented, student-driven projects, supported by learning portfolios and related scaffolding strategies. Throughout the process, teachers use diverse and interactive questioning practices—including probing, inference, and interpretation questions—to stimulate student thinking, avoid providing direct answers, and strengthen connections between interdisciplinary knowledge and practice. Building on these findings, future research may explore the integration of emerging technologies (e.g., Generative AI) or examine engineering design-oriented STEM courses and questioning strategies at other educational levels.

5 ACKNOWLEDGEMENTS

This research was supported by the National Science and Technology Council, Taiwan, under Grants MOST 110-2511-H-017-003- and NSTC 113-2410-H-017 -019 -MY2.

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“Technology is Like My Thing”: Swedish Preschool Children’s Digital Competence in Using an Infrared Camera

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Abstract

Digital technology has become a natural part of our life. Children in Swedish preschool are no exception. Digital tools are widely used in Swedish STEM education, from preschool to higher education. The Swedish preschool curriculum brings forth the technology subject as an important area and children should be given the opportunity to explore technology they encounter in everyday life. In preschool education, digital tools are primarily used as a teaching tool, but few studies have focused on young children’s ability to understand digital tools from a technology perspective. Therefore, the purpose of this study is to investigate preschool children’s ability to interpret and use the affordances of a previously unknown digital tool, an infrared camera. Two planned teaching activities with eight children, 5-6 years old, were video observed in their preschool. The results show that the digital design of the infrared camera is functional for the children. Early in the activity, they express understanding of how different colours represent different temperatures. In addition, their previous experiences with touch screens and the mobility of the infrared camera enable them to explore its affordance independently. The study identifies a three-step process in the children’s exploration: The children first explore the artefact, showing strong interest in its affordances and functionalities, engaging with it as producers of images, and deleting and navigating among images. Second, they use the camera to investigate heat as a physical phenomenon, designing their own inquiries. Finally, the digital functions spur the children’s imagination, and they involve the infrared camera in play, combining investigative and imaginative activities, such using the infrared camera as a spy camera. In conclusion, the children show considerable digital competence in relation to a previously unknown digital tool.

Key Words: Technology Education, Preschool Children, Digital Competence, Digital Tools, Infrared Camera

1 INTRODUCTION

According to the Swedish curriculum for preschool (Skolverket, 2025), education should provide each child with the conditions to develop an understanding of technological development and

innovations they encounter in everyday life. As the interest in and attitudes to technology, and technical confidence are developed among children at an early age, it is important that technology education is introduced already in preschool (Sundqvist & Nilsson, 2018). Preschool teachers consider teaching of artefacts to be an important part of technology education. However, they do not believe that they have sufficient knowledge to challenge the children in their investigation of technical artefacts, which means that the children can be left to explore the functionality of artefacts by themselves (Sundqvist & Nilsson, 2018). Knowledge of different artefacts involves interpretation of their affordances, the potential meanings and actions that people perceive when interacting with artefacts in an environment (Gibson, 1979; Norman, 2013). In particular, the notion of affordance can be used to describe how people interpret design features of an artefact (Norman, 2013). This study focuses on preschool children's encounter with a digital artefact that is previously unknown to them and designed to be used by adults, the infrared camera. The infrared camera was chosen due to the attractiveness of displaying what is warm and cold in colours and the similarity with a digital camera. While educational research on infrared cameras exists in school and university contexts, their use in preschool education has not previously been studied. The design of a digital artefact and how children interpret its affordances will influence their opportunities for independent exploration and use of it (Mantilla & Edwards, 2019). New digital artefacts in the hands of children create new opportunities, based on their interpretations, actions, creativity and fantasy (Petersen, 2015a). Against this background, the purpose of the present study is to increase knowledge about children's exploration of digital tools, and it is guided by the following research question:

How do preschool children explore the affordances of the infrared camera, an unknown digital artefact?

2 CHILDREN'S INVESTIGATION OF ARTEFACTS

Research in cognitive psychology shows that children in the age 2–4 years typically adopt a teleological perspective towards artefacts, i.e. an interest in what the objects are for and how you are supposed to use them (Asher & Kemler Nelson, 2008). In their investigation of how a novel artefact can be used, children interpret the intended function of the artefact in relation to its design. 1-3-year old children have been found to investigate objects haptically, with their sense of touch, but other factors influence, such as their previous experiences and social feedback (Rachwani et al., 2020). If the design of an artefact is adapted to the body of the child, there are larger opportunities for independent investigation. Bird and Edwards (2015) have found children to incorporate the use of digital artifacts in play. Initially, children engage in *epistemic play*, exploring the intended use of technology. When the children master the functions of the technology, the play changes character as the children add new content, imagination, and symbolic meaning. The play then turns into *ludic play*, which is characterized by fantasy play where children creatively reinterpret and transform the technology beyond its intended use. When children are given access to digital tools such as cameras or tablets, they document phenomena from their own perspectives and take on the role of producers of digital media (Magnusson, 2017; Mertala, 2016). By adapting the functionality of these tools to their own intentions during play, children demonstrate agency and creativity, thereby challenging assumptions that digital technologies constrain imagination (Kjällander & Moinian, 2014). The design and affordances of

screen-based digital tools, including mobility and shared screen use, enable children to engage in self-directed investigations with a high degree of independence and confidence (Petersen, 2015b). Similar patterns have been identified in educational studies using infrared cameras, where the screen functions as a shared object of attention that supports pupils' visual and verbal communication (Haglund et al., 2016; Jeppsson et al., 2017). In such contexts, pupils have also been shown to combine visual information from the screen with embodied exploration, using their sense of touch to confirm and refine their interpretations of thermal images.

3 AFFORDANCE

In order to analyse children's interpretations of the infrared camera and the actions they take, we have chosen to use the notion of *affordance*. The term 'affordance' was coined by Gibson (1979) in the context of his ecological approach to visual perception, referring to the potential for action that objects in the environment offer to an individual. Different individuals will experience different affordances of an object. Whereas an adult can perceive a table as a flat surface where things can be placed, it may serve as a tunnel to crawl under for a child. When children are introduced to new digital tools, affordances and children's abilities are revealed (Gibson, 1979). Norman (2013) argues that a well-designed artefact guides the user to appropriate action in the appropriate context at the appropriate time. Norman also considers the users' prior experiences and knowledge in their interpretation of the affordances of a previously unknown object. C. R. Samuelsson (2023) has identified three affordances of the use of infrared cameras: the colour scale, the numerals on the screen and the physical design of the handheld infrared camera.

4 METHODS

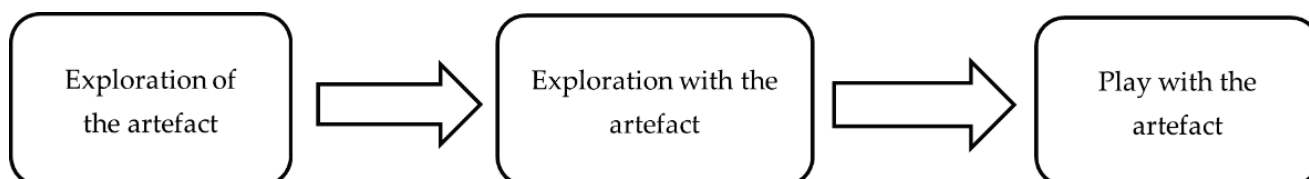
The study can be characterized as an example of design-based research (Barab & Squire, 2004), in which we designed, conducted, and analysed an activity in the preschool. The infrared camera was chosen as an example of an unknown digital tool based on our previous experience of using infrared cameras in primary education and educational research. The study was conducted at a preschool in Sweden where they have long experience of working actively with children's exploration with digital tools. Data was collected on two occasions with eight ($N = 8$) 5-6-year-old children. It is important to note that the children had not used an infrared camera before, which added an element of novelty to their exploration. This study gathered data through video and audio recordings of children's interactions with an exploratory activity, along with still images taken by the children using infrared cameras. The material was reviewed repeatedly and initially coded with a focus on the children's exploration of and with the infrared cameras, as well as their expressions of agency. Based on this coding, analytically significant episodes were identified and selected (Derry et al., 2010). These episodes were analysed using the concept of affordances (Gibson, 1979; Norman, 2013) and Petersen's (2015a) framework of children's agency, with an emphasis on initiative and creativity within social practices. AI was used solely as a supportive tool for translation and language editing.

5 RESULTS

The children's process of exploration was based on their interest and curiosity. The children themselves drove the exploration of and with the infrared camera, along the lines of the process shown in Figure 1.

Figure 1

The children's process of exploration



In the beginning of the activity, the children focused on exploration of the artefact, as shown in the box to the left. Here the children explored the functionality of the infrared camera, including interpreting the colours and icons on the screen, and the physical button to take still images. When the children mastered the functions of the infrared camera, their attention gradually moved to exploration with the artefact, the middle box. During this phase, they used the infrared camera to explore the phenomenon of heat. By the end of the activity, aspects of play with the artefact became more prominent, as indicated by the box to the right. During play, the children kept the main function of the infrared camera, i.e., visualizing how warm or cold different objects are, but in an increasingly creative and imaginative way. Selected episodes focus on the children's exploration of the artefact, and children's play with the artefact, the first and the last boxes in Figure 1.

5.1 *The children take an interest in the colours of the infrared camera*

When the children are introduced to the infrared camera, no information is given about its function. During the first occasion the four children, Calle, Line, Iris, and Vivi, sit around the table in the atelier and Vivi shows excitement about the activity, and expresses her interest and confidence in, as well as identification with technology: *Technology is kind of my thing!*

There is an infrared camera on the table. It is switched on and Iris picks it up. She wiggles it a bit and raises it up to the level of her eyes. She points it to Author 2. In a loud voice, Iris says: *This was strange... look!*

Iris: I can see you, but you are in a different color. [she laughs]

Author 2: What!?

Iris: Well, that's what you are. [she laughs again]

[Line steps down from the table and gets seated between Iris and Calle]

Line: Can I see?

Author 2: Am I in another color?

Iris: Yes.

[Vivi joins in and is impressed by what she sees on the screen]

Vivi: Wow, damn! That's cool!

[Line turns to Author 2]

Line: Yes, but you are warm, and I think the yellow shows that you are cold, and the red is maybe warm. [she puts her hand on her chest]

In this dialogue, when Line picks up the infrared camera, the screen immediately catches the children's interest, and already in the beginning of the activity they interpret what the colours mean.

5.2 *The children explore the physical design of the artefact*

Next, the children focus on the function of the infrared camera. They do not ask how it can be used. They explore the camera haptically by themselves. Vivi compares the infrared camera to a mobile phone, and points out similarities and differences to Author 3:

Vivi: A tele... a telephone, this is like a telephone, but the screen is on the side, and it is... it is a bit smaller... That is the difference between an infrared camera and... [Vivi shows the size of the infrared camera with her hands, and that its screen is held horizontally]

Author 3: It has the same shape as a mobile phone.

Vivi: But it is a bit smaller, and the screen is a bit smaller, and the screen is a bit...

Many of the affordances of the infrared camera that the children attend to are shared with mobile phones and tablets. Shared affordances include that they are handheld, relatively light, and portable. The possibility to take still images turns out to be central in the children's investigations.

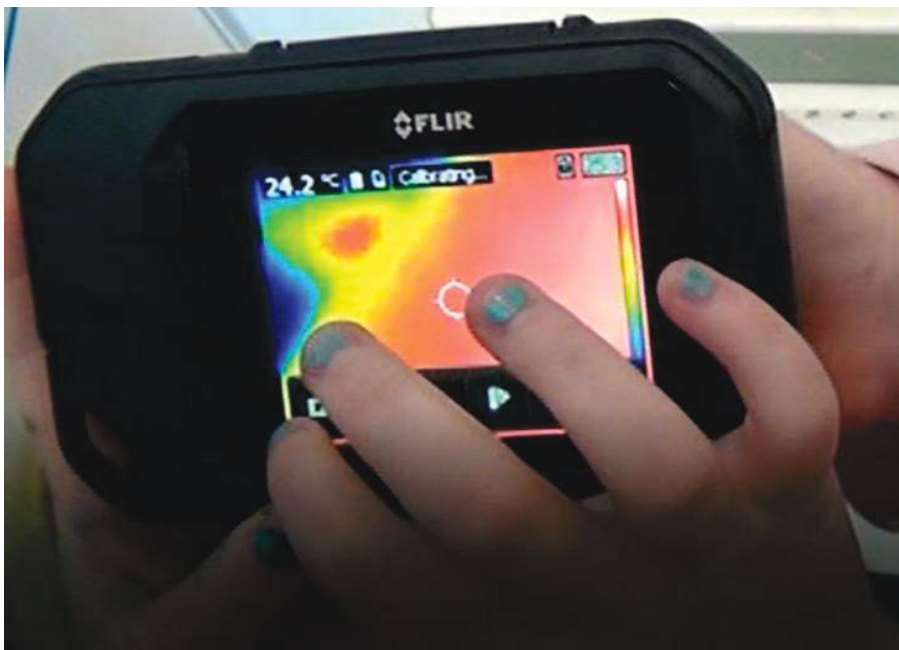
The affordance to take still images is exploited by the children in order to document what they see in real time, but also to share it with each other. The size and form of the infrared camera make it a bit unwieldy for the children. Taking still images requires a certain grasp of the infrared camera and some force to press the button, which is difficult for the children.

5.3 *The children explore the digital design of the artefact*

The children's understanding of the function of the touchscreen and the icons of the digital interface enables them to explore the functionality of the digital tool (see Figure 2). They are well acquainted with the structure of the icons from their previous experiences with other digital tools. They perceive many different affordances, for example when Iris ponders on which colour palette to choose, or when Line navigates between IR images, images in visible light, and the gallery view of many small images. The children also figure out how to delete images, a function that they often use.

Figure 2

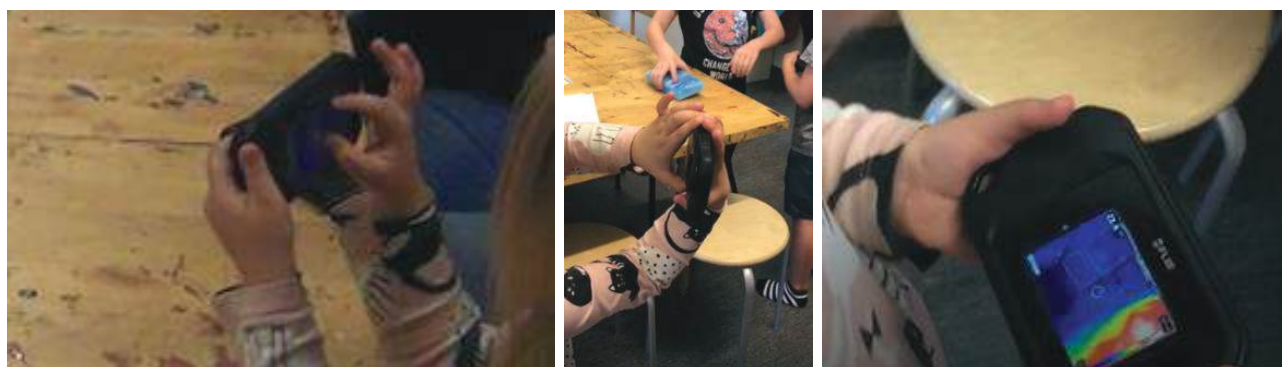
Two of the children explore the icons on the touchscreen of the infrared camera



Based on their experiences of other digital tools, the children also search for additional functionality of the infrared camera. During the second occasion of data collection, Maggie wishes to be able to zoom in on the screen (see Figure 3, left). Later, Maggie wishes to take a “selfie”. After having realized that it is not possible to set the infrared camera in selfie mode, she turns the lens towards herself as a workaround (see Figure 3, middle and right).

Figure 3

Maggie tries to zoom in on the touchscreen (left), Maggie finds a workaround to take a selfie (middle), the selfie only shows parts of Maggie's face (right)



5.4 *The children act as explorers and as producers of digital media*

The children's movement with the infrared camera in the room is a clear example of their expression of agency. The infrared camera's affordance of mobility and ease of use, combined with the children's creativity and imagination enables a dynamic exploration. In their exploration of how to use the infrared camera, the children often assumed the role as producers of aesthetically pleasing images. During the first occasion, the children organized their investigation by teaming up in pairs with one infrared camera per pair. One of the children took still images with the infrared camera, and the other child was often the motif, and took part in deciding what to document. The children posed, made funny faces, and arranged colourful and "cool" images (Figure 4). The still images generated discussion about what the colours represented, where the images served as a shared object of attention.

Figure 4

An example of a "rainbowy" infrared image of one of the children making a funny face in front of the infrared camera

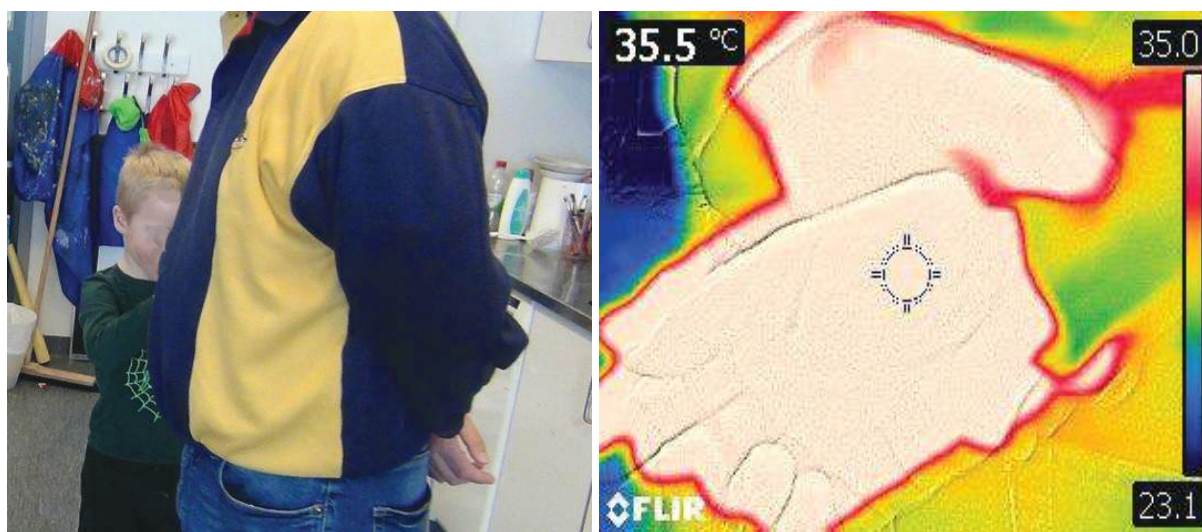


5.5 The children engage in play

As the children's investigations progressed, their interest, creativity, joyfulness, and agency were increasingly channelled into imaginative play, which altered the context in which the infrared camera was used. In some situations, the focus was no longer on investigating thermal phenomena; instead, the camera was reinterpreted within playful narratives. One example is when Calle used the infrared camera as a spy camera by secretly taking images of an adult's hands behind his back, a situation characterized by suspense and role-taking (Figure 5). Similarly, the children's exploration shifted from searching for hidden ice creams to imaginative play when a cold, ice-cream-shaped area remained visible on the floor through the infrared cameras when an ice cream had been removed. The discrepancy between visual representations prompted collective action and playful interpretations, culminating in Maggie's suggestion that the invisible object might be a "monster ice cream." These examples illustrate how the children appropriated the infrared camera as a resource for imaginative meaning-making, where the exploration of physical phenomena and ludic play became intertwined through their creative use of the technology.

Figure 5

Calle using the infrared camera as a spy camera (left), Calle's infrared image of Author 3's hands, as he snuck up behind his back (right)



6 CONCLUSIONS

This study sets out to increase knowledge about children's exploration of digital tools in preschool contexts, with particular attention to children's perspectives, agency, and the affordances of digital technology. The findings demonstrate that children are capable of meaningfully engaging with unfamiliar, authentic digital tools and appropriating them in ways that support both exploratory and imaginative activity. Through their interaction with the infrared camera, the children actively took initiative, navigated challenges, and shaped the direction of their own exploration by creating physical phenomena and digital media. The results indicate that introducing digital tools originally designed for adult use may be productive in preschool technology education, provided that the tools' affordances are accessible to children's physical

and cognitive abilities. In this study, the children quickly grasped the core function of the infrared camera (Norman, 2013) and developed an understanding of its purpose in terms of what it enabled them to see and do. Their exploration was characterized by a teleological orientation, as the children primarily focused on the camera's functions and potential applications rather than on its technical construction, which aligns with previous research on children's reasoning about unfamiliar artefacts (Asher & Kemler Nelson, 2008; Rachwani et al., 2020). The accessibility of the infrared camera was further supported by its touchscreen interface and familiar visual icons, which drew on the children's prior experiences with other digital tools. This reinforces the importance of previous digital experiences in shaping how affordances of unfamiliar artefacts are perceived and acted upon (Norman, 2013). Consistent with earlier studies, the children interpreted the color spectrum as representations of heat and cold, while numerical temperature values remained largely unattended (Kjällander & Moinian, 2014; Petersen, 2015b). Despite these limitations, the children demonstrated persistence and agency by overcoming practical challenges, such as stabilizing the camera, avoiding obstructing the screen, and developing strategies for capturing still images and selfies. Capturing still images played a central role in sustaining the children's engagement and supporting shared meaning-making, which contrasts with previous studies in primary school (Haglund et al., 2016). The images functioned as shared points of reference that facilitated collaboration, discussion, and reflection among the children. Similar to primary school pupils, the children used their sense of touch to confirm their interpretations of what appeared on the screen (Haglund et al., 2016; Jeppsson et al., 2017). By staging investigations themselves and deciding what to document and how to use the images, the children positioned themselves as active producers of both phenomena and digital content rather than passive users. This producer role enabled the children to take ownership of both the exploration and the technology, using it as a resource for expressing ideas, testing hypotheses, and communicating meaning, in line with previous research on children's digital production (Kjällander & Moinian, 2014; Magnusson, 2017; Mertala, 2016; Petersen, 2015b). Over time, the children's engagement with the infrared camera shifted from an initial investigative phase toward increasingly creative and imaginative forms of play. The camera was not only used as a tool for exploring temperature differences but was also reinterpreted within playful narratives, such as in Maggie's "monster ice cream" or Calle's use of the camera as a spy device. This progression illustrates how epistemic and ludic play can coexist and intertwine when children are given opportunities to explore digital tools on their own terms (Bird & Edwards, 2015).

Overall, the findings underscore the importance of considering digital tools not merely as instructional resources, but as materials that children can appropriate, transform, and use creatively. The affordances of the infrared camera supported children's agency by enabling them to act as confident explorers and producers who actively shaped both the tool and the activity. These results suggest that encounters with novel digital technologies in preschool settings can foster sustained engagement, collaborative meaning-making, and diverse forms of play and learning

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Where's the Beef? A Systematic Literature Review of the Relationship Between Technology Education and Student Achievement

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Abstract

Historically, technology education has struggled to assert and maintain its place in the general education curriculum of modern educational jurisdictions. From a Newfoundland and Labrador, Canada perspective the most recent issue has centred on a proposed restructuring of mandatory intermediate (students aged 12-15) technology education modules within the jurisdiction's K-12 curricula. Therefore, the purpose of this study was to develop an accurate account of any empirically supported relationships between K-12 student academic achievement and technology education to potentially assist curriculum decision makers moving forward. The study was positioned within the qualitative research paradigm using a descriptive systematic literature review methodology -in particular a scoping review method (Xiao and Watson, 2019). The study's research question was: What is the relationship between K-12 technology education curricula and student academic achievement? Preliminary analysis of the findings suggests that there are tangible benefits associated with K-12 students being enrolled in technology education curricula that cut across multiple subject areas and knowledge/skill domains. Significant research gaps and reproducibility issues have also been identified which present opportunities for further inquiry and research in this area.

Key Words: Technology Education, Academic Achievement, Systematic Literature Review

1 INTRODUCTION

Historically, technology education has struggled to assert and maintain its place in the general education curriculum of modern educational jurisdictions (Gill, 2023). This issue has fluctuated as ministries of education have undertaken various curricular reforms (Atkinson, 2023; Buckley, 2023; Strimel, 2023; Tuff & Gill, 2023; Xu et al., 2023). From a Newfoundland and Labrador, Canada perspective the most recent issue has centred on a proposed restructuring of mandatory intermediate (students aged 12-15) technology education modules within the jurisdiction's K-12

curricula (Hood, 2025; *Proposed Changes to Intermediate Program of Studies - Professional Learning NL*, n.d.).

Because technology education has been misinterpreted by outside actors in positions to influence curriculum reform, practitioners and researchers of technology education must continually define and defend its place in schools. One common defence is the idea that technology education is linked to positive student achievement within its domain and in cross-curricular subjects. While some literature reviews and meta-analyses exist on the effect of tangential curricular areas such as STEM, STEAM, and Engineering on student achievement (Belland et al., 2017; Ilma et al., 2023; Jeong et al., 2023; Khotimah et al., 2021; Monsang & Srikoon, 2021; Nhat et al., 2024) they do not precisely align with technology education as they tend to focus on science education with aspects of problem-based learning and/or deal with broader areas of achievement such as developing creativity. While technology education does deal with such topics these studies are not explicitly focused on technology education as defined in our study.

Educational policy makers and funding agencies typically value scientific empirical studies and quantitative data more than seemingly less rigorous methods (Torrance, 2008). While there are strong arguments for valuing a wider variety of research in supporting policy development (Kerrigan & Johnson, 2019; Natow, 2022; Parra Saiani, 2018; Torrance, 2008), if there is a corpus of scientific and empirical studies that position technology education as having positive effects on student achievement it will most likely be influential in maintaining and enhancing technology education.

Considering the context above, the purpose of this study was to explore any relationships between K-12 students' academic achievement and their participation in technology education. While we had no a priori assertion about the relationship, it was our goal to produce a systematic literature review that accurately described the current conceptual boundaries, methodologies, and research gaps. We hope that this endeavour may also influence curriculum decision makers across educational jurisdictions about the importance of technology education.

While there have been systematic literature reviews that partially align with our study's design, we were unable to find any reviews that fully articulate the boundaries and limits of the relationship between technology education and student achievement in the K-12 context. Therefore, we have positioned our study to address this gap in the technology education research literature.

2 CONTEXT AND CURRENT RESEARCH

Technology education is still a misunderstood curriculum area. With this misunderstanding comes confusion about both its implementation at the K-12 school level and within its research communities (Gill, 2018, 2024; Williams, 2011; Williams, 2016). Therefore, we decided to bound the literature review to a specific definition of technology education which would account for the wide breadth of international nomenclature and implementations. Similarly, we bound our definition of student achievement to quantitative cognitive and performance based outcomes.

2.1 2.1 Definitions of Technology Education

The foundational definition was taken from de Vries (2009) statement that technology education is "...the learning area that deals with the ways in which human beings change their environments to be better suited to their needs and wants, thereby using various types of knowledge" (p. 1). From this proposition and the purpose of the study we narrowed our literature review to only include empirical research that implemented activities that had characteristics of signature pedagogies associated with technology education (McLain, 2022, 2023). Specifically, the focus of the research studies had to conform with activities that included technical problem solving within a framework of ideation, design, make, and evaluate where the solutions to the purposeful technical problems were on a continuum of closed to open ended. Purposeful, in that students were challenged with designing a technical solution within context, rather than learning a finite skill or only acquiring propositional knowledge. This definition aligns with McLain's (2021, 2022) discussion of ideating, realising and critiquing on a pedagogical restrictive-expansive continuum.

2.2 2.2 Definitions of Student Achievement

While there are many definitions of student achievement, for the purpose of this study we will define student achievement as: the accomplishment of a learning goal within the context of the cognitive (concepts and skills) and/or psychomotor (performances and demonstration of skills) domains of learning (Guskey, 2013). Guskey (2013) also defined an affective learning domain rooted in subjective attitudes, interests, feelings, beliefs, and dispositions. As we have already established that educational policy makers prefer objective metrics, studies that exclusively report on the affective domain were excluded from our review.

2.3 2.3 Existing Literature Reviews

Through the review process we identified four previous literature reviews/meta-analysis that partially aligned with the scope of our study. The identified reviews spanned 1991 to 2020 and focused on educational instances that aligned with our definitions of technology education and student achievement. While the nomenclature varied (Engineering Design, Technology Education, Technology and Engineering Education, and Design & Technology) for each review, the core operational concepts were partially aligned with each other and this study. Analysing the methods and findings of these previous reviews allowed us to position our study within the context of existing literature and verify that it did address a research gap.

Wilson and Harris (2004) conducted a qualitative literature review focusing on the impact of Design and Technology (D&T) on schooling (K-12 equivalent), its unique educational components, and gaps in the research. The study analysed data from 1991 to 2003. While not explicitly focused on student achievement, some of their findings support the idea that Design and Technology can have a positive impact on achievement. While acknowledging not enough empirical evidence was available to prove a positive relationship, achievement levels in Design and Technology were nevertheless increasing compared to other subjects.

Ehsan et al. (2023) conducted a literature review on the relationship between engineering design and elementary (5-10 years old) student achievement. They found strong learning gains in disciplinary knowledge of math and science and improvements in engineering thinking skills, such as spatial reasoning, mechanistic reasoning, and computational thinking.

Delen and Sen's (2023) curricular sample was wide ranging, but most heavily focused on science and math. Different from the other studies noted here, the authors used the engineering design process as an overlay on other discrete subjects -a co-curricular approach. They reported significant gains in student achievement when design-based lessons were used.

Pappa et al. (2024) looked at the definition of primary technology education. They followed the PRISMA checklist for systematic reviews and only included high quality empirical studies. From their sample of 33 studies, they discovered that technology education continues to be conflated with computer science or informatics and lacks the prestige of science and math in STEM. While not the focus of their study, they did note that when technology education is implemented there are student learning gains.

While the systematic literature reviews/meta-analysis discussed above generally align with our definitions of technology education and student achievement none of them has the same purpose or scope. Pappa et al. (2024) and Wilson and Harris' (2004) reviews dealt directly with technology education as a discrete subject area whereas Delen and Sen (2023) and Ehsan et al., (2023) reviews contextualized design and engineering processes as curricular supports for other subject areas. As for schooling, two studies looked at the entire K-12 context whereas the others focused on primary/elementary age students. Only one of the reviews looked at student achievement in a holistic way within the K-12 context -Delen and Sen's (2023) meta-analysis.

While the literature reviews above touch on some parts of our study's design, we were unable to find any reviews that explicitly articulate the boundaries and limits of the relationship between technology education and student achievement in the K-12 context. It is from this context that we position our study to address this gap in technology education research.

3 METHODOLOGY

Literature reviews are foundational elements of scholarly inquiry. Without a solid understanding of the context, findings, and history of a phenomenon researchers would be "running blind". There are many methodological frameworks that should be considered before starting a literature review. Xiao and Watson (2019) described many systematic literature view methodologies across the continuum of research paradigms -from constructivist to positivist. By evaluating the methodologies described by Xiao and Watson (2019) in conjunction with the purpose of our study we selected a scoping review as our methodological framework.

3.1 *Scoping Review Rationale*

Many systematic literature review methodologies are positivistic - they have well defined and narrow research questions and answers based on similar methods and metrics e.g. meta-analysis

(Arksey & O'Malley, 2005; Peters et al., 2021; Xiao & Watson, 2019). These types of reviews would be useful if a large comprehensive body of research that used similar methods and metrics regarding technology education's relationship with student achievement existed. Since such a body of research is nascent, we needed a flexible, exploratory, and rigorous methodology to map our area of interest. Arksey and O'Malley (2005); Peters et al. (2021); and Xiao and Watson (2019) all noted that the purpose of a scoping review is to provide a broad and comprehensive overview of the conceptual boundaries, methodologies, and gaps relating to a specified scholarly area. Furthermore, a scoping review considers all available data sources. While a traditional meta-analysis would discard qualitative studies and studies that had low effect sizes or poor research methods, in general a scoping review would consider all sources as potentially valuable for describing and defining the extent of the research area (Arksey & O'Malley, 2005; Peters et al., 2021; Xiao & Watson, 2019). Since the purpose of our study was to explore and describe the extent to which technology education and student achievement may be related, a scoping review was justified as our methodology.

While scoping methodological frameworks are continuing to evolve (Peters et al., 2021) the original process outlined by Arksey and O'Malley (2005) is still valid and useful. By combining the original process with elements of the *Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for scoping reviews* (PRISMA-ScR) check list (Tricco et al., 2018) we were able to create custom methods to focus and organize our scoping review on technology education and student achievement.

3.2 Data Sources and Analysis

This scoping review followed Arksey and O'Malley's (2005) framework and used elements of the PRISMA-ScR checklist to strengthen the reliability and validity of our method. Arksey and O'Malley (2005) introduced one of the earliest and most widely cited methodological frameworks for conducting scoping reviews. Their framework consists of five core stages: 1. Identifying the research question(s); 2. Identifying the relevant studies; 3. Study selection; 4. Charting the data; 5. Collating, summarizing, and reporting the data.

3.2.1 Identifying the research question(s)

The guiding research question was: What is the relationship between K–12 technology education curricula and student academic achievement?

3.2.2 Identifying the relevant studies

Eligibility criteria were specified a priori and aligned with PRISMA-ScR recommendations to clarify scope and operationalize study selection (Tricco et al., 2018). Round 01 (initial eligibility) required that studies (a) involve any student population (e.g., gifted, students with disabilities, or general education); (b) employ empirical or review designs addressing technology education, STEM/STEAM integration, career and technical education, or similar curricular areas within K-12 contexts; and (c) be English-language, peer-reviewed sources. Studies were excluded if they (a) focused on teacher perceptions, in-service training, or professional development; (b) reported

student perceptions or attitudes about technology or engineering without measurable academic or skill-based outcomes; (c) were non-scholarly materials (e.g., editorials, news items, promotional content); or (d) were limited to higher-education contexts or lacked sufficient methodological detail for appraisal. Round 02 (full-text refinement) further required that included studies (i) examine an educational intervention or activity that is explicitly aligned with our definition of technology education; and (ii) report student achievement using concrete, explicit benchmarks (e.g., standardized test scores, rubric-based performance, credential attainment, third party observations, or objective skill demonstrations). For Round 02, meta-analyses were excluded from the analytic dataset (while retained for contextual discussion and interpretation), ensuring that the final corpus comprised primary empirical evidence or reviews suitable for synthesis in relation to the research question. These staged criteria operationalized the population, context, intervention focus, and outcome standards central to the review and supported transparent, replicable study selection consistent with PRISMA-ScR.

3.2.3 Study selection

Following PRISMA-ScR guidance, we used a structured, multi-source strategy to identify, screen, and consolidate relevant literature. Searches were conducted in SCOPUS and Google Scholar, complemented by searches of key field journals to enhance coverage beyond database indexing. Because bibliographic databases differ in coverage and historical depth, we paired Scopus with Google Scholar to enhance retrieval breadth. A comprehensive keyword string was constructed using TITLE-ABS-KEY fields and included terminology related to technology education, K–12 schooling, and multiple synonyms for academic achievement and learning outcomes (Gill & Jamil, 2025). Because terminological variation posed a risk of excluding relevant studies, ChatGPT 4.0 was used to help generate the final search string format with an expanded list of synonyms for technology education, K–12 education, and student achievement descriptors.

In SCOPUS, an initial rough search in October 2025 retrieved approximately 3,839 records; iterative refinement expanded this to 3,898, from which 572 records were retained after application of predefined eligibility criteria (Round 01). The Google Scholar query returned ~1,890,000 results; given the breadth and relevance-ranking of this platform, we systematically screened the first five pages using predefined search strings aligned with our SCOPUS search string which yielding 181 records for preliminary review (Round 01). All records were exported to spreadsheets for data management. Within-source checks removed 2 duplicate titles from the Google Scholar set (181 → 179) and 3 from the SCOPUS set (572 → 569). Cross-source reconciliation identified 6 overlaps between SCOPUS and Google Scholar. After removing cross-source duplicates, the final dataset comprised 742 unique records ($569 + 179 - 6 = 742$).

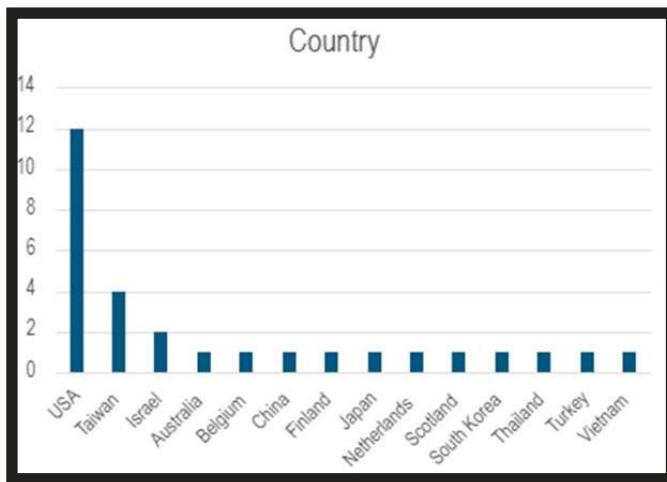
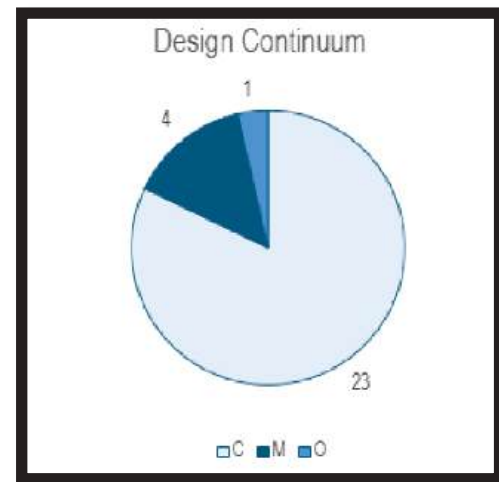
To further mitigate retrieval bias, we searched the following journals and screened newly identified items, if found, alongside database records: *Design and Technology Education: An International Journal (DTEIJ)*; *International Journal of Technology and Design Education*; *Journal of Technology Education*; *Journal of Industrial Teacher Education*; *The Technology Teacher*; and *The Australasian Journal of Technology Education*. These were selected due to their international prominence and researcher 1's familiarity as guest editor, contributor, and reviewer for several of the selected journals. It should be noted that all but *The Australasian Journal of Technology Education* were found in SCOPUS and/or Google Scholar therefore

minimizing manual searches. A manual search of this journal returned no criteria matching articles. This multi-step process ensured breadth of coverage, minimized redundancy, and produced a robust corpus for subsequent screening and analysis (Tricco et al., 2018).

Next, the 742 records identified were split in half between the two researchers for further investigation. Due to conference submission time constraints, it was decided to complete a preliminary analysis by reviewing the first 100 available full-text items from both SCOPUS and Google Scholar. This was conducted with a rapid relevance appraisal using NotebookLM -a generative AI tool. To promote consistency across reviewers and platforms, a standardized screening prompt was developed and used by both researchers to apply the Round 01 and Round 02 criteria during this phase (Gill & Jamil, 2025). Prior to beginning the full screening, Researcher 1 and 2 met and reviewed their first 10 articles together to ensure they were interpreting the output of the NotebookLM screening prompt in the same way. Researcher 1 then screened the remaining 90 available full-text SCOPUS items using NotebookLM to generate rapid summaries. NotebookLM summaries indicated 39 items met the eligibility criteria. A subsequent manual review of these 39 items against the full Round 01/02 criteria confirmed 25 studies as meeting the inclusion criteria. Researcher 2 screened the remaining 90 Google Scholar results using the standardized NotebookLM screening prompt. This process identified 16 items. Researcher 1 cross-checked by repeating the manual verification on the 16 items; 3 met the Round 01/02 criteria. Preliminary included items from the first 200 screened full texts: $25 + 3 = 28$ studies. A complete list of the studies can be found in our dataset (Gill & Jamil, 2025).

3.2.4 *Charting the data*

The first NotebookLM prompt was modified with greater detail to get more information and understand the results better (Gill & Jamil, 2025). The results of this prompt on the 28 identified studies revealed thematic clustering around K–12 design-oriented STEM interventions featuring robotics, engineering design challenges, CAD simulations, augmented reality, Micro:bit activities, 3D printing projects, energy-efficient housing, systems design, and wearable electronics that emphasized hands-on problem solving. Curricula are typically national or locally aligned to national standards and span integrated STEM, science/engineering, technology education, and craft/design & technology. Study interventions were implemented across regular class time, after-school/summer programs, and short camps. As figure 1 illustrates the work spans a wide international range (e.g., USA, Taiwan, Japan, China, Australia, Turkey, Vietnam, Israel, Thailand, the Netherlands, Scotland, South Korea, Belgium, Finland).

Figure 1*Country distribution***Figure 2***Design distribution*

For the design continuum (figure 2), we used the following definitions drawn from the figure's legend: Closed (C)—students know the final artifact (e.g., house, ROV, product commercial), and design is internal to that artifact (self-contained); Middle (M)—students encounter a combination of closed and open design elements/challenges (First Lego League Robotics challenges); Open (O)—students do not know the final artifact because the focus is an open-ended thematic problem with no predefined outcome (e.g., transportation or green-initiative themes). Most interventions are coded on the “Closed” end of the design continuum—where the final artifact is known—though several “Middle” and one “Open” design example appear, indicating some variation in problem framing, pedagogical approach, and outcome specificity.

As illustrated by figure 3 selected studies covered students from primary/elementary through secondary/vocational levels. Figure 4 outlines the distribution of curricular nomenclature of each study and there are multiple areas that teach technical design processes as this study defines technology education. Methodologies (table 1) were predominantly mixed or quantitative (with experimental and quasi-experimental designs common), complemented by qualitative case studies. A detailed table of methods and main findings can be found in our dataset (Gill & Jamil, 2025).

Figure 3

Education level distribution

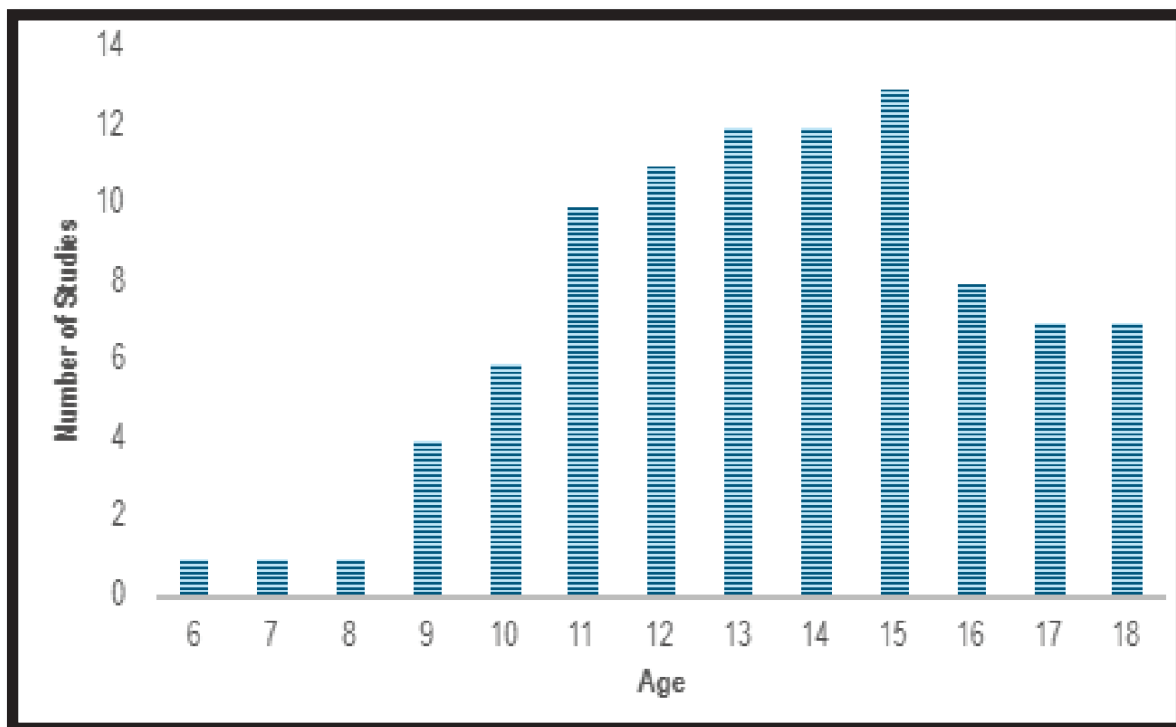


Figure 4

Curricular distribution

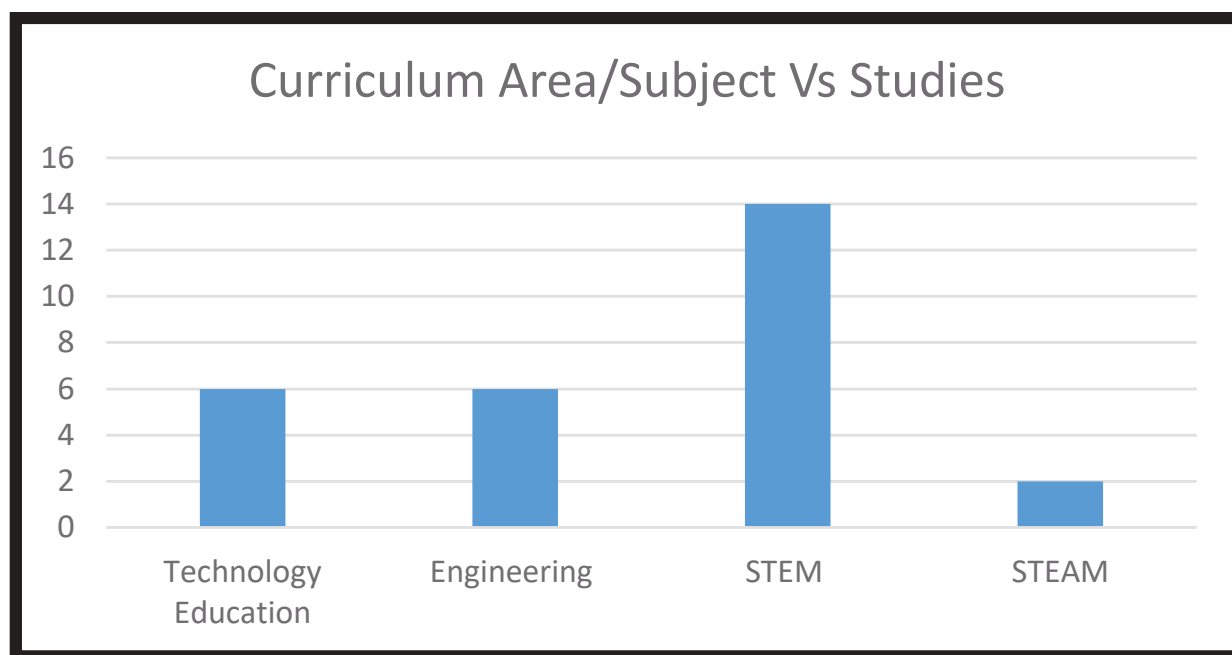


Table 1*Methodological Distribution*

Method/Data type		Subjective (perceptions)	Objective (verified)	Both
Quantitative	9	4*	2	3
Mixed-Methods	16	2*		14
Qualitative	3	1		2
Totals	28	7	2	19

* included studies that applied statistical measures to subjective data

4 FINDINGS AND DISCUSSION

As Arksey and O'Malley's (2005) fifth step is “*collating, summarizing, and reporting the data*” we will dedicate the findings and discussion section to this task. Peterson et al. (2017) iterated that the outcome of a scoping review is typically a narrative presentation that focuses on the overarching themes and the extent to which the subject in question is understood rather than a statistical analysis. The purpose of this scoping review was to explore any relationships between K-12 students' academic achievement and their participation in technology education.

Knowing that one potential audience would be policy makers that have a bias towards empirical data we did confine our search to studies that dealt with the cognitive and psychomotor domains of learning and excluded studies that exclusively dealt with the affective domain (perceptions and attitudes). Otherwise, we were inclusive of any research methodology and because of the disjointed implementation of technology education we cast a wide net within the sphere of operationalized curricula as per our definition. Without doing such, our review would have yielded a very small sample.

Before moving to the narrative description, it is important to again emphasize that this analysis is based on a subset of the available articles. The 28 articles were selected based on the criteria after reviewing the first 200 eligible studies. This description may change when the final sample is identified and analysed as there may be inherent bias in the rankings of the databases. Nevertheless, what follows is a narrative description of the available sources of information currently on the relationship between students' academic achievement through their participation in technology education.

First, reviewing table 1 and for quick reference [sa-te-Extracted-Data.html](#) in our dataset (Gill & Jamil, 2025), there appears to be a propensity of quantifiable data for addressing questions of student achievement as mixed-methods and quantitative research designs dominated the sample. That being said, all included studies rely in part on both quantitative and qualitative data

regardless of how they were positioned methodologically. There is a fluidity of methods as four of the quantitative and qualitative studies include statistical analysis of perception-based data - which means they can only quantify and verify perceptions, not results. When we dig a little deeper, while all studies fall within our broad definition of student achievement and technology education they all define both in their own unique ways. Regardless of this fluidity the self-categorization of the studies in table 1 are a useful analytical framework, therefore we will next describe the main points of each category in turn.

The qualitative studies used various research, data collection, and data analysis methods such as design-based research, case studies, and iterative research designs. Data was collected using interviews, observations, and evaluations on changes in student quality of work. Analysis was varied as well with Delphi rankings of student projects, some statistical methods, and the triangulation of data sources. Regardless, most of these studies relied heavily on participants perceptions of learning gains and/or achievement. There was also no replication of findings because all three studies looked at different variables. Findings indicated increases in tacit and procedural knowledge, gains in building, testing, optimizing technical solutions, and greater creative and experimental skills. Otherwise, there were multiple findings within the affective domain that did not meet our definition of student achievement.

Quantitative studies typically fell within quasi-experimental, experimental or quantitative case study methodologies and applied well known statistical analysis (t-tests, ANOV, McNemar's tests for quantitative changes in perceptions as examples) and standardized pre/post test instruments or in some cases looked for statistical trends in self-reported data. While it is not within the scope of our study to comment on the quality of the statistical analysis, we can say that there was no standardized measure of student achievement. These studies found learning gains in cross-curricular knowledge (math, science, etc.), increased skill development in CAD and physical prototyping. Some affective variables were tested as well, such as student gains in technical identity, confidence, and interest.

The most reported research methodologies were mixed methods. Referring to our dataset (Gill & Jamil, 2025) all the reported data collection and analysis methods that have been used in the qualitative and quantitative studies have been repeated here with some additions, such as video annotations, Factor Score Regression (FSR) for quantitative outcomes, and Latent Profile Analysis (LPA) to name a few. While this category also did not have any standardization of student achievement, they did have the added layer of being able to add depth to their findings by trying to answer both what (quantitative) and why (qualitative) questions.

As for the findings there is evidence that technology education within the scope of this paper's definition can have a positive effect on student achievement in multiple areas associated with the cognitive, psychomotor, and the affective learning domains. The 28 studies report gains in technical skills, spatial skills and reasoning in the context of CAD, organizational and managerial skills, technical verbalization, tacit and procedural knowledge, programming and mechatronics, electronics, and production and prototyping skills, and increased sophistication in students' understanding and application of design processes to solve technical problems. From a curriculum perspectives cognitive learning gains were reported in all the STEM subjects while also benefiting

students from lower socioeconomic backgrounds and raising the participation and confidence of girls.

5 CONCLUSION

Based on the findings we think it is a safe assumption to say that technology education that includes technical design problems requiring ideation, designing, making, and evaluating of technical solutions can have a positive effect on student achievement. Furthermore, the previous findings of existing literature reviews and meta-analysis can be confirmed and expanded to the entire K-12 context. With that being said, some issues were also identified. While this scoping review has illustrated a great breath, there is no standardization or reproducibility present at this point. To strengthen the case for the subject, developing standardized metrics for discipline specific achievement and methodology to reproduce findings would help legitimize the benefits of technology education in general education. As noted above and in figures 1 and 4 these studies are also pulled from different iterations of curricula that have varying levels of social and political capital depending on their local contexts. Social and political capital are essential elements in the perennial issues of what is technology education? Who teaches it? How is it taught? What is taught? Who are the students? What do they learn? And most importantly, should technology education be its own discrete subject? From our view this fragmentation of technology education across so many diverse curricular categories only compounds the issue of a perceived lack of importance that continues to hinder its implementation in general education. It is our hope that this study and potential future studies can raise technology education's social and political capital in the pursuit of cementing its place in general K-12 education.

6 ARTIFICIAL INTELLIGENCE (AI) DISCLOSURE

Generative AI (ChatGPT 4.0 and NotebookLM) were only used as described in the methodology section of the paper. Specifically, ChatGPT 4.0 was used to help create a list of synonymous for technology education, student achievement, and K-12 education and to help construct/validate a SCOPUS search string. NotebookLM was used to create factual rapid article summaries and in-depth article summaries for the purpose of the authors' analysis. Generative AI was not used in any part of the writing of the article text or in analysing the data.

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Gender and Diversity Awareness Among STEAM Teachers: Perspectives for Gender- and Diversity-Sensitive Technical Education

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Abstract

Technology education faces the challenge of appealing equally to all learners, regardless of gender and background, and empowering them to actively participate in a technology-driven world. Raising awareness among teachers about gender and diversity issues plays a key role in this. The article focuses on gender equality in creative and technical educational contexts. For several years now, the focus has been on promoting girls and women in STEM subjects. Teachers of technical subjects should address this key educational and socio-political challenge, as gender-specific differences in interest and self-concept manifest themselves at an early age.

This study examines the knowledge and attitudes of teachers in STEAM subjects (science, technology, engineering, arts, mathematics) with regard to gender- and diversity-sensitive teaching. It is based on a quantitative online survey of $N = 511$ teachers from Tyrol (Austria), which was conducted using validated Likert scales. Differences according to gender, subject taught, and experience with monoeducative teaching settings were analysed. The results show that teachers with different educational backgrounds and experience in gender-segregated education show greater awareness of the importance of gender-equitable lesson planning. Finally, there is potential for further developing STEM programs into STEAM approaches, in which art and creative forms of expression are consciously integrated.

Key Words: Gender Competence, Diversity, STEAM, Teacher Training

1 INTRODUCTION

Gender describes socially and culturally shaped gender roles that go beyond biological differences (Gildemeister & Wetterer, 1992). Gender equality means recognizing diverse identities and overcoming structural disadvantages. It is enshrined in international agreements such as the UN Charter of Human Rights (1948) and the SDGs, in particular Goal 5: “Achieve gender equality and empower all women and girls” (UNDP, 2015). In pluralistic societies, gender

equality is not only an ethical imperative, but also the foundation for stability, inclusion, and democracy. It promotes social justice, individual rights, freedom, and participation (Fraser, 2013; Butler, 1990; Walby, 2005). It is also considered a benchmark for openness, tolerance, and economic stability (Sen, 1999; WEF, 2023). Culturally, gender diversity broadens social discourse and promotes creative forms of expression (Hooks, 1984). Studies show that gender-equal societies are more peaceful, happier, more innovative, and more economically successful (UN Women, 2020; OECD, 2021; Catalyst, 2020). Currently, there is a lack of critical reflection on gender studies in teacher training and lesson planning (Bartsch & Wedl, 2015).

2 GENDER AND DIVERSITY: DEFINITIONS AND CURRENT RESEARCH

In German-speaking countries, the term diversity is often understood as cultural diversity in anti-discrimination measures (UNESCO, 2001) or as a means of maximizing benefits in management contexts (Roosevelt, 2001). While the term originally derives from the concept of biodiversity, such as the diversity of species or ecosystems in biology (Schaal, 2016), in the context of sociology it is mostly used synonymously with diversity (Salzbrunn, 2014). Today, gender mostly refers to social gender and encompasses attributed behaviours and characteristics (Wirtz, 2013). Several projects fostering women in STEM subjects in schools are currently being carried out in Germany, although teachers are rarely the focus of these projects (see, for example, <https://www.komm-mach-mint.de/MINT-Projekte/Projektlandkarte>).

Diversity in the school context of technical disciplines can therefore be understood as a heterogeneous composition of students, which bring together, for instance, different gender groups, students with and without a migration background, or students with and without special educational needs (Goreth & Windelband, 2020). Teachers must respond to this heterogeneous group of learners. Diversity competence enables them in (technology) education to appropriately deal with diversity and gender-related aspects. Studies on gender and technology (in the context of STEAM) within subject didactics focus on various aspects. Surveys that evaluate the implementation of gender and diversity aspects in technology education—using mixed-method designs—utilize classroom observations (observation sheets) and student surveys (Goreth et al., 2021). Further studies show that interest is reflected in gender-specific ways depending on the specific content area, as evidenced by students' responses in self-assessments. Gender-specific differences are particularly evident in the scientific and technical context (Virtanen et al., 2015; Kosack, 1994; Mammes, 2004; Brown, 1993; Goreth et al., 2021). The extent of technical socialization is also lower among female students than among male students (Goreth, 2026, submitted). Within STEM education, self-concept shows significant gender-specific differences, which also vary according to actual competence levels (Jann & Hupka-Brunner, 2020), and, alongside parents and internships, plays a decisive role the choice of a technical profession or course of study (Brämer, 2019; Acatech, 2011).

Furthermore, the background factors influencing students' career choices have been identified based on their experiences of technical socialization (Goreth & Vollmer, 2021), and also gender differences have been found in teachers' interests and knowledge of subject-related content areas (Goreth, 2021). Teachers with experience in mono-educational settings also demonstrate greater awareness of the importance of gender-sensitive teaching (Goreth & Lutz, 2025). There is a need

for empirical research across the various domains within STEAM education. This article therefore focuses on an online questionnaire study involving teachers in the broader STEAM field, aiming to examine their attitudes toward and knowledge of gender and diversity.

3 RESEARCH DESIGN

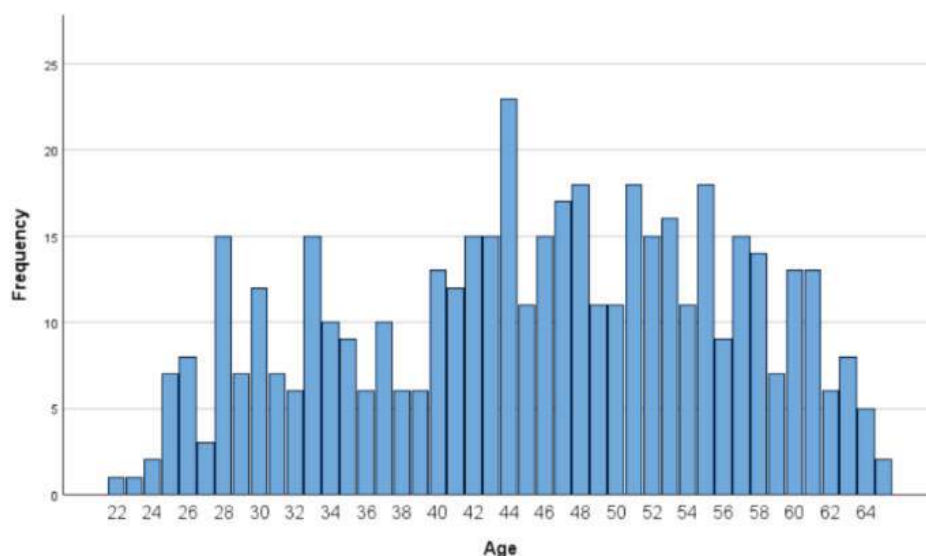
The goal of this quantitative online survey, conducted via *soscisurvey* and primarily targeting teachers in Tyrol (Austria), was to assess teachers' knowledge of and attitudes toward diversity and gender. A total of $N = 511$ teachers took part in the approximately 15-minute survey (Goreth & Lutz, 2025). Five-point Likert scales were used:

- Scale Gender in the Teaching comprises five items. Example item: Coeducational teaching has a beneficial effect on the academic development of female students.
- Scale Importance of Gender comprises six items. Example item: I believe it is important to offer different levels of complexity.
- Scale Planning/Reflection on Gender and Diversity comprises five items. Example item: I reflect on the extent to which my attitudes are influenced by social gender role perceptions.

This article addresses the following research question: What role do gender aspects play in teachers' attitudes toward teaching and lesson planning, and are there differences depending on the combination of subjects taught by teachers?

Figure 1

Age Distribution of Surveyed Teachers



The sample of this study has an average age of $M = 45.4$ years ($SD = 10.6$) and is predominantly *female* (68.4%), with a smaller proportion of *male* participants (30.9%) and individuals identifying as *diverse* (0.6%). For the statistical analysis of gender differences, individuals who selected “other gender” were excluded due to low absolute numbers (3). Consequently, no statistically valid conclusions can be drawn for this group.

An AI translation tool (DeepL) was only used to assist with the translation, which was then proofread.

The results of the teacher questionnaire are presented in this section and provide an overview of the data collected and key findings from the survey.



Teachers ($N = 159$) were also asked to define the term diversity in their own words. This resulted in the following frequency pattern (see Figure 2). The size of each term represents how frequently it was mentioned by the teachers. Only part of the teachers surveyed were reached via the open text field. These are presented here.

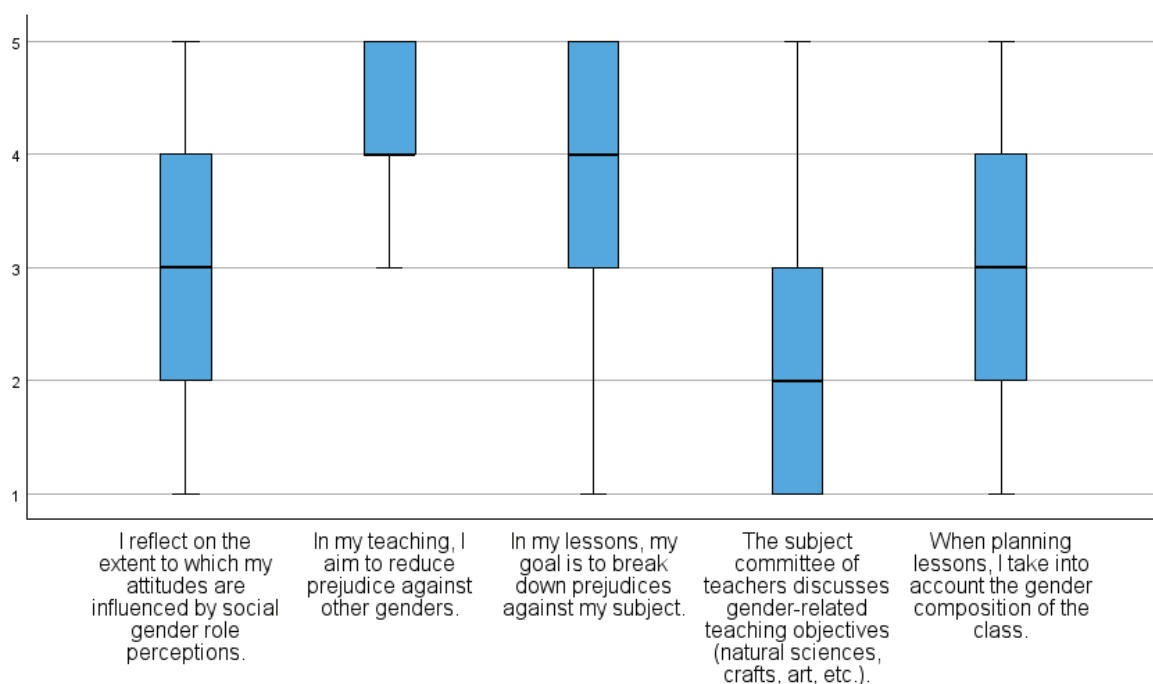
In German-speaking countries, the term “Vielfalt” (diversity) is most often used as a synonym for diversity. The terms “Unterschiedlichkeit” (difference) or “unterschiedlich” (different) and “Unterschied” (difference) are also frequently used to define the concept. Furthermore, explanations such as “Gruppe” (group) or “Menschen” (people) can also be identified.

The items *“In my teaching, I aim to reduce prejudice against other genders.”* and *“In my lessons, my goal is to break down prejudices against my subject.”* are rated above the midpoint of the scale. In contrast, the items *“When planning lessons, I take into account the gender composition of the class.”* and the item *“I reflect to which my attitudes are influenced by social gender role perceptions.”* are rated neutrally.

The median of the item *“The subject committee of teacher discusses gender-related teaching objectives (natural, sciences, crafts, art, etc.).”* is below the midpoint of the scale. Collaborative work and cooperation within the teaching staff is generally not desired or pursued. Instead, teachers consciously tend to address work on gender-related aspects individually.

Figure 3

Items on the “Planning/Reflection on Gender and Diversity” scale on a 5-point Likert scale from 1 = “strongly disagree” to 5 = “strongly agree”



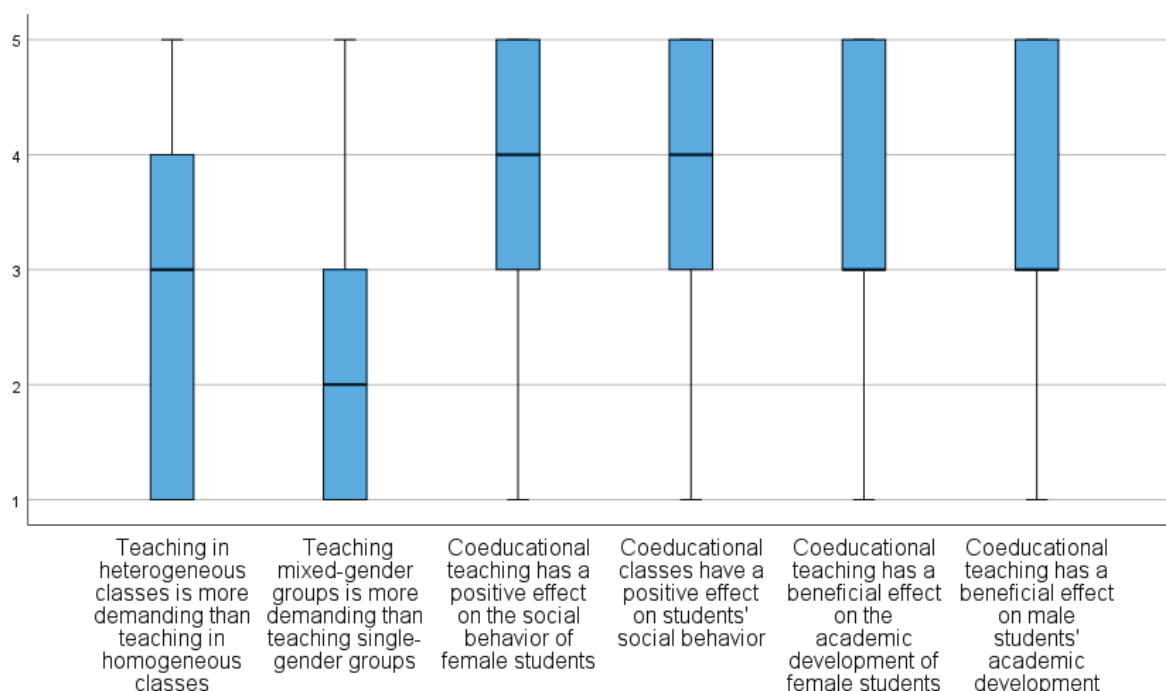
Similarly, teachers indicate less interest in cooperative formats for continuing education on gender than in other continuing education formats on the topic of gender. The median level of interest in using cooperative formats to continue education on gender is 2, which lies below the

midpoint of the scale, and the Q3 quartile is 3, meaning that 75% of respondents are undecided about or opposed to the possible use of cooperative formats (see Figure 3).

The items “*Teaching in heterogenous classes is more demanding than teaching in homogenous classes.*” and “*Teaching mixed-gender groups is more demanding than teaching single-gender groups.*” are rated as neutral to slightly below the midpoint of the scale. Coeducation is rated above the midpoint of the scale for both *boys* and *girls* in terms of social aspects, with a median of 4. *Academic development* is also rated almost as positively, with only 25% of respondents rating it below the midpoint of the scale.

Figure 4

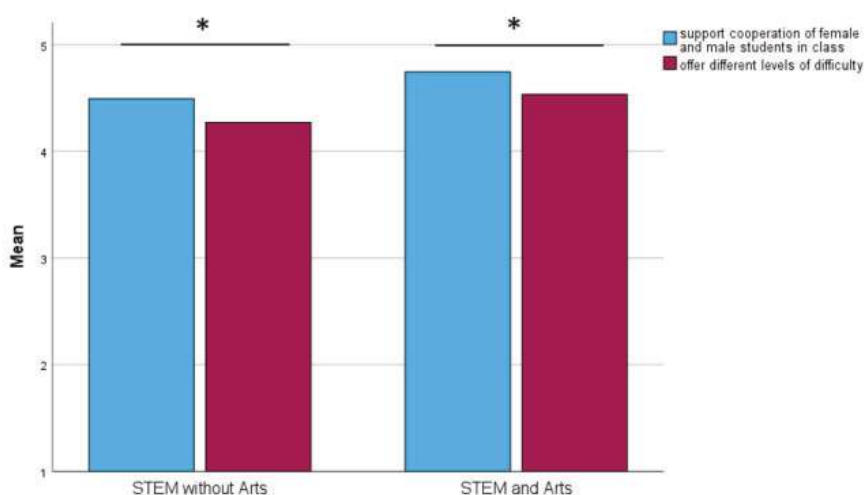
Items on the “Gender in the Teaching” scale on a 5-point Likert scale from 1 = “strongly disagree” to 5 = “strongly agree”



Heterogeneous or mixed-gender teaching is not considered to be more *demanding* than more *homogeneous*, and particularly, *mono-educational class compositions*. Positive effects are consistently associated with coeducational teaching experiences in both social and *academic development* for *female* and *male students* alike (see Figure 4).

Figure 5

Influence of teaching an Arts subject on STEM teachers regarding in class teaching, items on a 5-point Likert scale from 1 = “strongly disagree” to 5 = “strongly agree”



Teachers who teach *STEM subjects and also teach Arts* report a greater tendency to encourage cooperation between female and male students in class ($M_{STEMandArts} = 4.74$, $SD = .84$) than *STEM teachers who do not teach Arts* ($M_{STEMwithoutArts} = 4.49$, $SD = .56$) at $t(252) = -2.94$; $p < 0.05$; $d = -0.36$. *STEM teachers who also teach Arts* are likewise more likely to offer different levels of difficulty ($M_{STEMandArts} = 4.53$, $SD = .66$) than *STEM teachers without Arts* ($M_{STEMwithoutArts} = 4.27$, $SD = .89$) at $t(262) = -2.81$; $p < 0.05$; $d = -0.34$ (see Figure 5).

These differences represent small effects located in the upper range of the scale. Overall, STEM teachers who also teach art express greater confidence in their ability to contribute to gender-sensitive teaching practices than STEM teachers who do not teach Arts.

5 DISCUSSION, LIMITATIONS, OUTLOOK

The results presented here illustrate that gender-related issues are no exception when it comes to forms of cooperation addressing educational issues. As reported in previous studies, teachers often perceive themselves as working independently and shy away from offers of support involving forms of cooperation related to teaching, similar to the findings of Gräsel et al. (2006). This is accompanied by the sobering realization that encouraging cooperative activities through continuing education events must be considered difficult. Schadt et al. (2022) note that, despite the well-documented advantages, cooperative activities may also be perceived as a burdensome. Perhaps this is where we should start in order to strengthen the willingness to cooperate and cooperative activities among teachers.

At the same time, teachers themselves express very positive attitudes toward promoting forms of cooperation between female and male students. The positive correlation between a teacher's

connection to artistic subjects and STEM subjects also appears to have a positive influence on teachers' cooperation and awareness of differentiation in relation to their students.

The explicit affirmation of coeducation of male and female students reflected in the presented results aligns with the correlations reported in Lutz and Goreth (2025), between teachers' prior experiences of single-sex education and a stronger reflection of gender aspects in lesson planning. This supports the deliberately restrictive idea formulated in that study to experimentally test single-sex settings, particularly in teacher education, as a means of fostering more reflective consideration of gender aspects within coeducation teaching and learning experiences. Such environments are considered beneficial both theoretically and empirically, a view shared by most participants in the present study.

The scales used in this quantitative survey provide insight into a broad group of practicing teachers. The survey instrument is valid. However, closed research designs offer little in-depth insight into differing perspectives. A complementary qualitative interview study using questions derived from the results could certainly be beneficial.

Although these findings can only be assumed for Tyrol (Austria) so far, the STEAM approach can be discussed as an extension of the classic STEM subjects to include artistic, creative, and design elements (also to promote interdisciplinary problem-solving skills). STEAM then pursues the goal of not only strengthening technical and scientific skills but also integrating creative and social aspects.

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Instruments to Assess the Pedagogical Content Knowledge (PCK) of Technology Student Teachers

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Abstract

Pedagogical content knowledge (PCK) is key to teacher education, and the literature distinguishes between four methodologies to measure PCK in technology education. However, examples of such related instruments are scarce. The purpose of this paper is to present a set of theory-based instruments which were developed to measure technology student teachers' PCK during practice in teacher education. The research questions are: What are the features of such instruments? In what way can instruments used for practice in teacher education be viewed as research instruments measuring PCK? The underlying theory is the Content representation (CoRe) approach supplemented by Pedagogical and Professional experience Repertoires (PaP-eRs). The CoRes contain sets of key ideas and a set of pedagogical questions/prompts which unpack each key idea. PaP-eRs are a narrative account of a teacher's PCK for a particular topic and emerges from the actual practice. Based on the theoretical foundation of PCK, specifically a CoRe and PaP-eRs approach, and following desktop and action research, this paper presents a lesson plan, which requires technology students to reflect on the CoRes by relying on content knowledge, and the pedagogical questions which interrogate each big idea. A technology-specific observation schedule was also developed to elicit the students' CoRes and PaP-eRs. An existing, generic lesson presentation assessment rubric, which is mandatory for all students across all subjects during their practical teaching, is also presented. In hindsight PaP-eRs are developed from student's reflection on the lesson plan and presentation as well as detailed descriptions/reflections on and discussions about issues pertaining to the CoRes. The current PCK instruments hold substantial value for technology teacher education and research in developing contexts; however, their potential impact in developed contexts is even greater, provided they are systematically adapted to foreground Technological Pedagogical Content Knowledge (TPACK) more explicitly.

Key Words: Pedagogical Content Knowledge (PCK), Instruments to Assess PCK, Technology Teacher Education, Technological Pedagogical Content Knowledge (TPACK)

1 INTRODUCTION

Pedagogical content knowledge (PCK) is founded in the literature by a rigorous theoretical framework. Some parts of the theoretical framework for this paper have already been shared in other publications, including work on a parallel approach to developing technology student teachers' PCK (Grobler & Ankiewicz, 2022a, b). PCK is key to teacher education and the measurement of it is very important; however, examples of such instruments to measure the PCK of technology student teachers are scarce. According to Rowan et al. (2001) developing survey items to measure teachers' PCK will require the sustained effort of many researchers. To investigate a teacher's PCK is often complicated, and time and labour consuming (Rohaani et al., 2009). In addition, Morrison and Luttenegger (2015) indicated that PCK is a complex construct and has proven difficult to measure and therefore there is no single established approach for measuring PCK. The challenge in measuring teachers' PCK is to construct an instrument that is time and labour-efficient and makes it possible to investigate large sample sizes.

The purpose of this paper is to present a set of theory-based instruments which were developed to measure technology student teachers' PCK during practice in teacher education. The research questions are: What are the features of such instruments? In what way can instruments used for practice in teacher education be viewed as research instruments measuring PCK? To eliminate confusion, the concept 'learners' will be used for students at secondary school level (years 8–12; ages 14–18) and 'students' for technology student teachers at tertiary education level.

2 THEORETICAL FOUNDATION OF PCK AND TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK)

2.1 *The tenets of PCK and TPACK*

The well-known theoretical construct of PCK was introduced by Shulman (1986) to represent the knowledge applied by teachers when transforming their own subject-matter knowledge to make it comprehensible to learners. PCK depends on a teacher's subject-matter knowledge, knowledge of pedagogy and on how the teacher transforms this knowledge into various forms that enable learners in different learning environments to understand the subject matter (Shulman, 1987). For the learner to be readily able to access the content, the teacher needs to have a good grasp of the subject matter. Secondly, the teacher needs a suited teaching strategy to make the subject accessible to the learners. Thirdly, the teacher needs to have an idea of possible conceptions learners may have about the specific topic to prepare explanations that will help to eliminate or reinforce the conceptions as is necessary (Shulman, 1986; Sibuyi, 2012). Alonzo et al. (2019) argued that a teacher's PCK is informed by the kind of knowledge that the teacher draws upon when planning, implementing and reflecting on a lesson (their enacted PCK).

PCK can be viewed as a form of practical knowledge that is used by teachers to guide their action in highly contextualised classroom settings (Shulman, 1986, 1987). However, successful teaching depends not only on the teachers' subject-matter knowledge but also on their personal understanding of learners' prior knowledge and learning difficulty (Grossman, 1990; Lederman et al., 1994). As a result of teaching experience, teachers may start to restructure their subject-

matter knowledge into a form that enables productive communication with their learners (Lederman et al., 1994).

Shulman and Sherin (2004) argued that teaching and learning to teach must be viewed in discipline-specific perspectives. It was already mentioned that PCK depends on a teacher's subject-matter knowledge and pedagogical knowledge but subject-matter knowledge in technology education is problematic (Gill, 2019) as it encompasses not only conceptual knowledge (knowing that), but also procedural knowledge (knowing how) (Ankiewicz, 2015; Ankiewicz et al. 2006; McCormick, 1997). The knowledge about teaching technology i.e., pedagogical knowledge, is the knowledge the teacher uses to make the subject content comprehensible to learners (Engelbrecht & Ankiewicz, 2016).

Following Shulman's (1986) foundational articulation of PCK, Mishra and Koehler (2006) expanded this framework by developing the Technological Pedagogical Content Knowledge (TPACK) model. This model conceptualizes the complex, integrated forms of knowledge required for teachers to incorporate more advanced technology, such as internet and digital videos, meaningfully and coherently into their teaching practices, thereby addressing the demands of contemporary educational environments (Korkeaniemi et al., 2025). The TPACK model comprises four interrelated constructs: Technological Content Knowledge (TCK), PCK, Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPCK). TCK refers to an understanding of the dynamic relationship between technology and disciplinary content. It has already been mentioned that PCK encompasses teachers' knowledge of teaching strategies and techniques that are most effective for facilitating learning of specific content. TPK denotes knowledge of how various technological tools can be deployed to support teaching practices across educational contexts. TPCK represents the integrative knowledge required to design and enact pedagogically sound, technologically supported representations of content that effectively address learners' needs (cf., Moon et al., 2022).

2.2 Methodologies to measure PCK

Measuring PCK in technology education is a daunting task. A literature review of PCK (Grobler & Ankiewicz, 2022a), indicated four methodologies which were proposed by De Miranda (2018) to measure PCK in technology education. Firstly, the construct measurement method which is a combination of four existing scales that was used by Rohaan et al. (2012) to collectively measure teacher subject-matter knowledge, pedagogical content knowledge in teaching technology, teacher self-efficacy in teaching, and an attitudes scale. Secondly, Fantz et al. (2011) adopted the topical content knowledge measurement approach to investigate how teachers' educational training (subject-matter background) influences their design and conceptualization of engineering content in teacher-created design briefs. Thirdly, the Content representation (CoRe) approach was utilized by Williams et al. (2016) to articulate teachers' PCK whereby the CoRes contain sets of key ideas and a set of pedagogical questions/prompts which unpack each key idea from the teacher's perspective. Finally, the combined knowledge measurement approach was used by Hill et al. (2008) to measure teachers' knowledge of content and that of students.

Loughran et al. (2004) developed a method for capturing and portraying PCK that comprises two important elements. The first is linked to the subject content, termed Content Representation (CoRe), and the second is linked to teaching practice, termed Professional and Pedagogical experience Repertoire (PaP-eR). The CoRe approach was introduced by Loughran et al. (2004) and refined for technology education by Williams et al. (2016). PaP-eRs emerge from the teacher's actual practice and are validated through a process of verification between researchers and teachers (Loughran et al., 2004). Doyle et al. (2019) indicated that observation of classroom practice may be helpful in eliciting teachers' PCK.

3 RESEARCH METHODOLOGY

Based on the theoretical foundation of PCK and Loughran et al.'s (2004) and Williams et al.'s (2016) ideas when developing technology-specific instruments to measure students' PCK during practice in teacher education, two instruments were developed mainly through desktop and the application of the stages of action research, namely diagnosing, action planning, action taking, evaluating and specifying learning (Baskerville & Wood-Harper, 1996). Firstly, a template to assist and guide technology subject methodology students with their planning of a lesson—the lesson plan—for junior high school (years 7–9; ages 13–15). Secondly, a technology-specific observation schedule (Grobler & Ankiewicz, 2021, 2023) to be used by subject methodology lecturers when assessing the technology students' lesson presentations during their work-integrated learning (WIL), also known as practical teaching at schools. An existing, generic lesson presentation assessment rubric, which is mandatory for all students across all subjects during their practical teaching, is also presented.

The instruments underplayed TPACK as they were developed for use in a developing context where teachers and learners have limited access to more advanced technology (learning technologies). The students were, therefore, not expected to select learning technologies to use in their classrooms that enhance what they teach, how they teach, and what learners learn. Thus, the TPACK constructs, namely TCK, TPK and TPCK (cf., Moon et al., 2022) did not serve explicitly as the theoretical underpinnings of the instruments. However, the constructs feature implicitly in some aspects of the instruments, e.g., in teaching resources/instructional media.

By delineating the features of each instrument through the provided figures and appendices, it is argued that instruments used for practice in teacher education can simultaneously serve as research instruments for measuring PCK. Based on this premise, the instruments were administered to a purposive population of five fourth-year students enrolled in a subject methodology course for senior high school (years 10–12; ages 16–18).

Larsson and Stolpe (2025) indicated that a teacher's personal PCK cannot be fully understood in isolation from their teaching practice. Therefore, the students' PCK was assessed as displayed in only one of their lessons which they planned and presented during their teaching practice. The observation schedule was administered by the researcher, and the lesson presentation rubric by the subject methodology lecturer (Grobler & Ankiewicz, 2021). Unfortunately, the students' specific lesson plan could not be assessed as none of them opted for technology subject methodology for junior high school.

4 FINDINGS

4.1 *The proposed instruments to measure PCK*

4.1.1 *The lesson plan and lesson plan assessment sheet*

For over three decades the technology subject methodology lecturers have developed and refined a technology-specific lesson plan through action research. A refined version requires students to identify, as part of the CoRe, the ‘big ideas’ of the topics prescribed by the national Curriculum and Assessment Policy Statements (CAPS) and set out by the annual teaching plan for the specific time frame during which students were doing their practical teaching at schools (Grobler & Ankiewicz, 2023). The big ideas for a specific topic highlight several concepts as being commonly viewed as important for learners to learn to understand this topic (Loughran et al., 2004). The students have to implement a set of pedagogical questions/prompts which interrogate each big idea (Loughran et al., 2004; Williams et al., 2016) across the various lesson phases. The lesson plan requires the students to reflect on the CoRes by relying on content knowledge, and the pedagogical questions which interrogate each big idea.

The pedagogical questions/prompts used in the lesson plan are: What are the difficulties/limitations regarding teaching these ideas? What knowledge about learners’ thinking will influence your teaching of these ideas? What other factors will influence your teaching of these ideas? What do you intend the learners to learn about this idea? What else do you know about this idea (that you do not intend learners to know yet)? Why is it important for learners to know this? What teaching procedures will you use (and particular reasons for using these to engage with this idea)? Which specific ways of ascertaining learners’ understanding or confusion around this idea will you use?

Figures 1 to 4 are examples of how some of these questions/prompts were incorporated in the lesson plan.

Figure 1

Situation analysis (Who? When? Where?)

What are the difficulties/limitations regarding teaching these ideas? _____
What knowledge about learners’ thinking will influence your teaching of these ideas? _____
What other factors will influence your teaching of these ideas? _____

Figure 2

Learning content (What?)

What do you intend the learners to learn about this idea?
Procedural knowledge: _____
Conceptual knowledge (Factual knowledge: Definitions, concepts, rules, etc.): _____
What else do you know about this idea (that you do not intend learners to know yet)? _____

Figure 3

Teacher activities (How?)

What teaching procedures will you use (and particular reasons for using these to engage with this idea)?
Teaching approach: _____
Teaching strategy(ies): _____
Teaching skill(s): _____

Figure 4

Assessment

Which specific ways of ascertaining learners' understanding or confusion around this idea will you use?
Assessment type (Person, time, manner): _____
Technique: _____
Instrument: _____

The lesson plan assessment sheet (Appendix A) focuses on the five corresponding features/aspects of the lesson plan, i.e., (1) situation analysis; (2) specific aims and lesson objectives; (3) learning content; (4) teaching/pedagogy; and (5) assessment. Each of the five aspects of the lesson plan is assessed on a ten-point scale with a maximum total score of 50, which is then converted to a percentage. Assessing the lesson plan requires a document analysis of, *inter alia*, students' PCK (including its CK and PK components) and TPACK (TCK, TPK and TPCK).

4.1.2 The observation schedule

A team of four technology subject methodology lecturers have developed and refined a technology-specific classroom observation schedule through action research, consisting of 15 aspects based on the lesson plan and on the lesson presentation rubric (Appendix B). It includes the following features/aspects which are supposed to elicit the students' CoRes and PaP-eRs: (1) setting the context; (2) working towards a goal; (3) clarity about the learning content; (4) adjusting to the prior knowledge of the learners; (5) teaching approach; (6) teaching strategies; (7) teaching skills; (8) preparedness for the lesson; (9) explanation of the relevance of subject matter on society; (10) learner activities; (11) resources utilised during the lesson; (12) assessing whether the aim and objectives of the lesson content have been achieved; (13) responses to learners' questions; (14) formative assessment in relation to Bloom's taxonomy; and (15) overall impression of the lesson presentation. The observer assesses each of the 15 aspects of the observation schedule on a four-point scale, namely expectations not achieved (1); approaching competence (2); competent (3); and exemplary (4); with a maximum total score of 60 which is then converted to a percentage (Grobler & Ankiewicz, 2021, 2023). The observation schedule focusses on observing, *inter alia*, students' PCK (including its CK and PK components) and TPACK (TCK, TPK and TPCK).

Figure 5 is an excerpt from the observation schedule of aspects which deal specifically with PCK.

Figure 5*Observation schedule*

Number	Aspect	Observer's remarks	1	2	3	4
3	Clarity about the learning content: Conceptual knowledge (I know that {explicit} – process knowledge) and/or Procedural knowledge (I know how {implicit – you cannot see it} – must do – look at the product)					
5	Teaching approach – uses variety of teaching approaches/methods to transform subject matter into comprehensible knowledge (questions, discuss) Direct instruction /or Constructivism					
6	Teaching strategies (method) – teacher activities – opportunities for active involvement in the lesson (demonstration, dialogue/discussions, etc.)					
7	Teaching skills – process skills – activities to help explaining the main concept; group work; management skills (communication, time, examples, etc.)					
1 - Expectations not achieved		2 - Approaching competence				
3 - Competent		4 - Exemplary				

4.1.3 *The lesson presentation assessment rubric*

A task team consisting of five experts representing the major fields to which the students' subject methodologies belong, i.e., humanities, natural sciences, and commerce designed a generic lesson presentation assessment rubric which is mandatory for all students across all subjects during their practical teaching. It was finalised after it had been circulated to all staff members in the faculty for their comments.

The instrument consists of three sections and subsections. Each section is scored according to predetermined weightings as determined by the task team with a maximum total score of 100, which is then converted to a percentage.

The sections are: Section A: Written lesson design criteria (the written lesson design includes all aspects and are in alignment); Section B: Lesson presentation criteria such as B1: Introduction (learner interest, elicit reflection on own experiences, invokes previous knowledge); B2: Presentation style (The student implements effective teaching and learning by being dynamic, creative, interesting and engaging learners. Learners respond positively to the student. The student displays innovation and applies 21st century skills); B3: PCK (The student knows the subject content, knows how to teach it, and utilizes appropriate engaging teaching strategies. Correct terminology is used); B4: Resources (Credible and authentic resources are used creatively and are appropriately applied. The use of resources contributes directly to enhance the teaching and learning of the content to develop 21st century skills); B5: Classroom management and professionalism (The student develops an inclusive learning environment, manages learner behaviour effectively. Gives clear and appropriate instructions and models good verbal and non-verbal communication skills. Interaction between learners and the student teacher are respectful. The student teacher maintains a supportive and safe learning environment whilst managing time affectively); B6: Assessment (A variety of assessment strategies is used. Assessment aligns with lesson objectives and curriculum expectations. Learners' questions are answered accurately and appropriately. The assessment is meaningful and support learning.); B7: Conclusion (The student summarises and concludes effectively. Important aspects of the lesson are emphasised. The student engages the learners during the conclusion phase.); Section C: Debriefing session (Reflection – The student reflects deeply on the following: What went well, what did not, what changes are necessary? Explain with evidence responses to the above. The assessor provides feedback to the student on the reflection process to improve the student's teaching practice). Finally, the assessor makes overall comments on the lesson (Grobler & Ankiewicz, 2021, 2023).

Figure 6 is an excerpt from the lesson presentation assessment rubric dealing with the student's PCK and indicating the scoring out of 100.

Figure 6*Lesson presentation assessment rubric*

B3. PCK	Mark possible	Mark allocated	Comments
The student knows the subject content, knows how to teach it, and utilizes appropriate engaging teaching strategies.	30		
Correct terminology is used. Exemplifies ‘to be’ (e.g., as a biologist, mathematician).			
The student teaches and does not revert to reading.			

In hindsight it seems that a CoRes approach underlines parts of Section A and B, and that specifically the debriefing session in Section C—where the student reflects on the lesson plan and the lesson that was presented—is underpinned by the PaP-eRs. PaP-eRs are developed from the student’s reflection on the lesson plan and presentation as well as detailed descriptions/reflections on and discussions about issues pertaining to the CoRes. The lesson presentation assessment rubric requires a document analysis of, *inter alia*, students’ PCK (including its CK and PK components) and TPACK (TCK, TPK and TPCK), observation of, *inter alia*, students’ PCK and TPACK, and an interview/discussion to elicit students’ PaP-eRs (PK).

4.2 *Consistency in PCK measurement across two distinct instruments*

Due to the structural differences between the technology-specific observation schedule and the generic lesson presentation rubric, which were administered respectively by different assessors, the outcomes of the two instruments for each student’s PCK were compared and the students ranked based on their scores (shown in brackets), as indicated in Table 1. The purpose of the data is to determine how the measured PCK, determined with different instruments and scores expressed as a percentage, compares for each student. By doing this, an indication is given of the degree of consistency and discrepancy in the student’s enacted PCK by applying various instruments.

Table 1*Ranking order of the students based on the applied instruments*

Student	Technology-specific observation schedule	Generic lesson presentation rubric
C	1 (79%)	1 (82%)
B	2 (70%)	2 (80%)
A	3 (66%)	3 (79%)
E	4 (64%)	4 (77%)
D	5 (45%)	5 (76%)

The technology-specific observation schedule produced lower scores compared to the generic lesson presentation rubric. However, despite discrepancies between each student's scores of a minimum of three (student C) and a maximum of 31 (student D) percentage points, the ranking order of the students remains consistent irrespective of which instrument was used.

5 CONCLUDING DISCUSSION

Based on the theoretical foundation of PCK, specifically a CoRe and PaP-eRs approach, and following mainly desktop and action research, the paper presents a lesson plan, which requires technology students to reflect on the CoRes by relying on content knowledge, and the pedagogical questions which interrogate each big idea. A technology-specific observation schedule was also developed to elicit the students' CoRes and PaP-eRs. An existing, generic lesson presentation assessment rubric, which was developed for students across all subjects, was applied as a point of reference to the technology students. In hindsight PaP-eRs are developed from student's reflection on the lesson plan and presentation as well as detailed descriptions/reflections on and discussions about issues pertaining to the CoRes (Grobler & Ankiewicz, 2023).

The discrepancies between students' scores that were produced by the technology-specific observation sheet, and the generic lesson presentation rubric may be ascribed to the instruments themselves and/or to the different assessment standards that various assessors have. However, totally skewed scores due to assessor bias can be limited by applying the various instruments concurrently and frequently by various assessors. Opportunities should be sought to also apply the lesson plan in future to enable research on comparisons with the outcomes of the remaining two instruments. The assessment of the students' PCK needs to be done regularly to assess the students' PCK development trajectory between lessons in which they teach different content in different contexts.

Beyond their unique features, these instruments share several commonalities. They require technology students to demonstrate Content Knowledge (CK) through CoRes and to reflect on their Pedagogical Knowledge (PK) to elicit PaP-eRs. While the instruments place limited emphasis on TPACK overall, they still enable students to apply TCK, TPK, and TPCK when selecting advanced instructional media/learning technologies. Consequently, future research and development should focus on explicitly highlighting and strengthening the role of TPACK and its related constructs within these instruments.

The three instruments used for practice in technology teacher education rely on observation, document analysis and interviews which are also fundamental qualitative data-collection methods (Merriam, 2009). This creates a natural bridge between research and practice. Consequently, these instruments allow qualitative researchers to investigate various components of technology students' PCK, specifically their conceptual and procedural content knowledge as well as their pedagogy (teaching approaches, strategies, and assessment). Furthermore, they offer a window into students' TPACK, albeit to a more limited extent. The current PCK instruments hold substantial value for technology teacher education and research in developing contexts; however, their potential impact in developed contexts is even greater, provided they are systematically adapted to foreground TPACK more explicitly.

Acknowledgements

The authors express their sincere appreciation to Prof. Estelle de Swardt, Dr. Francois van As, and Mr. Werner Engelbrecht for their invaluable contributions to the development and refinement of the technology-specific instruments over the years. Their expertise, dedication, and ongoing commitment have significantly strengthened the quality and rigour of this work.

6 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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8 APPENDICES

Appendix A

Lesson plan assessment sheet for technology education

NAME OF STUDENT: _____ STUDENT NUMBER: _____

Assessment criteria	U (1-2)	T (3-4)	C (5-6)	HC (7-8)	M (9-10)
1. Situation analysis Grade; prior knowledge; class size Resources (materials and tools) available Attitude and motivation Gender distribution Language proficiency Remarks: _____ _____					
2. Specific aims, lesson and stage objectives; Project brief Specific aims (CAPS) Lesson objective aligned with specific aims Stage objectives aligned with lesson objective, specific aims and Bloom's taxonomy Project brief Remarks: _____ _____					

3. Learning content Aligned with specific aims and focus, content, concepts and skills in CAPS Remarks: 					
4. Teaching/pedagogy Teaching approach Teaching strategies Teaching skills Learner tasks (case study, resource, capability) Instructional media Remarks: 					
5. Assessment Assessment aligned with stage objectives? Types of assessment (time, person, manner) Assessment techniques/methods Assessment instruments (observation sheets, rubrics) Questions aligned with Bloom's taxonomy Remarks: 					

- U - Ungraded: insufficient evidence for assessment
 - T – Threshold: evidence exists but does not comply fully
 - C – Credit: available evidence demonstrates the achievement of the outcomes %: _____
 - HC – Higher credit: evidence is of noticeable standard
 - M – Merit: evidence is of exceptional standard
- Total:** _____
Max: 50

Appendix B

Observation schedule

Name: Student number:
 School: Grade:
 Title/Topic of lesson:
 Date:

	Aspect	Observer's remarks	1	2	3	4
1	<u>Setting the context</u> – What evidence was there to proof that the student understands the importance of the introduction to the lesson?					
2	<u>Working towards a goal</u> - How were the <u>aim and objectives</u> explicitly or implicitly addressed?					
3	<u>Clarity about the learning content</u> : Conceptual knowledge (I <u>know that</u> {explicit} – process knowledge) and/or Procedural knowledge (I <u>know how</u> {implicit – you cannot see it} – must do – look at the product)	Conceptual knowledge – Procedural knowledge –				
4	Adjust to the <u>prior knowledge</u> of the learners					
5	<u>Teaching approach</u> – uses variety of teaching approaches/methods to transform subject matter into comprehensible knowledge (questions, discuss) Direct instruction /or Constructivism	Direct instruction/Behaviouristic - Constructivism (questions and answers, discussion, group work) -				
6	<u>Teaching strategies</u> (method) – teacher activities - opportunities for active involvement in the lesson (demonstration, dialogue/discussions, etc.)					

7	<u>Teaching skills</u> - process skills - activities to help explain the main concept; group work; management skills (communication, time, examples , etc.)				
8	Was the student well prepared for the lesson?				
9	Did the student explain the relevance/application of subject matter on society? (Technological authentic examples)				
10	What learner activities (types of tasks) were done?				
11	What <u>resources</u> were utilised during the lesson? instructional media (IM); learning materials (LM); tools/equipment How does he/she handle a shortage thereof?	Instructional media – Learning materials – Tools –			
12	How did the student assess whether the aim and objectives of the lesson content have been achieved? (continuous, formative, summative)				
13	How well did the student respond to learners' questions?				
14	How did the formative assessment relate to Bloom's taxonomy?				
15	My overall impression				

1 Not achieved/Poor effort/Not competent

3 Accomplished/Competent

2 Developing/Approaching competence

4 Exemplary/Excellent

Technology Education in Action: Integrating Action Competence in the Technology Subject

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Abstract

The global climate situation requires a comprehensive technological transition, which leads to an increased demand for a skilled workforce in science and technology. However, forecasts show that the number of graduates with environmentally relevant degrees is too low, which is identified as a bottleneck for Sweden's climate transition. Today, the gender distribution in technical education is severely skewed. In the academic year 2023/24, 82 percent of students in the technology program were men, and in the electrical and energy program, a full 96 percent were men. Even in higher education, only 30 percent of first-time applicants to the Master of Science in Engineering and Bachelor of Science in Engineering programs were women in the fall of 2024. A paradox is made visible: Women as a group, who are generally more committed to climate issues than men as a group, are unwilling to invest in technical education as a means to perform transformation. Conversely, men tend to choose technical education areas than women but without a corresponding environmental commitment. The differences can be attributed to norms surrounding femininity and masculinity. Feminine values are linked to care work, and thereby also environmental commitment, while masculine values are associated with interest and knowledge in 'hard' technology. To break these gender stereotypes and gender segregation, this project addresses inclusion of Action Competence for Sustainable Development as well as knowledge about gender norms, care and emotions in technology education in grades 7–9. The aim is to develop and challenge technology education by incorporating awareness of gender and emotions to promote action competence in the context of green transition. The project, which are still in the planning stage, will examine teachers' planning and teaching when knowledge about gender, emotions, and action competences will inform technology teaching.

Key Words: Technology Education, Action Competence, Gender, Emotions

1 INTRODUCTION

The global climate situation requires a transition that includes a thorough technological shift, and the need for a scientific and technical workforce will likely increase (Tillväxtanalys, 2025). The

number of graduates with environmentally relevant degrees is forecast to be too low and has been identified as a bottleneck for the climate transition in Sweden (Pareliussen & Purwin, 2023). In February last year, the Swedish government presented a new education strategy, “A STEM strategy for Sweden – from preschool to postgraduate education” (Utbildningsdepartementet, 2025) which highlights the need to strengthen the supply of skills in the STEM area to be at the forefront of the green transition. The strategy aims to increase the proportion of students studying science and technology programs, both in school and higher education, and it particularly emphasizes the importance of utilizing the potential of both women and men. To achieve this change, it is essential that the investment is long-term and starts at an early age to stimulate children's interest in science, technology, and mathematics and strengthen their knowledge in these areas. The fact that the government is paying special attention to the need to increase the representation of women in STEM is commendable and necessary since the proportion of women in technical education remains low. In the 2023/24 academic year, 82 percent of upper secondary school students in the technology program were men. The gender distribution is also skewed in higher education; in the civil engineering and Bachelor of science engineering programs, only 30 percent of first-time applicants were women in the autumn semester 2024 (Utbildningsdepartementet, 2025). If women in general lack interest in choosing technical education, they are, on the other hand, more involved in sustainability and climate issues than men as a group (Sand, 2022). The Nordic Council of Ministers' review report "Sustainability, lifestyle and consumption with a gender perspective" shows that this involvement leads to a lifestyle and consumption pattern that leaves a smaller climate footprint and fewer emissions than men. The differences in individuals' attitudes towards climate change can be explained by norms around femininity and masculinity (e.g. Sand, 2022). The more individuals, regardless of gender, exhibit feminine values, the more these individuals are oriented toward sustainability. Commitment to recycling and nutrition is considered caring work, highly related to feminine values. What is associated with masculine values and ideals, on the other hand, is interest and knowledge in technology. Men's commitment to climate change is combined with technology positivity, which is expressed in, for example, wanting to invest in solar panels or replacing fossil-fueled cars with electric cars. One conclusion in Sand's study is that to succeed in the green transition, gender segregation in the labor market needs to be broken, and the gender stereotypes that exist in terms of educational choices, consumption and lifestyle need to be challenged (Sand, 2022). Women, as a group, are thus committed to climate issues but are unwilling to invest in technical education as a means of engaging in climate issues. Conversely, men, as a group, choose technical education areas to a greater extent but without a corresponding environmental commitment. We know from previous experience that efforts to attract women to technology and science rarely achieve the goals sought (Beck et al. 2022). Science and technology education research also show that technology still surrounded by masculine connotations (Ottemo et al. 2020), which is one explanation for why women hesitate to choose these areas. Based on their research findings, Sultan et al. (2024) claim that a broader conception of technology in the classroom could make gender codes less influencing and “make girls more willing to engage with technology and pursue a technological or STEM career” (p.668).

In the planned research project, we want to contribute to breaking the stereotypical gender patterns that cause women and men to choose different directions in their lives. To achieve this, we want to broaden the teaching of technology subjects about sustainable development in grades 7-9 by teaching action competence in technology (ACiTE - Action competence in technology),

including knowledge about gender, care and emotions. The aim is to develop technology teaching by including awareness of gender and emotions to promote action competence (ACiTE) in green transition.

Research questions:

- (i) How can increased knowledge about gender and emotions among technology teachers develop teaching about action competence in sustainable development?
- (ii) How can students' emotions about sustainability challenges be recognized and addressed in technology education?

2 LITERATURE REVIEW

2.1 *Youth concerns about climate change*

Almost half (48%) of 1002 Swedish children aged 12-18 years report being very or somewhat concerned about what will happen to the climate and the environment in the future (Karlton & Löwgren, 2023). At the same time, the proportion of children who feel they can influence the future of the climate and the environment is decreasing, from 65% in 2020 to 48% in 2023. Even within this age group, there is a significant gender difference; 59% of girls but only 37% of boys are concerned about climate change. When asked children aged 12-15 years what, if anything, they would consider doing to get involved in the climate and the environment, 19% of boys answered that they “couldn’t imagine doing anything,” while only 8% of girls gave the same answer (Karlton & Löwgren, 2023).

In an international literature review by Léger-Goodes et al. (2022), 18 studies on children's anxiety about climate change (eco-anxiety) are summarized, with 14,000 children aged 11-18 participating. The children expressed anxiety about the effects of climate change in the future but also anger that their generation is affected and that adults have done too little to stop climate change. According to the study, there are different ways for children to deal with their anxiety, such as minimizing, denying, or ignoring the problems. Ojala showed in her studies that anxiety can be turned into hope when addressed appropriately and can be channelled into action (Ojala, 2012; Ojala, 2015). Over many years of research, she has shown the importance of including emotions and coping strategies in education for sustainable development, especially in pluralistic approaches where complexity and value conflicts are in focus (Ojala, 2017). Such teaching addresses wicked problems, in which one strives to illuminate issues from as many perspectives as possible. This type of problem often arouses strong emotions, and Ojala concludes that emotions, therefore, need to have a place in teaching, especially in practicing different coping skills. In a study on climate change coping (Rikner Martinsson & Ojala, 2024), researchers have found different attitudes in children towards climate change. The three central attitudes are un-involvement, avoidance, or solution-oriented. In the Un-involvement group minimize or deny that climate change will cause problems. The Avoid group is those who feel great anxiety but actively try to suppress it by avoiding questions about the climate. A group of children face the climate issue problem-focused in such a way that they try to find solutions. According to Rikner

Martinsson & Ojala (2024), the latter group is characterized by seeking information, discussing with others, and wanting to change their lifestyle, such as stopping eating meat.

Ojala (2015) pointed out the importance of teaching about strategies to foster hope. This study also reveals statistically significant differences in gender, where boys, to a greater extent than girls as a group, expresses hope based on denial. Ojala argued that it is essential for teachers to be aware of and manage how children react to negative emotions in the classroom and also to be attentive to how girls and boys are treated (Ojala, 2015). For boys, it is not permitted, according to the masculine norm, to show emotions in the same way as for girls. Boys experience that their negative feelings are not legitimate and thus risk repressing them to a greater extent than girls do.

2.2 *Action competence as a teaching element to curb climate anxiety*

It can be challenging to teach about how humans affect the climate and the environment with significant negative consequences, and there is a risk that the teaching will increase students' anxiety about climate change (Hicks & Bord, 2001). Value conflicts can also arise, leading to strong emotions that the teacher must manage (Wals, 2011). Therefore, it is central for the teacher to understand how young people respond emotionally, how different values can be set against each other, and how to include various aspects in teaching about a sustainable future (Ojala, 2017). Interventions in teaching have been carried out where they have focused on developing hope for the future. Malboeuf-Hurtubise et al. (2024) showed that hopefulness increases if children are allowed to discuss their anxiety and despair. Adults must support children by acknowledging and discussing these feelings with them. In a survey on anxiety among children and young people, almost two-thirds of the participants expressed the need to invest extra resources in strengthening teachers' knowledge of environmental change (Karlton & Löwgren, 2023). Such knowledge should also include tools for "sustainable behaviors" (Lenhard et al., 2024). In a research study on climate worry, the relationship between "functional impairment", "pro-environmental behaviors," and "perceived need for support" was analyzed (Lenhard et al. 2024). The conclusion was that the group with "severe and frequent climate worry" wanted support. Such support should include teaching about climate change knowledge and tools for sustainable behaviors.

Pro-environmental behavior is the concept used by environmental psychologists to describe behavior that seeks to harm the environment as little as possible or even improve the it (Steg & Vlek, 2009). In sustainable development education research, the concept "Action competence" (AC) is often used to define what type of competences are needed to be able to have a pro-environmental behavior. Common denominators are to have relevant knowledge and skills, willingness, and confidence in one's capacities to contribute to sustainability positively (Sass et al., 2020; Olsson, et al., 2022). Sass et al. (2020) described an "action competent person" as someone who "is committed and passionate about solving a societal issue, has the relevant knowledge about the issue at stake as well as about the democratic processes involved, takes a critical but positive stance toward different ways for solving it, and has confidence in their own skills and capacities for changing the conditions for the better". (Sass et al. 2020, p. 300).

In a review article, Husamah et al. (2022) examined 193 publications that, in various ways, touch on "Action competencies for sustainability" and its implications for prospective science teachers

and science teacher educators who will teach about sustainable development. Based on their compilation, the researchers determined the importance of an enhanced focus on the implementation of gender in sustainable development education, both in teaching and in research, to achieve action competence. Meinck et al. (2025) claimed that AC methods create a “nurturing critical thinking and engagement, fostering a sense of responsibility, and enhancing collaboration and empathy”, abilities strongly linked to feminine characteristics such as care (p.89).

Adolescents who can learn about agency in school enhance their awareness of environmental issues and environmentally friendly behaviors (Uitto et al., 2015). To measure the effectiveness of AC in sustainability education, Sass et al. (2021) developed a questionnaire instrument of self-perceived AC for sustainability focusing on the environment, social issues, and peace. In addition, the form contains questions about the willingness to act in an environmentally beneficial way when they become adults. The measurement tool has been used in several studies to examine AC in different groups and at different times in sustainable development education (e.g., Sass, et al., 2020; Olsson, et al., 2022). For example, Olsson, et al. (2022) showed in a longitudinal study that when teachers include teaching about AC, students' knowledge increases in parallel with their willingness to act. However, Van Poeck et al. (2024) argued that these measurement tools do not fully provide insights into how changes in knowledge, abilities, and values occur in practice. They call for more empirical studies examining how teachers' choices and actions, as well as their didactic work, affect the development of students' AC. Moreover, Brommesson et al. (2025) called for more support for teachers to enrich students' competence to actively engage in sustainability challenges.

3 METHODOLOGY

To challenge and develop technology education within sustainable development with elements of gender and emotions to achieve action competence in students, we will work together with teachers to plan and teach this competence. Technology teachers (grades 7-9) together with the researchers, form research circles (RC), which meet regularly during the project period (Rönnerman & Olin 2014). Teaching in sustainable development is planned and then implemented in the teachers' classes (in so called ACiTE projects). The outcomes of the teaching are analyzed and the evaluation forms the basis for planning further teaching elements.

3.1 *Empirical design*

3.1.1 *Research circles (RCs)*

In the research circles, teachers and researchers will read articles and discuss gender theories, education for sustainable development, how emotions are part of learning, and how teaching, including emotions, can be performed. The goal is to design “Action Competence in Technology Education” (ACiTE), projects that teachers can implement in their classes. Through group discussions, the teachers and researchers learn more, and the projects in the classes are being developed. We will collect data from the RCs by video recordings, interviews, stimulated recalls using critical episodes, field notes and questionnaires (to monitor emotional aspects and the

progress of gaining action competence during the ongoing project). Our goal is to recruit twenty technology teacher and their classes (year 7-9) in a three-year research project.

3.1.2 *Action Competence in Technology Education (ACiTE)*

The ACiTE-projects will be carried out by the technology teachers in their classes. The themes of the projects will be locally situated, making them relevant for the students and the teachers and resulting in a technical solution aimed to promote a sustainable future. Each teacher will execute at least two ACiTE-projects in different classes. We will start with one project, evaluate and use the insights to inform the next projects (Rönnerman & Olin 2014).

Video recordings. In the ACiTE-projects the technology teachers will film the activities in the classrooms. We will encourage teachers to film in pairs, with the technology teacher performing the teaching, and a helper teacher doing the filming. The helper teacher can be another teacher in the school or a teacher in the research circle.

Field notes. The technology teachers will take field notes to remember occasions that otherwise easily slip from the mind.

Questionnaires. To monitor the progress of gaining action competence during the ongoing project, the students will fill in a questionnaire (ACiSD-Q) both at the start and at the end of the ACiTE-projects (Sass et al 2021).

3.1.3 *Data analysis*

The responsible researcher will first review their ‘own’ data material individually to identify “critical episodes” where didactic choices become visible. These preliminary “episodes” will be discussed, adjusted, and organized in collaboration with the other researchers and calibrated with the technology teachers’ statements. A special focus will be on how gender and emotions are intertwined with technology education and how that will affect teaching. ATLAS.ti software will be used to organize, sort, and mark the data during the analysis. In the next step, the various critical episodes will be thematized according to the didactic considerations that play a role in the developing of teaching the ACiTE-projects. This analysis will be performed according to Reflexive Thematic Analysis (Braun and Clark, 2022) in six distinct iteratively phases 1. Familiarizing yourself with the dataset, 2. Systematic coding, 3. Generating initial themes, 4. Developing and reviewing themes 5. Refining and defining themes and 6. Writing up your analysis.

To monitoring teachers’ and students’ action competence in sustainable development in science the measurement instrument: the Action Competence in Sustainable Development Questionnaire (ACiSD-Q) developed by Sass et al (2021) will be used. The questionnaire has 36 items where agreement or disagreement is expressed by means of a five-point Likert scale with a neutral center.

4 DISCUSSION

In the proposed study, we aim to develop technology education in secondary schools by combining Action Competence (AC) with gender and emotions. As revealed in the review article by Husamah et al. (2022), the science subjects in STEM have largely received all the attention in studies on Action Competence in Sustainable Development (ACiSD). The subject of technology is crucial for many sustainable development issues and a green transition. However, both education and research in AC in technology are sparse, something that this project highlights and will act upon.

There is a deficit of studies that integrate gender knowledge as part of teaching of sustainable development education, which means that the proposed study fills a need. A rare exception is Biström & Lundström (2021) who investigated the relationship between gender equality and sustainable development across several subjects in Swedish lower secondary school textbooks. In textbooks, gender and sustainable development are addressed separately which hinders understanding of how gender shapes how we think about climate change and our willingness to act pro-environmentally.

Secondary school is the stage where teachers experience the greatest challenge to educate in sustainable development since the students' interest in STEM drops during that stage. Therefore, it is urgent to get deeper knowledge and develop teaching strategies that maintain students' interest during grades 7-9.

It is unusual for emotions such as grief, sorrow, despair, and anxiety to be addressed in technology education. Teaching about sustainable development and action competence takes students' feelings about the effects of climate change seriously. The hope is that the view of the technology subject can be broadened and, in the long term, foster broader interest in STEM issues related to the green transition among both girls and boys.

5 AI DISCLOSURE

Artificial Intelligence (AI) technology, specifically Grammarly, was used solely to enhance the clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Teaching Ethics of Technology in Swedish Secondary Education

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Abstract

Recently, there have been renewed calls for developing ethical awareness and judgement among young technologist and designers, not least in relation to societal unsustainability and rapid development of artificial intelligence. While there is a burgeoning literature on ethics as a topic of instruction in engineering education, suggesting that its status is contested, little empirical work have investigated how ethics is taught and understood at the level of secondary technology education.

This paper reports on interviews with 11 technology teachers in secondary education in Sweden, where ethics of technology is an explicit albeit small part of the technology curriculum. Drawing on practice theory, the study unveils characteristic purposes, sayings, doings and relatings of ethics teaching, embedded in the architecture of a broader technology education practice.

Findings suggest that teaching ethics of technology is a predominantly implicit endeavour, and that fragments of ethics teaching is embedded in three more prominent projects: 1) developing technological-analytical capacities, 2) developing socio-technical understanding and awareness, and 3) developing responsibility, agency and openness. The teachers' commitment to fostering responsible users and developers of technology suggest that ethics of technology in certain respects may be better positioned in the secondary curriculum as compared to higher engineering education. At the same time, the teachers express significant challenges, concerning for instance motivating student to engage sincerely and making space for open-ended discussions in a crowded curriculum.

Key Words: Technology Education, Ethics of Technology, Teaching Practices, Teacher Experiences

1 INTRODUCTION

The importance of developing young people's ethical awareness and judgement in and through technology education has been elaborated in much previous work (Haug, 2017; Huyke, 2001, Petrina et al., 2004). Nordlöf et al. (2022) argues that socio-ethical understanding of technology

is one of three main knowledge areas in technology education, alongside technical skills and technological scientific knowledge. A considerable body of work has investigated how ethics of technology is and may be taught at the level of engineering education (Hess & Fore, 2018). However, very little empirical work has investigated ethics of technology as a topic in primary and secondary school (Ahuja & Kumar, 2025).

This paper reports on an interview study investigating how ethics of technology is taught in secondary technology education in Sweden, where ethics is an explicit but relatively small part of the technology curriculum. The study draws on practice theory (Kemmis et al., 2014) to conceptualize teaching practices as characteristic projects constituted by particular purposes, saying, doings and relatings.

2 LITERATURE REVIEW

2.1 *Ethics of technology in technology education*

In Sweden, the technology subject (“Teknik”) is mandatory and studied by all students at the primary and lower secondary level. At the upper secondary level, the technology subject is studied only as part of the higher education preparatory programme focused on technology (“Teknikprogrammet”).

Developing ethical awareness and judgement among young people is often considered an important goal in technology education (Conway, 2000; Huyke, 2001, Petrina et al., 2004), at least in theory. In practice, Gradwell (1999) asserted that while ethics of technology has often been accorded “lipservice”, it has “never really been integrated into technology education studies or activities as an aspect equal to designing and making products” (p. 262). Haug (2017) further argued that if and when technology is problematized in technology education, it is usually done through highlighting its consequences for the environment, and seldom its consequences for people. Lönngren (2021) showed that where ethics of technology is explicitly addressed, the topic may still be constructed by teachers and students as low status and irrelevant for technological practice.

Ahuja and Kumar (2025) presented one of few empirical studies focused on secondary education, detailing and evaluating ethics instruction delivered as part of a module on persuasive digital design to 419 students in five public schools in India, showing impacts on students’ design outcomes and their assessments of designs. Similar interventions at the level of engineering education were systematically reviewed by Hess and Fore (2018). The authors found that ethics instruction often aim to develop students’ 1) ethical awareness, 2) ethical judgement and decision-making, and – in some cases – 3) ethical courage, confidence, or commitment. The authors found a broad variety of pedagogical strategies utilized, the most common being 1) reviewing ethics codes or standards for engineers, 2) introducing case studies and 3) facilitating discussions or debates on ethical issues. While these findings are indicative of some of the practices that could potentially be observed in secondary technology education, an important difference is that the taxonomies presented by Hess and Fore (2018) are based on interventions specifically designed to facilitate learning about ethics. As such, these distinctions capture an idealized picture of ethics

teaching, rather than analysis of teachers' regular practices, where learning about ethics is negotiated among a multitude of other curricular goals and educational commitments.

2.2 *Technology education practice and its practitioners*

As outlined by Nordlöf et al. (2022), technology education spans a broad set of knowledge areas and traditions, including not only technical skills and technological scientific knowledge but also socio-ethical understanding originally derived from sociological, historical and ethics research concerned with the interrelationships between technology and society. In light of this breadth, a range of studies has engaged with the question of how teachers' teaching practices within technology education may be characterized and what knowledge traditions are most prominent in certain contexts. Doyle et al. (2019) investigated 15 Irish technology teachers' perspective on secondary technology education practice, finding that most described activities focused narrowly on developing students' technical competency through content knowledge and craft skills, rather than a holistic technological capability including problem solving and reflection on values. Fahrman et al. (2020) investigated technology teaching practices in Sweden through interviews with four experienced secondary technology teachers. While the respondents' view of knowledge and purpose in technology education varied, the authors identify consensus concerning the main and most important classroom activity, namely, project work.

These studies indicate that socio-ethical understandings of technology are only partially addressed in technology education, but do not delve deeper into teaching practices connected specifically to ethics of technology. Furthermore, the core concept of teaching *practice* remains weakly conceptualized in previous work, instead theorizing teachers' descriptions in terms of perceptions or conceptions.

3 PRACTICE THEORY

Among many versions of practice theory available, this study draws on practice theory as outlined by Kemmis et al. (2014) and, specifically, the theory of practice architectures. According to Kemmis et al. (2014):

“A practice is a form of socially established cooperative human activity in which characteristic arrangements of actions and activities (doings) are comprehensible in terms of arrangements of relevant ideas in characteristic discourses (sayings), and when the people and objects involved are distributed in characteristic arrangements of relationships (relatings), and when this complex of sayings, doings and relatings ‘hangs together’ in a distinctive project.” (p. 31)

Importantly, practices are always located in certain sites, and these sites come with certain arrangements that prefigure the sayings, doings and relatings of a practice. The theory of practice architectures particularly focuses on three types of arrangements that enable and constrain practices: 1) cultural-discursive, e.g. including certain ways to speak about a practice, 2) material-economic, e.g. physical resources and funding, and 3) socio-political arrangements, e.g. organisational rules and relationships.

This study is concerned with understanding teaching ethics of technology as a practice characterized by particular doings, sayings and relatings that hang together with particular purposes. This practice is conceptualized as situated within a broader technology education practice, enabled and constrained by particular practice architectures, partly specific to the Swedish schooling context and partly germane to technology education internationally.

The study investigates the following research question:

What purposes, doings, sayings and relatings characterize ethics teaching within the Swedish secondary technology curriculum, as expressed by technology teachers?

4 METHODOLOGY

An interview study was conducted with 11 technology teachers, 5 at the lower secondary and 6 at the higher secondary level in Sweden. A first benefit of an interview study vis-à-vis an observation study was the possibility to investigate teaching practices across multiple schools and teaching situations. Second, interviews gave the opportunity to identify and discuss fragments of teaching practices concerned with ethics of technology embedded in other content and activities.

A convenience and snowballing sampling strategy was employed, starting from already established contacts and progressing through recommendations of teachers who could be interested in participating in the study. Interviews lasted between 40 and 80 minutes, were semi-structured, and aimed at investigating the respondents' understanding of ethics in relation to technology, their view of ethics of technology as a topic and perspective in technology education, as well as their teaching and assessment activities.

The material was analyzed in terms of how teachers describe the project or projects of teaching ethics of technology, searching for “bundles” (Kemmis et al., 2014) of characteristic aims and intentions “hanging together” with characteristic sayings, doings and relatings. Importantly, the respondents' talk about their practices was not approached as necessarily corresponding to their “actual” practices. Rather, the analysis aimed at interpretatively reconstructing teaching practices from interview accounts saturated by practice, employing systematic comparisons, looking for regularities and inconsistencies and relating to the theoretical starting points in practice theory.

No generative AI tools was used in preparing the manuscript.

5 RESULTS

A clear pattern across interviews was that the teachers on the one hand described ethical questions as central to technology education and ethics as an important area of instruction, but on the other hand reported very little explicit instruction on ethics. That is, what teachers described as ethical questions in interviews were in the classroom seldom framed using “ethics” as a concept, and theories or frameworks concerned with ethics were seldom drawn on. As such, teaching ethics

seemed to be a largely implicit project, conducted in bits and pieces embedded in several other topics of instruction that are more central to the curriculum. In particular, fragments of ethics instruction were embedded in three more prominent projects: 1) developing technical-analytical capacities, 2) developing socio-technical understanding and awareness, and 3) developing responsibility, agency, and openness. These projects are described briefly below, and an overview of common sayings, doings, and relatings bundled together in these projects are presented in Table 1.

Table 1

Overview of characteristic projects, sayings, doings, and relatings of teaching ethics in Swedish secondary technology education

Projects	Sayings	Doings	Relatings
Developing technical-analytical capacities	Ethics is concerned with consequences for sustainability and social justice	Developing good technology	Students as users of technology
Developing socio-technical understanding and awareness	Ethics is concerned with rules and regulation	Assessing products and solutions	Students as future developers of technology
Developing responsibility, agency and openness	Ethics is concerned with actions and responsibility	Discussing disruptive technology	Students as developing moral agents
		Debating and taking a stand	Teachers as catalysts
		Discussing behaviour and responsibility for technology	Teachers as neutral facilitators

5.1 *Developing technological-analytical capacities*

First, the teachers described how they touched on ethical questions when teaching design and technology assessment. In the classroom, these activities were generally not framed as being concerned with ethics, but the teachers described them as helping students develop capacities important to being a responsible designer or user and consumer of technology. Ethics was here construed as mainly concerned with what consequences a particular product or technology brings about. The teachers particularly talked about consequences for environmental sustainability, but to some extent also consequences in terms of inclusion, fairness, and labour conditions. Talking about how he tried to engage students in developing “good” technology, Anders described how:

“Our students are creating products and artefacts, either as an add-on to something existing or something completely new. And then the idea is that it should always be sustainable

development. There should be sustainability in it, in terms of resources, social sustainability and economics.” (Anders)

Along the same line, other teachers talked about prompting their students to reflect on environmental consequences of their material choices when developing products. One teacher talked about teaching methods for inclusive design and prompting students to reflect on whether their designs could exclude certain groups, such as people with physical disabilities.

In terms of assessing existing products and technologies, Alice described how:

“When we worked with recycling, we talked about: Our clothes, where do they come from? They got to look at the information inside their own sweaters, in what part of the world are they produced? And should we keep consuming as much as we are doing? And we looked at how much a person in Sweden throws away as garbage and so on” (Alice)

Several other teachers similarly talked about investigating the lifecycle of existing products, some drawing explicitly on Life Cycle Analysis (LCA) but in a simplified format.

5.2 *Developing socio-technical understanding and (ethical) awareness*

Another prominent project was to develop students’ understanding of the role of technology in society. In this project, ethics were sometimes referred to explicitly, with teachers wanting to raise awareness of the ethical questions and dilemmas that certain technologies entail. In comparison to developing technological-analytical capacities, the teachers here did not mention any methods or theories. Instead, the main activity in this project was to discuss *examples*, particularly examples of disruptive technology, including for instance: autonomous vehicles, generative AI, genetic engineering, nuclear power, surveillance technology, digital communication and social media. Anne described the following activity:

“I usually describe some historical innovations and inventions, and then they get to choose one to delve deeper into and then present that to each other. And one of the things they need to answer then is “Was this development only positive? Or were there negative consequences?””

Fredrik was one of few teachers who described sessions explicitly labelled and focused on ethics of technology. Similar to many of the other teachers, he described how his students would get to read or hear about disruptive technologies and then discuss questions concerning consequences and responsibility, for instance describing how:

”I mean, autonomous cars need to act in dangerous situations. Who gets saved? Who should decide that, and what happens if something goes wrong? Who is responsible?” (Fredrik)

Although the teachers mainly talked about raising such questions for open discussion, some described how they introduced exercises where students needed to take a stand and justify their opinions, or debate in groups after having prepared arguments for an assigned perspective. In

relation to such exercises, the teachers mainly described themselves as catalysts, sometimes provoking discussion but at the same time trying to adopt a neutral stance, emphasizing that there are no right or wrong answers. In terms of assessment, the teachers were unanimous in describing how students' socio-technical understanding was assessed in terms of how well-crafted, nuanced, or cohesive reflections or arguments they produced, orally or in writing.

5.3 *Developing responsibility, agency, and openness*

Almost all teachers further talked about a more overarching and long-term project of developing responsibility, agency and openness in students. This project was loosely connected to all activities discussed by the teachers, but never formally assessed. Several teachers expressed significant commitment to this project, often put in relation to a general commitment to societal betterment or a wider educational mission to foster students into good citizen and – in the case of upper secondary teachers – responsible future engineers. Anders, for instance, who early in his career had worked as an engineer, described this as a central aim of his technology teaching practice:

”When they [the students] are working with technology, they need to take responsibility. This is an important part. And part of the reason I changed occupations. Not only because it is fun to teach. I had worked in industry and been in Shanghai and seen these long tables with young people sitting adding components to circuit boards. It impacted me, I wanted to move away from that. It’s not enough that we produce and mass produce. We need to do it the right way.”

Being responsible for technology was also discussed in relation to students' own use of technology, often in terms of appropriate and inappropriate digital communication or use of AI in school. This was particularly common at the lower secondary level, whereas at the higher secondary level, students were more often prompted to think about the responsibility of engineers developing technology rather than their own responsibility as users of technology.

In relation to the ambition of fostering responsibility and agency in relation to technology, several teachers talked about students as only just developing as moral agents. Here, teachers' descriptions of students' capacity for moral judgement were multi-faceted and at times contradictory, alternatively describing them as both able and unable to discuss and appreciate multiple perspectives, and as both willing and unwilling to shoulder responsibility for technology use and development.

6 DISCUSSION

In several respects, the results of this study echo and substantiate previous findings and claims. First, in line with what has been claimed in previous work, the teachers in this study most often used sustainability concepts to discuss what they saw as ethical questions related to technology, and here focused more on the environmental impact of technology than on consequences in terms of fairness, inclusion or equality (Haug, 2017). Second, teaching ethics of technology appeared as a largely implicit project when compared to topics such as design and technology assessment

(Gradwell, 1999). Some reported activities aligned with exercises outlined in literature on ethics interventions (Ahuja & Kumar, 2025; Hess & Fore, 2018), however, these activities seemed few and far apart and were seldom framed in terms of ethics. Instead, teachers described ethical questions as being addressed in conjunction with design, technology assessment, and disruptive technology, where ambitions to develop knowledge about ethics were subsumed under the development of technological-analytical capacities and broader socio-technical understanding.

Although these findings indicate that teaching ethics of technology is a somewhat peripheral project in secondary technology education in Sweden, the participating teachers still expressed a clear commitment to developing students' sense of responsibility and agency, an ambition that seems less common among ethics of technology interventions at the higher education level (Hess & Fore, 2018). This indicates that the position of ethics of technology in the secondary technology curriculum may in certain respects be less contested than at the tertiary level (cf. Lönngren, 2021). Whereas teachers at the secondary level work and are trained in relation to a broader educational mission, explicitly including the formation of young people into independent and responsible adults, teachers in tertiary technology education are generally subject experts facilitating teaching focused on technical specialization. Seen in this light, the upper secondary level may present both particular challenges and particular opportunities, because teaching at this level is shaped both by a broad educational mission and by a burgeoning technical specialization.

The study contributes new empirical insights into how ethics of technology is addressed in technology education at the secondary level. While the moderate number of participating teachers and the focus on the Swedish technology curriculum naturally entail certain limits to the generalizability and transferability of the findings, the observation that ethics was taught as an implicit rather than explicit topic was coherent across all interviews and is aligned with previous research. Tentative differences observed between educational stages further underscores the need for more empirical work conducted at pre-tertiary levels. Such empirical work is key to understanding how teachers at the secondary level can translate their commitment to developing students' sense of responsibility and agency into practical action.

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Technology and Engineering for Integrated STEM: Synthesised Findings from a Research Programme on Authentic STEM Education

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Abstract

STEM is arguably one of the most widespread and enduring educational visions of the early 21st century. Yet its meaning is largely unclear in a technology and engineering education context, for example, whether integrated STEM represents a sought-after epistemological position or merely a method for teaching technology and engineering. The present paper aims to synthesise research findings from the aSTEM research programme, which investigated the affordances of models and modelling for authentic STEM education, specifically in upper secondary technology and engineering education. In this paper we therefore conduct a qualitative evidence synthesis of all results generated within the research programme, as reported in the published articles and chapters from 2019-2025. The most important findings emerging from the research programme indicate that integrated, authentic STEM education must be taught in ways that are both interdisciplinary (STEM) and that respect the integrity of each included subject domain (S|T|E|M). Consequently, such an approach should be taught by specialised teachers who possess both strong subject knowledge *and* the ability to integrate disciplines. Furthermore, authentic STEM education projects are often viewed as being primarily technology- and engineering-based (engineering design), although they are not always explicitly labelled as such. Lastly, the research programme demonstrates that STEM subject integration is easier said than done, since in practice the integration of STEM content and methods rarely draws on more than two disciplines.

Key Words: Technology Education; Engineering Education; Integrated STEM; Upper Secondary School; Authenticity; Models and Modelling

1 INTRODUCTION

STEM (science, technology, engineering, and mathematics) is arguably one of the most widespread and enduring educational visions of the early 21st century, and could be employed to

describe education in the separate subjects (that is, siloed S|T|E|M) or integration of two or more of the subjects (iSTEM). STEM education has made a significant impact on technology and engineering education. Yet the meaning of the STEM acronym is largely unclear in the technology and engineering context, for example, whether integrated STEM is a sought epistemological position or only a method to teach technology and engineering. Furthermore, the role of science and mathematics in such technology and engineering projects remains elusive, which is particularly troublesome when considering the applications of such projects in real-world contexts (so-called embedded STEM, see Roberts & Cantu, 2012). Despite the extensive discussion and promotion of STEM education, many unknowns remain, and relatively little scientific research has examined the actual implementation of authentic STEM projects (Nordlöf et al., 2024).

The present paper aims to synthesize research findings from the aSTEM research programme which investigated the affordances of models and modelling for authentic STEM education, specifically in upper secondary technology and engineering education.

2 LITERATURE REVIEW

Literature grounding the domain of STEM education research often emphasises the urgent need for authentic, integrated STEM education that maintains disciplinary integrity while allowing for cross-disciplinary connections between disciplines (Kelley & Knowles, 2016). It follows that *authenticity* is often referred to as fundamental to STEM education, and regularly defined as students' participation in real-world practices like those of professional scientists and engineers, where it is deemed essential for meaningful STEM engagement (Murphy et al., 2006; Roth, 1995).

Models and modelling have also emerged as central for achieving integration and authenticity in STEM education. Models are simplified representations of phenomena that support prediction, explanation, and communication across STEM disciplines (e.g., Nia & de Vries, 2017). Kelley and Knowles (2006) advocate modelling as a shared practice in both science and engineering, and essential for solving real-world problems. Hallström and Schönborn (2019) argue that modelling serves as a bridge across STEM subjects, which further enable authentic educational experiences that promote "STEM literacy". Despite their curricular presence, models are often underdeveloped in educational resources. For example, the crucial modelling steps of verification and validation are often omitted in textbooks and curricula, which limits students' grasping of the intricacies of modelling processes (Norström & Hallström, 2023). More frameworks are required to help students understand and scaffold modelling processes in STEM education that are also associated with authentic teaching activities (e.g., Nicaise et al., 2000). A further aspect in the STEM education literature is how *design-based* approaches can support problem-solving in technology and engineering education. In this regard, design projects, especially those grounded in students' everyday contexts, have been shown to enhance relevance and encourage interdisciplinary collaboration (e.g., Anker-Hansen & Andréé, 2019). Nevertheless, full STEM integration remains a challenge, often only involving the integration of two disciplines (Nordlöf et al., 2024).

The STEM education literature also identifies shortfalls in teacher competence and curricula design for meaningful STEM integration. Banks and Barlex (2014) and de Vries (2018) have stressed the need for teacher education programs that directly support avenues for STEM integration. Herein, Leung (2020) has advocated for collaborative teaching approaches to overcome disciplinary silos, and Cole (2019) has noted the scarcity in expert consensus on how to approach these current limitations.

3 METHOD

The research method for this paper consisted of a synthesis of the main contributions of the aSTEM research programme. Thus, the selection of literature did not require a literature search in the traditional sense but included only the peer-reviewed published articles and book chapters within the programme, from 2019-2025 (see Table 1). The type of review and corresponding analysis carried out are aligned with what Grant and Booth (2009) term *qualitative evidence synthesis*, which is a “method for integrating or comparing the findings from qualitative studies” (p. 94). This review method involves purposive and selective sampling, and qualitative thematic analysis and narrative synthesis where findings from the included studies are juxtaposed to identify similarities and differences (e.g., Braun et al., 2023). Furthermore, the synthesis is aided by a conceptual visualisation technique to pinpoint especially pertinent contrasts and ambiguities in the findings (see Figure 1). The authors have not employed AI in the analysis or writing of the paper.

4 SYNTHESISING OUTPUTS FROM THE AUTHENTIC STEM RESEARCH PROGRAMME

Across the period 2019-2025, the aSTEM research programme has developed a progressive research base on the role of models, modelling, and design-based practices for pursuing authentic STEM education in school technology and engineering contexts. A synthesis of journal article and book chapter research output from the aSTEM research programme is provided in Table 1 below. Overall, the aSTEM project’s publications feature aspects of conceptual argumentation and positioning, empirical exploration, as well as forward-looking pedagogical perspectives.

Table 1.

Collection of peer-reviewed journal articles and book chapter outputs from the aSTEM research programme, 2019-2025. The order of the output descriptions also represents the general progression of the research programme.

Output year	Title of work	Publication venue (in-text citation)	Description of relevance and significance of output
2019	Models and modelling for authentic STEM	<i>Int. J. STEM Educ.</i>	Synthesises the core message of the aSTEM research programme, in that

	education: reinforcing the argument.	(Hallström & Schönborn, 2019).	models and modelling are essential for authentic and integrated STEM education. The paper positions authenticity as crucial for STEM literacy, and highlights modelling as the bridge across disciplines.
2023	Models and modeling in STEM education: nature, roles, and implementation	<i>International Encyclopedia of Education, 4th Ed.</i> (Elsevier) (Hallström & Schönborn, 2023).	Foundational to the project in reinforcing the notion that models, and modelling are indispensable across STEM disciplines. Also connects to the pedagogical power of models and modelling in engineering contexts.
2023	Models and modelling in secondary technology and engineering education	<i>Int. J. Technol. Design. Educ.</i> (Norström & Hallström, 2023).	Operationalises the idea of modelling in technology and engineering education through a six-step framework that complements the integrative perspectives in other project outputs. By being grounded in curricula and textbooks, it also supports the project's emphasis on authenticity and disciplinary integrity.
2023	Authentic STEM education through modelling: an international Delphi study	<i>Int. J. STEM Educ.</i> (Hallström et al., 2023).	Central to the potential impact of the aSTEM project by empirically anchoring the concept of authentic STEM education through expert consensus. The study validates and extends the other outputs by identifying design-based elements of authenticity via modelling, e.g. the need for tailoring definitions for different educational levels or audiences. The Delphi also provides a foundation for informing integrated STEM pedagogy.
2024	Experts' Views on the Role of the 'T' and 'E' in Integrated STEM Education and Implications for Out-of-Field Teaching	<i>Locating Technology Education in STEM Teaching and Learning</i> (Springer)	Experts opine that integrated STEM contains contradictions; the 'S' and the 'M' are usually fore fronted while the 'T' and 'E' are downplayed. Engineering design could act as integrator though it would require specialised disciplinary and interdisciplinary teacher expertise to

		(Hallström et al., 2024).	carry out. Integrated STEM education could be construed as a continuum with subject integrity at one end and authenticity at the other.
2024	Easier Said than Done: STEM subject integration through engineering design in Swedish upper secondary school.	<i>Canadian J. of Sci. Math. Technol. Educ.</i> (Nordlöf et al., 2024).	A pivotal study of the aSTEM programme given the emphasis on authenticity and modelling in a real classroom context. While findings show that engineering design projects can support integration, collaboration and real-world relevance, it exposes persistent challenges in achieving true STEM integration. In doing so it both validates and “stress tests” the aSTEM project’s core findings.
2025	Design-based thinking in problem solving in technology and across the STEM disciplines	<i>Ways of Thinking in STEM-based Problem Solving</i> (Routledge) (Hallström & Schönborn, 2025).	Frames design-based thinking as a potential unifying mechanism for authentic STEM education. The articulation of authentic, visual, and entrepreneurial thinking as essential elements complements the other outputs by indicating forward-looking perspectives for integrating creativity, innovation, and real-world relevance into STEM education.

The early outputs of the aSTEM programme contributed to one of the foundational stances of the work, namely, that authentic STEM education requires more than the mere thematic overlap between disciplines. Instead, authenticity can be enhanced by the purposeful use of models and modelling as learning and teaching practices that can actively link scientific and mathematical reasoning with technological and engineering design, for example. Our emerging work has shown that authenticity demands *both* real-world relevance as well as disciplinary ways of knowing, a finding that becomes a recurring feature, almost anchor, of the research findings overall. Subsequent output also extended this position by elaborating on the nature and functions of models and modelling across STEM disciplines. Such examples included clarifying their pedagogical affordances for engineering design education and identifying gaps in the curricula related to modelling processes. In fact, the aSTEM research programme strengthened the emerging claim that models and modelling are a STEM integration “mechanism” as well to maintain disciplinary integrity. Thus, our research has contributed to these key tensions that are often central to the wider domain of STEM education research.

As the research programme developed further, we explored how modelling could potentially be embedded in classroom practice, and in a sense tested how conceptual arguments could be

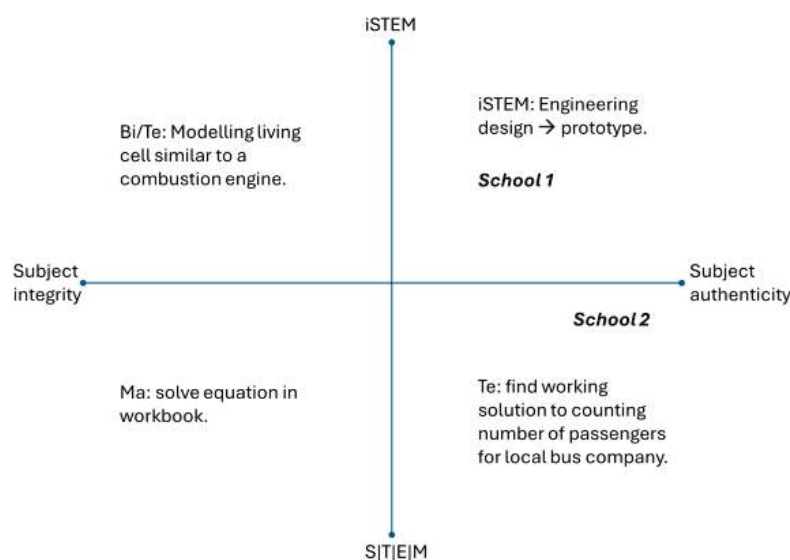
translated into pedagogical steps. In this regard, whilst findings from our Delphi study indicated that authentic STEM education can benefit from a design-driven approach, that is be contextually meaningful and adapted to learners' levels, we showed that pursuing such integrative intentions nevertheless revealed challenging practical constraints and contradictions in how authenticity is enacted. In terms of overall challenges, the research programme showed the dominance of science and mathematics in curricular and policy discourse (cf., Chiu et al., 2025), the often under-emphasis of technology and engineering, and the resulting pressures on teachers working outside of their disciplinary specialisation. In doing so, our work points to integrated STEM as a type of continuum, which requires careful navigation between disciplinary depth and real-world authenticity. Our findings also reassert that successful integration depends on specialised teachers that can traverse and connect disciplinary boundaries. The research programme reinforced the finding that authentic STEM is perhaps attainable, but complex. It requires intentional design, interdisciplinary expertise, and sustained pedagogical support.

5 DISCUSSING PROJECT FINDINGS IN TERMS OF SUBJECT INTEGRITY AND INTEGRATION

The review of the aSTEM project publications 2019 to 2025 shows that STEM education projects can play out in two different, but interlinked, dimensions. Figure 1 displays a horizontal (x) axis showing the degree of real-world connection, from subject integrity on the left to subject authenticity, collaborative and inquiry-based learning on the right. The vertical (y) axis visualizes the degree of subject integration within STEM, from discipline-based, siloed S|T|E|M education at the bottom to fully integrated STEM education (iSTEM) at the top.

Figure 1.

Visualization of synthesised findings from aSTEM programme



It is notable that the programme's introductory theoretical or review studies have a somewhat idealised view of integrated STEM and the role of modelling and real-world connection, showing the importance of models and modelling as a bridge between STEM subjects in order to make them authentic (Hallström & Schönborn, 2019, 2023). Whilst this is certainly true as a central objective of integrated STEM education, later studies also point to some paradoxes and potential pitfalls when implementing such pedagogy, which are pointed out in the figure. The notion that authentic, project- or inquiry-based working methods also entail some kind of compromise with the disciplinary integrity of single STEM subject(s) stands out. The fact that actual integrative STEM teaching also requires teachers with firm grounding in their respective STEM discipline *and* capacity for interdisciplinary cooperation and thus sufficient knowledge of the other STEM disciplines is also prominent (Hallström et al., 2023; 2024).

Figure 1 also indicates where the studied projects at School 1 and 2 from Nordlöf et al. (2024) would be located along the two axes. School 1 employed an engineering design approach and thus scored high on subject integration while also scoring high on authenticity and real-life connection. However, the school also scored low on subject integrity in the sense that the included technology and engineering content was not very discipline specific, and the mathematics and science content was also weak. The School 2 design project was perhaps even more related to real-world contexts on account of its use of quite extensive role-playing components, but it did not implement STEM subject integration to the same degree as at the other school. The subject in question was mainly software engineering which could be construed as a STEM component but was also not connected to other STEM subjects (Nordlöf et al., 2024).

In terms of theoretical grounding of design projects and their relation to STEM, Bernstein (2003) theorises ways of organizing knowledge in the curriculum. He introduces the concept of the *collection* type of curriculum as comparable to the siloed S|T|E|M curriculum, with strong insulation between contents, and the *integrated* type of curriculum, much like the iSTEM curriculum, with weak insulation between contents. Indeed, what separates the two kinds of curriculum is the strength of the boundary between contents. The lower part of Figure 1 also features insulated educational knowledge with typical activities *within* one STEM subject, whereas in the upper part knowledge is less insulated and could incorporate two or more subjects, or an iSTEM working method such as engineering design.

The most important findings to emerge from the research programme are that integrated, authentic STEM education must be taught in a way that is both interdisciplinary (iSTEM) and respects the integrity of each included subject domain (S|T|E|M), so it must be taught by specialised teachers who know the subjects *and* how to integrate them (Hallström et al., 2023). In Bernstein's (2003) terms, these STEM teachers know how to negotiate the strength of the boundary between contents, which may vary depending on the nature of the content and its context. For example, because the teacher team at School 1 was very diverse and heterogenous, the engineering design project became highly integrated and authentic, but it also lacked subject integrity and did not delve into more specific, insulated knowledge components that are also important in technology and engineering (e.g., solid mechanics, materials science). The design project at School 2, on the other hand, was led essentially by one software engineering teacher and as such incorporated more discipline-specific components, though not necessarily having increased subject integrity.

A further finding is that authentic, integrated STEM education projects are often viewed as being primarily technology and engineering based, centred around engineering design, although they are not always labelled as such, presumably because in engineering design it is possible to incorporate elements from all four STEM disciplines in a meaningful and authentic manner (Hallström et al., 2023). On the other hand, the research programme also shows that STEM subject integration is easier said than done, because in reality, integration of STEM content and methods rarely draws on more than two disciplines. This meant that the two schools in our study really foregrounded technology and engineering, but it also led to a superficial integration of STEM subjects and loss of subject integrity, where central content and methods in all four subjects were skimmed over (Nordlöf et al., 2024). There was also deliberate reduction of authenticity at School 2 because it would help in reaching course goals, which begs the question as to whether a balance between subject integrity and authenticity must be struck. Finally, the importance of models and modelling for achieving authenticity was weaker than had been expected, both in the Delphi experts' views and in the actual implementation, for example, at School 1 (Hallström & Schönborn, 2019; Hallström et al., 2023; Nia & de Vries, 2017; Nordlöf et al., 2024).

6 CONCLUSIONS AND IMPLICATIONS

The aSTEM research programme has demonstrated that authentic, integrated STEM education demands far more than multidisciplinary philosophies. It requires a deliberate and active interplay between disciplinary integrity and real-world relevance, which can be strongly supported by the epistemic power of models, modelling and design-based thinking. Across six years of publications, a key take home message emerges from our research. Perhaps STEM integration becomes meaningful only when learners and teachers engage with the distinctive ways of knowing within science, technology, engineering, and mathematics, while simultaneously working across their boundaries. Our research has shown that while this balance is challenging, it is essential for achieving authentic STEM learning experiences.

The findings illuminate several implications for teaching. Firstly, integrated STEM cannot be effectively implemented by generalists alone, it requires teacher (teams) with strong disciplinary expertise and the competence to collaborate across subjects. When planning for STEM projects, teachers need to consider the aim of the teaching. In a project, it can be challenging to achieve both subject integrity and subject authenticity, as well as simultaneously reach STEM integration and in-depth subject knowledge at a level in relation to the curriculum. Therefore, in a design project, it may be appropriate to choose both a strategy and the learning outcome, early in the planning stage. Secondly, modelling and technology and engineering design should be treated as core pedagogical practices, not mere supplementary activities, because they can provide students with opportunities for inquiry and problem-solving. Thirdly, teachers need support in recognising when to maintain disciplinary rigour and when to cross boundaries to favour authentic pathways.

In closing, conducting the aSTEM research programme also opens potential avenues for future research, which could include investigating the development of modelling competence over time, and how teachers negotiate STEM disciplinary boundaries as part of more classroom-based research.

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Technology Education Meets Invention Education: Towards Authentic Design and Problem Solving in School

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Abstract

Technology education is a global phenomenon that is a widespread and critical component of school systems in many countries. At the same time, different conceptions of the nature of technology education may be challenging for teachers and hamper authenticity and real-world connection. The (engineering) design process can be found as a backbone of technology education standards and curricula in many countries and is furthermore a common phenomenon that features across STEM subjects as well. In this position paper, therefore, the aim is to propose an infusion of elements from invention education into technology education, to more firmly ground subject matter specifically around design and thus increase authenticity of the subject and motivate students. Invention education is a novel educational intervention connected to STEM that explicitly foregrounds the processes and activities by which inventors approach problem solving, which are closely related to design. It is concluded that technology education may gain access to a more invention-oriented conceptual framework from exploring aspects of invention education which can, in turn, inform signature pedagogies in relation to design. At the same time, invention education may benefit from integrating with a well-established disciplinary tradition that exists in many countries throughout the world from exploring technology education more deeply.

Key Words: Invention Education, Technology Education, Design, Authenticity

1 INTRODUCTION

Technology education is a global phenomenon that is a widespread and critical component of school systems in many countries. At the same time, however, technology education also struggles for its place in the curriculum, not the least because of the great variation in how the subject is manifested in national curricula and standards (Jones et al., 2013; Nordlöf, 2022; Norström, 2022). In this regard, over the world technology education could be conceived of as based on or related to craft and sloyd (e.g., Finland), design (e.g., the UK, Norway), STEM (e.g., the USA), vocational education (e.g., the USA, South Africa), technological literacy (e.g., New Zealand, Sweden), or even be perceived as a digital subject concerned with digital tools and

systems, ICT, and computational thinking (e.g., Denmark, planned subject 2027, partly Australia, “Digital technologies”) (ACARA, 2015; Gill et al., 2023; Norström, 2022). The different conceptions of the nature of technology education may be challenging for teachers since they lead to uncertainty about the subject matter to be taught, which in turn hampers authenticity and real-world connection of classrooms activities (Nordlöf, 2022).

There is, however, one element that is all but universal in technology education, namely, the (engineering) design process. It can be found as a backbone of standards and curricula in many countries and is furthermore a common phenomenon that features across STEM subjects as well (e.g., Hallström & Ankiewicz, 2023; Rossouw et al., 2011; Stables, 2020; Sung & Kelley, 2022). In this position paper, therefore, the aim is to propose an infusion of elements from invention education into technology education, to more firmly ground subject matter specifically around design and thus increase authenticity of the subject and motivate students. Invention education is a novel educational intervention connected to STEM that explicitly foregrounds the processes and activities by which inventors approach problem solving, which are closely related to design. Invention education has gained momentum in the USA and South Korea, for example, and could be defined both as a pedagogical approach and a field of research (Lemelson Foundation, forthcoming).

2 INVENTION EDUCATION: INVENTIVENESS AND PROBLEM SOLVING

At face value, invention education is an intuitive and easily conceived phenomenon; it is about experiences tied to learning about inventions, the invention process, entrepreneurship, and how to develop inventiveness and problem-solving skills. Though that may seem straightforward, the invention education community has not settled on a single definition so multiple conceptions abound. In this paper, we advance a conceptualization of invention education that builds upon the prior definition put forth by the Invention Education Research Group (2019):

Invention education offers learners engagement in ideation, design, making, testing, revision and marketing of creations that they conceived to solve real-world problems of their choice. The main learning goal of IvE is occasionally the end product or invention. More often, the goal is on the process and the development of inventiveness—mindsets, capacities, skills and knowledge—frequently used by boundary-crossing inventors and valuable to the workforce of tomorrow. These educational opportunities may support learners through the entire process or select components and experiences that take place in multiple contexts over time with educators from various backgrounds facilitating the learning.

What this means in practice is something that researchers have enquired about without coming to a conclusive definition. In this section, we will outline a framework of strategies as a way of breaking down main components of invention education and connecting it to a broader technology education agenda.

2.1 *Strategies for inventive problem solving*

In recent work, Maltese et al. (2025) conducted a Delphi study with experts with roots in invention to identify the capacities and strategies necessary for doing inventive problem solving. This work produced a set of 20 capacities and 23 strategies that were identified as critical to problem solving. The list of *personal capacities* includes traits and abilities that an individual can develop that are helpful toward developing solutions, for example: 1) Seeking to identify with and share diverse perspectives, experiences, and/or feelings (Empathy), and 2) Adjusting goals and strategies to handle changing situations and circumstances (Adaptability). In contrast, *strategies* are characterized as approaches, heuristics or other components of problem solving that can be employed to assist in the process. Here we specifically focus on the 23 strategies as they can be easily compared with activities and components of the design process, see Table 1.

Table 1

Strategies for Inventive Problem Solving

Strategy	Description
Perspective taking	Examining problems and solutions from multiple points-of-view.
Critical thinking	Carefully evaluating information, evidence and options, through reasoning, reflection and analysis, to draw conclusions.
Visualization	Envisioning and considering potential outcomes and challenges before they arise.
Valuing diversity	Intentionally considering and including input from those with varied perspectives, backgrounds, and experiences.
Divergent thinking	Generating a wide range of ideas and possibilities related to a task or problem.
Inquiry	Active questioning, research, analysis, and comprehension; sometimes inclusive of experimentation and/or observation.
Design process	Engaging in cycles of idea generation, prototyping and testing to refine solutions or improve results.
Evaluation	Determining value or quality through use of evidence; may involve establishing and comparing against a set of criteria.
Synthesis	Making connections and consolidating ideas across existing knowledge, research and/or experiences.
Human-centered design	Considering and appropriately incorporating the needs of intended users/audience at all stages of the process.

Experimentation	Investigating a phenomenon through a designed set of tests, data collection, analysis and interpretation.
Questioning assumptions	Aware of and questioning biases, existing norms, assumptions, and processes.
Iteration	Engaging in multiple rounds of prototyping for the purpose of integrating new information or to improve outcomes.
Exploring complexity	Seeking to understand the relationships and dynamics between system components across domains.
Asset identification	Identifying and evaluating information, people and materials that may be useful toward solving a problem.
Observation	Noticing and discerning meaningful details, patterns, occurrences, and insights in information.
Reflection	Thinking deeply on the meaning or implications of experiences, beliefs and actions.
Incrementalism	An approach that involves accomplishing small goals toward a larger solution.
Problem definition	Defining and understanding the problem you're trying to solve, in detail.
Strategic thinking	Analyzing critical factors and variables that will influence long-term success.
Collaboration	Working with others, in an integrated way, toward a collective goal.
Leadership	Providing guidance to others in the form of oversight, direction, ideas and work to accomplish shared goals.
Communication	Bi-directional ability to convey/understand ideas, solutions, and perspectives presented through verbal, written and visual forms.

Note: Based on Maltese et al. (2025).

The strategies outlined in Table 1 are general and applicable to many different areas, and thus they constitute components of problem-solving capabilities or design thinking that may be useful while addressing any type of problem (e.g., Royalty, 2018). A similar case could be made for 21st century skills which also overlap with the strategies in Table 1, for example, creativity, innovation, critical thinking, and collaboration (Banks & Barlex, 2020). However, the strategies stem from a design and innovation context where each of them has an explicit meaning and role to play when through processes of design one invents and innovates products and systems that should meet customer desires and standards requirements (Glaa et al., 2023; Hallström & Schönborn, 2025; Maltese et al., 2025). Therefore, although they can be seen as general problem-solving strategies, they are, in fact, deeply rooted in (engineering) design, invention, and innovation, in all their variety. This makes sense given that inventions are often born from a desire

to solve an issue that an individual or group identifies or to improve aspects of life and work in some way.

3 TECHNOLOGY EDUCATION INFUSED WITH AN INVENTION EDUCATION PERSPECTIVE

By tradition, technology education has incorporated design as a central component, but at the same time the conception of design has often been formulaic and centred on one, linear model or step-based representation of the design process. Stables (2020) describes the challenges of relying on one “true” model of the design process as:

a quest among professional designers to create a modernist, universal approach to designing, which was made manifest through a clinical, linear set of steps to be followed – a model that was adopted in schools and reinforced through assessment structures. Drawing on more recent design research, the linear model that persists as something often called ‘the’ design process has been challenged, questioning whether it is either true or helpful in developing design capability. [...] This more recent analysis has provided a less simplistic, more authentic perspective, drawing together the speculative, wicked, uncertain, iterative nature of designing, negating an idea that there is one standard design process (p. 101).

Stables (2020) argues that pinning down with certainty exactly what is design knowledge might be construed as akin to the search for a holy grail, when design knowledge is more about having access to a repertoire of skills (p. 102). This more iterative and authentic notion of design, including key aspects about failure and iteration (e.g., Simpson & Maltese, 2017), is nowadays embraced both in technology education and invention education (e.g., Schut et al., 2020). However, although many of the above items from Maltese et al. (2025) are well known in technology, engineering, and design education contexts, the exact nature of their relation to design and the extent to which they are applied in curricula and classrooms remain unclear. In what follows we map central elements of invention education onto technology education with the objective of boosting design thinking and design processes for elementary and secondary classrooms. The selection of literature was performed following a protocol for narrative reviews, the object of which is to pinpoint pertinent literature for the topic at hand without following a pre-determined procedure (e.g., Demiris et al., 2019). Following an inductive, comparative reading of central literature, it was decided to compare Stables (2020) and Maltese et al. (2025) by mapping central facets of design in invention education onto signature design pedagogies in technology education (see Table 2). GenAI was used solely to soundboard initial mapping ideas.

Most, if not all, problem solving strategies in Table 1 relate to design directly or indirectly, but the extent to which they can be brought in as part of a repertoire of design thinking in technology education is hitherto unknown. Thus, in Table 2, we attempt to superimpose these strategies onto Stables’ (2020) “signature pedagogies” (Shulman, 2005) of design knowledge, see Table 2.

Table 2*Signature Pedagogies for Design Knowledge and Strategies for Inventive Problem Solving*

Signature Pedagogies (Stables, 2020)	Problem Solving Strategies (Maltese et al., 2025)
Pedagogies of speculation	Divergent thinking
<i>Exploring possibilities, generating alternatives, asking “what might be?”</i>	Exploring complexity
	Questioning assumptions
	Visualization
Pedagogies of imaging and modelling	Communication
<i>Externalizing and refining ideas through representation, prototyping, and iterative design work</i>	Design process
	Incrementalism
	Iteration
	Visualization
Pedagogies of need to know	Asset identification
<i>Identifying and pursuing the knowledge needed to move a design forward</i>	Inquiry
	Problem definition
	Exploring complexity
Pedagogies of critiquing	Critical thinking
<i>Evaluating ideas, reasoning through evidence, and reflecting on decisions</i>	Exploring complexity
	Evaluation
	Reflection
	Strategic thinking
	Synthesis

Pedagogies of collaboration	Collaboration
<i>Designing with and for others; incorporating multiple perspectives</i>	Communication
	Leadership
	Human-centered design
	Perspective taking
	Valuing diversity
Pedagogies of materiality	Asset identification
<i>Learning through experimentation, observation, and interaction with materials or systems</i>	Experimentation
	Observation

Note: Based on Stables (2020) and Maltese et al. (2025).

Table 2 presents our attempt to align two different sets of constructs that are related to teaching principles of design, among many. Whenever this type of comparison is done there are likely to be areas where the fit is better than others. Regardless of how perfect the fit is within and across these categories, we feel it is worth considering how such an alignment or reaching beyond disciplinary traditions may be beneficial to consider.

4 CONCLUDING DISCUSSION AND IMPLICATIONS

Just like invention education, it can be argued that technology education lacks a clear, unified knowledge base, manifested in the multitude of curricular representations that were exemplified in the beginning of the paper. Will we not just add a new layer and another set of concepts to an already shaky epistemological foundation? We believe not and thus present this paper to attempt to make explicit some linkages between disciplines and disciplinary practices that are typically not connected. We believe that the bridge between these two areas, invention education and technology education, can help the flow of ideas between these bodies of research literature and instructional practices and should enable multilateral improvements, epistemologically as well as in educational practice. We think that technology education may gain access to a more invention-oriented conceptual framework from exploring aspects of invention education (Table 1) which can, in turn, inform signature pedagogies in relation to design (Table 2). At the same time, invention education may benefit from integrating with a well-established disciplinary tradition that exists in many countries throughout the world from exploring technology education more deeply. For example, the signature pedagogies suggested by Stables (2020) could inform

invention education pedagogy with elements from a more structured conception of design that is at the same time focused on “wicked” problems and iterative problem-solving.

We thus argue that the signature pedagogies and identified strategies could lead to more effective problem-solving, inventiveness, and real-world relevance in technology education classrooms. Additionally, this will ground design and invention more clearly in the technology education subject philosophy, and vice versa, inform invention education with more structured philosophical and pedagogical elements from technology education. A downside is that the mapped pedagogies and strategies are conceptually very similar, so the mapping has been done with care and not as a 1:1 mapping but several strategies could be mapped onto more than one pedagogy. Apart from being a better mapping, it is, we believe, also more in line with the iterative nature of both design and invention.

Traditional presentations of the design process seem to be plagued by the same issues that are problematic in other disciplines when a non-linear process is distilled (cf., Keirl, 2020). For example, the “scientific method” is taught in schools around the world as a set of ordered steps. This method, which is an abstraction of science in action, may have some structure and temporality that makes sense in a school context, but if it is presented as a rigid set of steps it will not be representative of how science is done (e.g., Osborne et al., 2003; Rudolph, 2019), just like the notion of the design process and how it is carried out in practice. In a similar vein, invention education is not strictly about studying famous inventors or the patent process, just like science is not about only knowing established facts or doing laboratory work, or technology education is not merely about designing and making products. Although it is much easier for an educator to transmit concrete times, dates, places, facts, and procedures than taking time to develop students’ creativity, critical thinking, or resilience, if the former is complemented with the latter it is obviously more authentic and beneficial to the long-term impact on our students, be it in science, invention, or technology education (e.g., Herrington et al., 2010).

As researchers, we may be interested in semantics or determining where fields overlap or not. Yet, the impact of this paper will likely be small if it is left at the stage presented here, where it is detached from the reality of education, educators, and learners. Thus, we argue there are some important next steps that we plan to pursue to push these ideas further. We plan to gather input from elementary and secondary educators in Sweden through interviews and observations of teaching, to understand how they conceive of this overlap and how they attempt to put some of these ideas into practice when teaching design-related and non-design content, in technology education and across STEM disciplines. We also plan to review the broader education ecosystem in Sweden to understand what current programming exists that provides youth with the opportunities to engage in these types of activities (e.g., design or invention competitions).

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Investigating the Link Between Professional Vision and Professional Action in Technology Education

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Abstract

Effective teaching requires the ability to swiftly and accurately interpret classroom situations - a skill known as professional vision (PV). PV is considered crucial for teaching quality. This article introduces two research instruments that have been developed to evaluate professional teaching practices and PV among technology and design teachers. The first instrument analyses teachers' classroom videos using a structured observation manual focusing on cognitive activation and constructive support (N = 9). The second instrument assesses PV through instructional video vignettes depicting classroom situations that highlight pupils' conceptions. Teachers respond to these vignettes by describing, evaluating, and proposing alternative instructional actions (N = 121).

Together, the instruments provide complementary perspectives on professional competence by linking teachers' interpretive processes with their enacted classroom practices. This combined approach allows an examination of how teachers perceive, interpret, and respond to pupils' conceptions in instructional situations and provides a basis for investigating professionalisation pathways, particularly across different entry routes into the teaching profession.

Key Words: Professional Vision, Professional Action, Teaching Videos, Video Vignettes

1 INTRODUCTION

Understanding teaching quality requires more than analysing observable instructional behaviour alone. Teachers continuously interpret classroom situations, attend to pupils' contributions, and make sense of learning processes while teaching. These perceptual and interpretive processes, commonly conceptualised as professional vision, are considered a key component of professional competence and a prerequisite for adaptive instruction. In recent years, video-based approaches have become a prominent means of investigating professional vision, as they allow teachers'

situation-specific skills to be examined in a controlled yet context-rich manner (Eghtessad & Goreth, 2023).

At the same time, research on teaching quality has emphasised the importance of analysing enacted instructional practice in authentic classroom settings. Classroom video studies provide insight into how teaching unfolds in situ and how instructional quality can be described along established dimensions such as cognitive activation and constructive support (Minnameier et al., 2015). However, approaches focusing exclusively on either professional vision or observable teaching practice remain limited in their ability to capture the complexity of professional competence.

Against this background, the present article introduces a linked research approach that combines vignette-based measures of professional vision with analyses of teachers' own classroom video recordings in the context of Technology and Design education. Using robotics as an exemplary content domain, the study focuses on how teachers perceive, interpret, and address pupils' conceptions. By presenting first empirical findings, with focus on teachers with different entry backgrounds, from both instruments, the article aims to illustrate the analytical potential of combining these perspectives and to discuss the opportunities this approach offers for research on professional competence and teacher professionalisation.

2 LITERATURE REVIEW

2.1 *Professional Vision as an Analytical Construct*

The construct of professional vision originates from Goodwin's (1994) notion of professional vision, which describes how members of a profession learn to perceive and interpret situations in profession-specific ways. Sherin (2001) transferred this concept to the teaching profession, conceptualising professional vision as teachers' ability to selectively attend to relevant classroom events and to interpret them based on professional knowledge. Since then, professional vision has been established as a central construct in research on teachers' professional competence and teaching quality (Blömeke et al., 2015; Seidel, 2022).

Professional vision is commonly described as comprising two interrelated components: selective attention (or noticing) and knowledge-based reasoning (Sherin & Van Es, 2009). Selective attention refers to identifying pedagogically relevant events in complex classroom situations, whereas knowledge-based reasoning involves interpreting and evaluating these events using pedagogical and subject-specific knowledge. Importantly, professional vision goes beyond descriptive observation and entails theory-informed sense-making of instructional situations (Seidel & Stürmer, 2010).

Within broader models of teacher competence, professional vision is understood as a situation-specific competence that mediates between teachers' professional knowledge and their instructional actions (Blömeke et al., 2015). It is therefore not a stable trait, but sensitive to instructional context, subject matter, and teachers' professional experiences. Video-based research has shown that professional vision can be fostered through systematic engagement with

instructional videos and is related to central dimensions of teaching quality (Seidel & Stürmer, 2010; Steffensky & Kleinknecht, 2016).

What teachers attend to and how they interpret classroom events depends on instructional goals, subject matter, and normative orientations toward teaching and learning. From this perspective, professional vision provides an analytical lens for examining how teachers make sense of instructional situations rather than a direct measure of teaching performance. This distinction is particularly relevant for the present study, which does not aim to evaluate teaching effectiveness per se, but to analyse how teachers perceive and interpret pupils' thinking in technology-related learning contexts.

2.2 *Pupils' Conceptions as Analytical Focus*

Pupils' conceptions represent a central reference point for analysing teaching and learning processes, as they shape how learners interpret instructional tasks and make sense of subject matter (Dorfner et al., 2017; Kattmann et al., 1997; Gropengießer & Marohn, 2018). Research on teaching and learning emphasises that pupils' understanding is not directly observable, but becomes visible through their verbal contributions, actions, and problem-solving strategies in classroom situations. Analysing pupils' conceptions therefore requires an interpretive perspective that goes beyond surface-level task performance and focuses on the underlying assumptions guiding pupils' thinking (Schecker & Duit, 2018).

From an analytical standpoint, pupils' conceptions are not treated as isolated misconceptions or individual errors, but as coherent explanatory frameworks that influence learning processes (Kattmann et al., 1997; Gropengießer & Marohn, 2018). These conceptions can support learning when they are productively connected to instructional goals, but they may also constrain conceptual development when they remain implicit or conflict with central subject-specific ideas (Wilhelm & Schecker, 2018). For instructional analysis, identifying such critical aspects of pupils' thinking is therefore a prerequisite for understanding learning opportunities and instructional challenges within classroom situations.

In the present study, pupils' conceptions are approached through teachers' analyses of instructional situations. Video-based representations of classroom practice and scripted instructional scenarios provide access to situations in which pupils' ideas become visible through interaction and different tools used by the teachers in the videos.

The present study operationalises the analysis of pupils' conceptions by focusing on specific analytical emphases: (a) the recognition of critical aspects of pupils' thinking, (b) the interpretation of these aspects with respect to pupils' understanding and learning processes, and (c) the evaluative framing of pupils' conceptions in relation to instructional goals. Emphasis is placed on whether teachers identify relevant conceptual issues and how they make sense of them.

2.3 *Interpreting Video-Based Measures of Professional Vision*

Video-based approaches have become an established method for assessing situation-specific professional competencies, particularly professional vision.

By presenting standardised yet context-rich representations of classroom situations, video-based instruments allow teachers' perceptual and interpretive processes to be elicited in a controlled manner (Seidel & Thiel, 2017; Junker et al., 2020). Teachers' responses to video stimuli reflect which aspects of instructional situations they perceive as relevant, how they interpret pupils' contributions, and how they evaluate instructional decisions (Sherin & Van Es, 2009).

The interpretation of video-based measures requires careful consideration of their analytical scope. Professional vision, as assessed through video vignettes, does not capture teaching behaviour itself, but teachers' reasoning about instructional situations. Empirical studies indicate that such analytical abilities are related to professional knowledge and instructional quality and may predict aspects of teaching performance (Kersting et al., 2012; Santagata & Yeh, 2014). At the same time, the relationship between professional vision and enacted teaching practice is complex and mediated by situational and contextual constraints (Steffensky & Kleinknecht, 2016). For the present study, video-based measures of professional vision are interpreted with a specific analytical focus on pupils' conceptions as they are a key component for pupils learning as described above.

2.4 *Observed Teaching Practice as Complementary Evidence*

While video-based vignettes provide insight into teachers' professional vision, analysing observed teaching practice offers a complementary perspective on enacted instructional behaviour. Video recordings of classroom instruction enable complex teaching processes to be captured in situ and allow repeated, systematic analysis of instructional interactions (Denn & Hess, 2018; Seidel, 2011). In contrast to vignette-based assessments, classroom videos reflect actual instructional decisions under authentic classroom conditions.

Research on teaching quality has shown that video-based observation is particularly well suited for analysing core dimensions of instructional quality, such as cognitive activation and constructive support (Klieme, 2019; Gräsel & Göbel, 2022). These dimensions focus on the depth of students' cognitive engagement and the quality of instructional support provided by teachers, rather than on surface-level teaching behaviours. In science and technology-related subjects, cognitive activation is considered especially relevant, as it involves engaging pupils with conceptions (Steffensky & Neuhaus, 2018).

In the present study, observed teaching practice is analysed with a specific focus on if and how teachers diagnose, address, and reflect pupils' conceptions during instruction. Low-inference observation indicators are used to document whether and how pupils' ideas are elicited, taken up, and integrated into instructional processes. This approach allows instructional behaviour to be described in a structured and comparable way, while minimising interpretive overreach. Observed teaching practice serves as complementary evidence that illustrates how teachers' instructional

actions relate to pupils' conceptions and how diagnostic aspects may become visible in classroom interaction. By combining vignette-based measures of professional vision with descriptive analyses of teaching practice, the study adopts a triangulated perspective that supports a nuanced interpretation of teachers' professional competence. In this article, findings from classroom video analyses are reported descriptively.

Their primary purpose is to demonstrate the analytical potential of the observation framework and to contextualise results from the vignette-based assessment of professional vision.

3 METHODOLOGY

3.1 *Research Design*

The present study follows a cross-sectional research design and is embedded in a broader project (*ProQ-STEAM*) on professional vision and teaching practice in *Technology and Design* education in Austria. The aim of the project is to find appropriate measures to qualify different groups of teachers, with focus on career changers and out-of-field teachers but also certified teachers. This contribution focuses on the analytical approach and first empirical findings derived from two complementary video-based instruments. The leading research questions are:

- (i) Do career changers, out-of-field teachers and certified teachers differ in their professional vision with regard to the diagnosis of pupils' preconceptions?
- (ii) How do the various groups address aspects of cognitive activation and constructive support with regard to pupils' preconceptions in their instructional practice?

Since only a small number of video recordings are available for professional action, these will initially be examined descriptively. However, the overarching goal is to investigate how the two concepts are linked and how the groups differ to find appropriate measures for further training.

3.2 *Sample*

Two samples were included in the study. First, data from the vignette-based instrument were collected from $N = 121$ teachers in *Technology and Design* education in Austria. The sample comprised teachers with different professional backgrounds, including certified subject teachers ($N = 62$), out-of-field teachers ($N = 38$), and career changers ($N = 21$). This composition allowed comparisons between groups with varying professional qualifications. Furthermore, the sample consists of 80 female, 40 male teachers and one diverse teacher.

Second, a subsample of $N = 9$ teachers provided classroom video recordings of their own instruction. The sample consists of five career changers, two certified teachers and two early teachers (still studying but working in school).

3.3 Instruments

3.3.1 Video Vignettes on Pupils' Conceptions

Professional vision was assessed using instructional video vignettes developed within the *VidNuT* project. The vignettes depict scripted classroom situations using robotics as an exemplary content domain. Each vignette focuses on pupils' conceptions related to robotics.

The vignettes represent prototypical instructional situations and focus on diagnosing and dealing with pupils' conceptions in selected robotics-related contexts (e.g., line-following robots). At predefined stop points, participants responded to structured prompts using a combination of open-ended formats and 5-point Likert-scale items (see Figure 1) aligned with core components of professional vision: noticing and describing relevant aspects (three items), interpreting & judging situations (eight items) and generating instructional alternatives (two items). The items are interpreted relative to an expert norm ($N = 5$). To ensure comparability across response formats, both closed Likert-scaled items and open-ended responses were transformed to a common three-level scoring scheme reflecting proximity to the expert-based reference. For closed items, participants' ratings were compared to item-specific expert medians. An exact match with the expert median was awarded one point, a deviation of one scale point was awarded 0.5 points, and deviations greater than one scale point received zero points. Open-ended responses were scored analogously based on an expert-informed coding rubric and subsequently transformed to the same 0–0.5–1 scale (see Table 1). Item scores were aggregated to form a total professional vision score.

Figure 1

Example of Items to assess Professional Vision including Noticing and Describing, Interpretation and the Development of Alternative Courses of Action

Schauen Sie sich die Videosequenz an und beantworten Sie anschließend die untenstehenden Fragen.



Beschreibe, wie die Lehrperson auf die Aussagen bzw. Vorstellungen der Schüler:innen eingegangen ist.

Die Lehrperson ist im ausreichenden Maße auf die Vorstellungen der Schüler:innen eingegangen.

trifft gar nicht zu trifft eher nicht zu trifft teilweise zu trifft eher zu trifft vollständig zu

Begründe Sie bitte Ihre Bewertung.

Wie hätte die Lehrperson alternativ auf die Aussagen der Schüler:innen eingehen können?

Table 1

Example: Assessment-Matrix for the Vignette “Line-Following-Robots” (Diagnosing Conceptions)

Stop Point	Dimension	0 Points	0.5 Points	1 Point	Expert Anchor
Stop point 1_2: Menti-meter	Justification of the assessment.	No assessment or mere repetition of the scale.	Assessment without clear justification.	Explicit assessment with comprehensible justification (advantages and disadvantages).	Positive: Quick overview; activating; easy to implement; patterns; initial brainstorming. Negative: No differentiated statements; results need to be discussed.
Stop point 2_1	How the teacher responds to answers.	No or purely vague description.	Partial / superficial description.	Differentiated, observation-based description.	Positive: Praise; no classification of answers; connection strategy. Negative: Linguistic reformulation / correction of answers.
Stop point 2_3	Assessment of responding to pupils' statements.	No assessment or mere repetition of the scale.	Assessment without clear justification.	Explicit assessment with comprehensible justification (advantages and disadvantages).	Positive: Pupils statements partly addressed (not sufficiently). Negative: Weighting of results not discussed; no collection for further progression.
Stop point	Alternative course of	No	General / unspecific	Concrete didactically	Ask follow-up questions; discuss and save aspects (hypotheses based on Mentimeter); distinguish robotics

3.3.2 Classroom Video Recordings

To analyse teachers' instructional practice, classroom video recordings were examined using a structured observation manual. The manual is designed to capture central aspects of instructional quality with a specific focus on cognitive activation and constructive support. Its development

draws on established approaches from large-scale video studies such as *PERLE* (Lotz et al., 2013) and *Pythagoras* (Hugener et al., 2006) and follows a low-inference observation logic to ensure analytical transparency and reliability.

The observation manual is organised according to the temporal structure of a lesson and distinguishes between three instructional phases. Across these phases, the manual targets key instructional processes related to pupils' conceptions (see Table 2). In addition to phase-specific indicators, the manual includes overarching dimensions that apply across all lesson phases. Each indicator was coded dichotomously (0 & 1) to capture whether specific practices occurred during the lesson. Since there are only a few video recordings and this is an initial descriptive insight into the results, they were initially coded by one person. Several coders will review the material for the overall analysis.

Table 2

Overview: Dimensions of the Observation Manual for Professional Action

Section of the Manual / Phase	Dimensions
Lesson Introduction: Diagnosis of pupils' conceptions.	1 Making learning status explicit. 2 Exploration of prior knowledge. 3 Elicitation of individual concepts. 4 Use of instructional methods.
Working Phase: Dealing with pupils' conceptions	1 Exploration of pupils' reasoning. 2 Support of cognitive autonomy. 3 Cognitively challenging tasks and problems. 4 Insisting on explanation and justification
Lesson Conclusion: Reflection on pupils' conceptions.	1 Making learning status explicit. 2 Content of reflection. 3 Feedback. 4 Use of instructional methods.
Across all phases: Basic elements	1 Teacher as mediator / cognitively challenging engagement with pupils' contributions. 2 Constructive and content-related feedback. 3 Positive "failing culture".

4 RESULTS

4.1 Professional Vision

Descriptive analyses of the overall professional vision score indicate a moderate level across the sample ($M = 4.03$, $SD = 1.54$, $N = 121$). The aggregated score ranged from 0.54 to 8.13, with a theoretical maximum of 13 points. On average, teachers thus achieved approximately one third of the maximum possible score.

At the same time, the wide observed range points to substantial heterogeneity in professional vision, with some teachers showing very low proximity to the expert reference and others reaching comparatively high levels. To further differentiate the overall findings, the aggregated professional vision score was complemented by facet-specific analyses focusing on describing, evaluating, and generating alternative instructional actions.

Scores for the facet “noticing and describing relevant aspects” ranged from 0.00 to 0.67 with a theoretical maximum of three points ($M = 0.26$, $SD = 0.20$, $N = 143$). Scores for the facet “interpreting & judging situations” ranged from 0.00 to 0.88 ($M = 0.33$, $SD = 0.16$, $N = 134$) with a maximum of eight points. For the facet “generating instructional alternatives” scores ranged from 0.00 to 1.00 with a maximum of two points ($M = 0.27$, $SD = 0.25$, $N = 103$). Figure 2 presents the mean scores for the three facets expressed as proportions of their respective maximum scores.

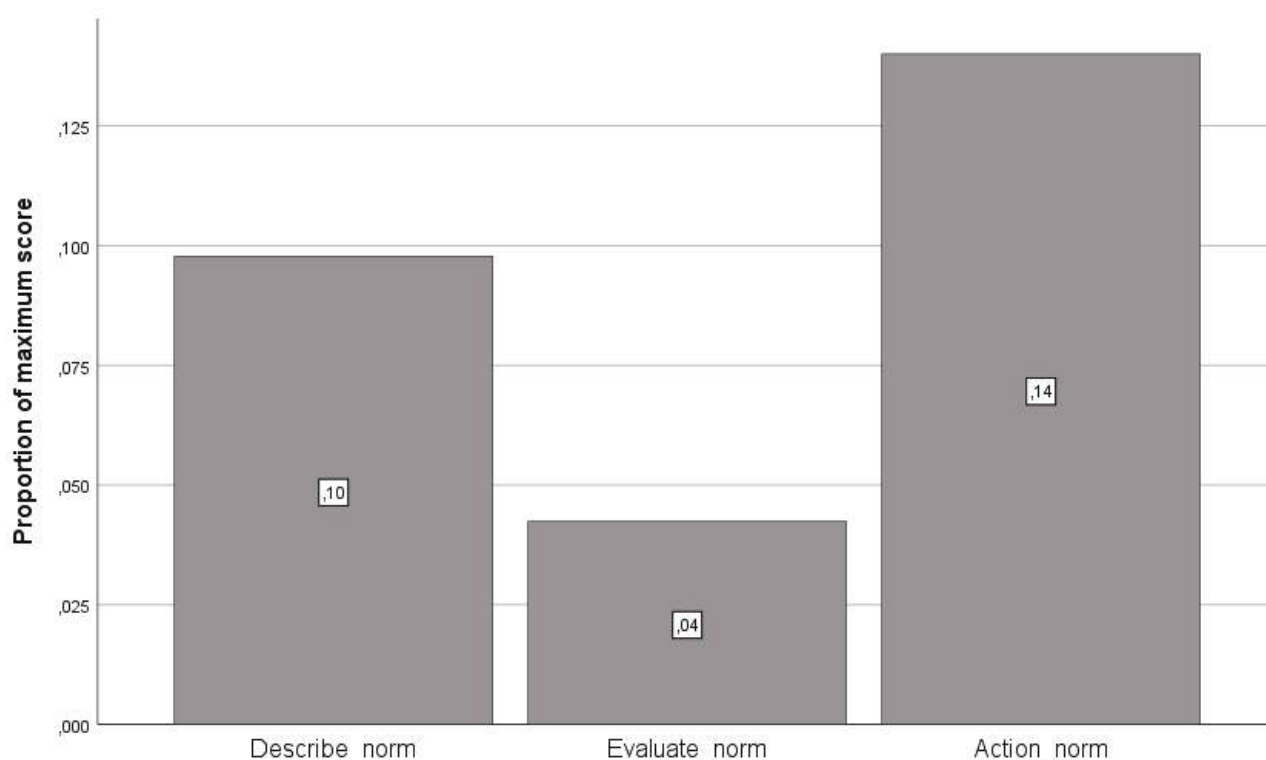
For the overall professional vision score, the analysis revealed no statistically significant group differences, $F(3, 111) = 2.54$, $p = .060$. The corresponding effect size indicated a small to moderate effect ($\eta^2 = .064$). Although the result did not reach conventional levels of statistical significance, descriptive differences between groups were observed. Out-of-field teachers showed the highest mean score ($M = 3.73$, $SD = 1.54$), followed by certified teachers ($M = 3.23$, $SD = 1.35$), whereas career changers displayed comparatively lower mean scores ($M = 3.09$, $SD = 1.66$).

Due to the comparatively high scores among out-of-field teachers, an additional comparison examined whether professional vision differed between out-of-field teachers with and without a STEM-related background. The analysis revealed no statistically significant difference between out-of-field teachers with a STEM background ($M = 4.17$, $SD = 1.64$) and those without ($M = 4.01$, $SD = 1.47$), $t(108) = 0.52$, $p = .606$. The corresponding effect size was negligible (Cohen’s $d = 0.10$), indicating that disciplinary background was not meaningfully associated with professional vision within this subgroup.

Facet-specific analyses also yielded no statistically significant group differences for evaluating pupils’ conceptions, $F(3, 124) = 1.73$, $p = .163$, generating alternative instructional actions, $F(3, 94) = 1.13$, $p = .340$, or describing pupils’ conceptions, $F(3, 133) = 0.29$, $p = .835$. Effect sizes for all facet-level analyses were small ($\eta^2 \leq .040$), indicating limited explanatory power of entry pathway for these aspects of professional vision.

Figure 2

Facet-Specific Professional Vision Scores (Normalised)



4.2 Professional Action

The classroom video analyses provide a descriptive overview of how instructional practices related to pupils' conceptions were enacted across lesson phases (see Table 3-5). Overall, explicit and sustained engagement with pupils' conceptions was observed only selectively. While elements of constructive support and a positive error culture were present in several lessons, systematic elicitation, exploration, and revisiting of pupils' conceptions did not emerge as a dominant feature of classroom practice.

Table 3

*Occurrence of instructional practices during the lesson introduction by teacher group
(Percentages indicate the proportion of lessons in which instructional practices were observed)*

Indicator	Early-Career	Career Changers	Certified
Learning status addressed	100%	60%	100%
Prior knowledge elicited	50%	40%	100%
Pupils' conceptions elicited	0%	0%	50%
Appropriate methods for diagnosis	50%	20%	100%
Subject-related explanations framed constructively	50%	40%	100%
Positive error culture	100%	20%	100%
Pupils positioned as mediators of learning	0%	0%	0%
Appropriate dealing with conceptions	50%	20%	100%

Across lessons, diagnostic practices such as activating prior knowledge or referring to pupils' current learning status occurred more frequently at transitional moments of the lesson, whereas deeper engagement with pupils' reasoning and conceptual understanding remained limited.

Cognitively engaging tasks were implemented in a number of lessons; however, sustained insistence on pupils' explanations and the explicit treatment of their conceptions were observed only occasionally.

Table 4

Occurrence of instructional practices during the working phase by teacher group (Percentages indicate the proportion of lessons in which instructional practices were observed)

Indicator	Early-Career	Career Changers	Certified
Ways of thinking	0%	0%	50%
Cognitive engagement	50%	40%	50%
Appropriate tasks	50%	40%	100%
Insistence on reasoning	0%	0%	100%
Constructive subject-related explanations	0%	20%	100%
Pupils positioned as mediators of learning	0%	0%	0%
Positive error culture	100%	40%	100%
Appropriate dealing with conceptions	0%	0%	0%

Descriptive comparisons across teacher groups suggest that certified teachers more often implemented cognitively demanding and concept-related practices, such as insisting on pupils' reasoning or providing constructive subject-related explanations. Early-career teachers showed some similar practices, though less consistently. In contrast, such practices were observed less frequently in the lessons of career changers. Across all groups, explicit and systematic work with pupils' conceptions remained comparatively rare.

Table 5

Occurrence of instructional practices during the conclusion phase by teacher group (Percentages indicate the proportion of lessons in which instructional practices were observed).

Indicator	Early-Career	Career Changers	Certified
Learning status addressed	100%	0%	100%
Appropriate methods for conclusion	100%	0%	50%
Pupils positioned as mediators of learning	100%	0%	50%
Constructive subject-related explanations	0%	0%	100%
Positive error culture	100%	0%	100%
Appropriate dealing with conceptions	100%	0%	50%

5 DISCUSSION

This study examined the potential of combining vignette-based assessments of professional vision with classroom video analyses of professional action in Technology and Design education. By linking how teachers interpret pupils' conceptions in standardised situations with how they act in their own classrooms, the study offers complementary perspectives on professional competence.

Across both dimensions, engagement with pupils' conceptions emerged as selective. Although many teachers were able to identify and evaluate relevant aspects of pupils' thinking in the vignette-based assessment, sustained instructional practices explicitly building on these conceptions were less frequently observed in classroom videos. Instead, more general supportive practices, such as maintaining a positive error culture, were more common. This pattern highlights the complexity of translating diagnostic sensitivity into classroom practice and suggests that recognising pupils' conceptions does not automatically lead to systematic instructional use of them.

Group comparisons further indicate that formal qualification pathways alone do not sufficiently explain differences in professional vision and action. While certified teachers tended to show more frequent cognitively demanding and concept-related practices, overall patterns were not consistent enough to support strong group-based conclusions. However, what stands out in the

results is that the career changers did not address the aspects examined at all in the final phase of the lessons.

This highlights an area that should be focused on when planning appropriate interventions, namely securing and clarifying knowledge at the end of the lesson. Professional competence in dealing with pupils' conceptions therefore appears to develop through more context- and experience-dependent processes than can be captured by formal background variables alone.

A key contribution of the study lies in demonstrating the value of a linked research design. Combining vignette-based measures with classroom video analyses makes it possible to examine relationships between interpretive orientations and enacted practices without reducing differences to a simple deficit perspective. Instead, divergences can be understood as characteristic features of professional action under authentic classroom conditions.

This perspective informs the next phase of the project. In a subsequent intervention, career changers will participate in a learning module focusing on pupils' conceptions. The module integrates theoretical input with the analysis of participants' own classroom videos in a microteaching format, aiming to support teachers in connecting diagnostic perspectives with instructional decision-making. In addition, further classroom videos will be collected from the participants to enable a more systematic analysis of the link between professional vision and professional action.

Overall, the study shows how integrating analyses of professional vision and professional action can contribute to a more differentiated understanding of teachers' professional competence, especially in subjects where pupils' conceptions are central to learning. It should be noted that the sample sizes still vary too greatly to be able to make any meaningful statements about the relationship between the two constructs. This is an aspect that needs to be investigated further in the study setting presented.

6 AI DISCLOSURE

The authors utilized AI (DeepL and ChatGPT) to assist in translating the manuscript.

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Curriculum Integration Through Permaculture Gardening

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Abstract

This fourth paper in a series on curriculum integration, examines the long-term establishment and maintenance of a permaculture garden within a Māori-medium school context in Aotearoa New Zealand. Curriculum integration is defined in this paper as a continuum of practice, involving the application of a series of lenses in the planning and delivery of integrated content in the classroom context. The project, a collaborative effort involving students, their families and their teachers in 1998, was inspired in part by the release of the inaugural draft Hangarau curriculum [Māori-medium Technology]. Over more than a decade, the garden became a dynamic site for integrated learning and sustained inquiry. Using a longitudinal case study approach, combining documentary analysis of planning artefacts with reflective commentary, the paper explores the evolution of curriculum design and classroom practice from 1998–2010, and how pedagogical intent and coherence can be sustained across successive curriculum reforms. The permaculture garden served as both a learning environment and a living system through which students developed understandings of ecological relationships, sustainability, and kaitiakitanga [environmental stewardship]. Integration was guided by mātauranga Māori [Māori knowledge] principles, weaving together Hangarau, and all of the curriculum learning areas through culturally grounded inquiry and community engagement. The findings reconceptualise curriculum integration as a system-based, place-responsive practice sustained through designed environments rather than time-bound units. The paper situates this work within the broader landscape of Hangarau curricula development (1999, 2008, and the forthcoming refreshed curriculum), considering how kaiako might continue to align authentic, place-based learning with evolving national frameworks. A design heuristic is proposed to support educators in developing enduring, system-based approaches to integrated curriculum design in technology education contexts.

Note: Please see the glossary at the end of this paper for extended definitions of Māori language terms.

Key Words: Curriculum Integration, Māori-Medium Technology, Hangarau, Permaculture, Documentary Analysis

1 INTRODUCTION

This paper is the fourth in a series examining curriculum integration in primary and intermediate education (ages 5–12) in Aotearoa New Zealand, with a particular focus on Māori-medium educational contexts. Earlier papers in the series have explored curriculum integration through principled design (Lemon & Hanly, 2023), episodic event-based learning (Lemon & Hanly, 2024a), and cyclical, ritual-based integration (Lemon & Hanly, 2024b). This paper extends that work by examining curriculum integration as a long-term, place-based, system-sustained practice, using the establishment and ongoing use of a permaculture garden as a case study.

The mārā was first established in 1998–1999 in a Māori-medium school context, redesigned and extended through an explicit Hangarau [Māori-medium Technology] process in 2000–2001, and subsequently became a permanent learning site that supported integrated curriculum learning for more than a decade. Rather than being treated as a discrete ‘unit’ or themed project, the mārā functioned as a living curriculum infrastructure: a designed system that absorbed successive curriculum reforms, changing cohorts of learners, and evolving pedagogical emphases, while maintaining coherence over time.

This paper positions Hangarau as the organising discipline that enabled this sustained integration. Science and technology education are increasingly recognised as domains that profoundly shape social, environmental, and political futures. As both authors have articulated in teacher education contexts, science and technology will either save or destroy the planet and its peoples; therefore, broad participation in scientific and technological thinking is essential, particularly for groups historically marginalised from such discussions, including Indigenous peoples. The mārā provided a context through which tamariki could come to see themselves as practising scientists and technologists: engaged with systems, materials, design decisions, and ethical responsibilities embedded in everyday life.

Drawing on documentary analysis and reflective commentary, this paper examines how the mārā evolved over time as a Hangarau-led system, how mātauranga Māori and permaculture principles shaped curriculum design, and how long-term curriculum integration can be sustained through place-based learning. This paper makes two contributions. First, it reconceptualises curriculum integration as a system-based practice sustained through designed environments rather than time-bound units. Second, it proposes a design heuristic for enduring integrated curriculum sites, derived from longitudinal analysis of the mārā as a Hangarau system.

2 CONCEPTUAL FRAMING: CURRICULUM INTEGRATION, PLACE, AND SYSTEMS

This paper builds on earlier work in this series that examined curriculum integration in Māori-medium education through principled design (Lemon & Hanly, 2023), episodic event-based integration (Lemon & Hanly, 2024a), and cyclical, ritual-based learning (Lemon & Hanly, 2024b). Collectively, these studies positioned Hangarau [Māori-medium Technology] as a powerful organising discipline for integrated curriculum design. The present paper extends this

trajectory by examining curriculum integration as a long-term, place-based, and system-sustained practice, using a permaculture garden as a case study.

In prior papers, curriculum integration was explored through intensive, time-bounded contexts framed around inquiry and problem-solving, aligning with common interpretations of integrated STEM education (Capraro et al., 2013; Kelley & Knowles, 2016). These approaches relied on a clearly defined organising centre, guiding questions, and culminating outcomes (Jacobs, 1989). While effective for episodic or cyclical learning, such models do not fully account for how integrated curriculum might be sustained across multiple years, cohorts, and curriculum reforms.

As in earlier work, this paper begins from a Kaupapa Māori foundation while incorporating other knowledge systems. We align with Stewart's (2023) caution that simply replacing a universalist framing of "Western science" with an exclusively relativist or Kaupapa Māori approach may be unproductive for learners. Instead, *mātauranga Māori* is positioned as the epistemological starting point within which scientific, technological, and ecological knowledge are brought into dialogue. As the focus here is Māori-medium education, literature addressing the inclusion of Indigenous perspectives within English-medium or mainstream contexts (e.g. Gillies, 2021; Kulnieks et al., 2013) is not central to the analysis.

The literature reflects ongoing contestation around the meaning and purposes of curriculum integration and STEM education. Curriculum integration has been variously described as interdisciplinary, multidisciplinary, or transdisciplinary (Jacobs, 1989), while STEM integration is often framed through inquiry, problem-based learning, or real-world application. Rennie et al. (2012) identified key conditions supporting integrated STEM programmes, including stable learning environments, leadership, flexible structures, planning time, and strong community connections. In the Kāuta case study, these conditions were temporarily established to support a short-term project. In contrast, the māra case study demonstrates how these attributes can be materially embedded within a designed technological system, reducing reliance on repeated re-planning and enabling coherence over time.

This shift from organising events to organising systems aligns with Fogarty's (2009) conception of curriculum integration as a continuum of lenses rather than a single model. Across its lifespan, the māra simultaneously embodied the Webbed model (through thematic coherence grounded in seasonal and ecological cycles), the Threaded model (through shared design tools, language, and systems thinking), the Integrated model (through collaborative planning across learning areas), and the Immersed model (as learners continually connected prior knowledge with new experiences). These lenses operated concurrently and evolved over time, rather than being applied sequentially.

Place-based and ecological perspectives further strengthen this framing. Drawing on place-conscious education, learning in the māra was grounded in *whenua* as both a physical site and a source of knowledge, identity, and responsibility. Permaculture principles were treated as a knowledge system parallel to curriculum theory, offering a design framework grounded in systems thinking, feedback, observation, and ethical responsibility. When enacted through

Hangarau, permaculture supported learners to engage with sustainability not as an abstract concept, but as an ongoing technological practice embedded in everyday decision-making.

Within Indigenous education contexts, place-based and ecological learning add further depth to understandings of curriculum integration. Penetito's (2008) work on place-conscious education foregrounds whenua (land) as a source of knowledge, identity, and responsibility. In Māori-medium settings, learning is inherently relational, situated within whakapapa connections between people, land, seasons, and the wider cosmos. From this perspective, curriculum integration is not primarily about linking subjects, but about weaving knowledge systems together in contextually meaningful ways.

Permaculture principles are treated in this paper as a knowledge system in their own right, rather than as a set of gardening techniques. Permaculture offers a design philosophy grounded in systems thinking, observation, feedback, and ethical responsibility—principles that align closely with Hangarau and mātauranga Māori. When enacted through a living site such as a māra, permaculture becomes both a technological system and a pedagogical framework.

3 METHODOLOGY

This research adopts a longitudinal case study approach, informed by documentary analysis and reflective commentary. While autoethnographic elements remain present—given the authors' involvement in the design and use of the māra—the emphasis in this paper shifts toward examining artefacts as evidence of pedagogical intent, design thinking, and curriculum coherence over time.

Analysis was conducted in three stages. First, artefacts were organised chronologically to identify shifts in design intent and curriculum emphasis across phases. Second, documents were coded for evidence of technological practice, systems thinking, and curriculum integration (e.g. planning structures, evidence of feedback loops, integration across learning areas). Third, patterns were interpreted across phases to identify enduring design features that supported long-term integration.

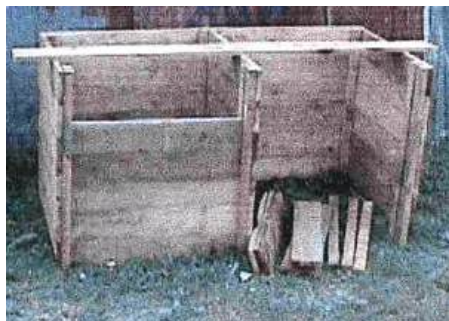
The data corpus includes planning documents from 1998–2010, site analyses, permaculture design plans, and reflective reports produced in 2003 and 2008, alongside supporting visual and video records (see Figure 1). These artefacts are treated not as historical memorabilia, but as design documentation that reveals how curriculum integration was conceptualised, enacted, revised, and sustained across multiple phases.

Rather than tracing changes in student cohorts, the analysis focuses on how the māra itself functioned as a stable learning system that supported evolving curriculum priorities and pedagogical practices.

Figure 1

Screenshots from the Video Documentation of Phase 1 - Setting up a Compost Box (a); Establishing a School-wide Composting System (b); The Initial Māra (c); The Worm Farm (d)

a



b



c



d



4 FINDINGS: THE MĀRA AS A HANGARAU SYSTEM OVER TIME

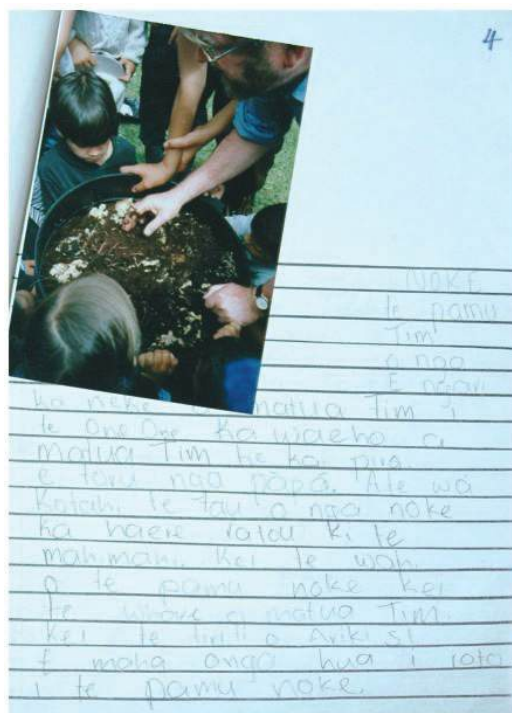
4.1 Phase One (1998–1999): Establishment

The initial establishment of the māra coincided with the release of the inaugural draft Hangarau curriculum. From the outset, the māra was conceived not as a decorative garden, but as a purposeful response to identified needs and opportunities within the school and community (see Figure 1). Early planning documents reveal attention to site constraints, resource availability, and community expertise, alongside explicit intentions to integrate learning across Hangarau, pūtaiao [Māori-medium science], pāngarau [Māori-medium mathematics], tikanga-ā-iwi [Māori-medium social sciences], and te reo Māori [Māori language].

Learning during this phase emphasised observation, soil preparation, planting decisions, and basic systems understanding (see Figure 2). Students engaged (with whānau and other stakeholders in their local communities) in hands-on technological practice, learning that design decisions had consequences, and that environmental systems required care, patience, and responsiveness.

Figure 1

One of the Students' Big Books Recounting their Research and the Trips that Informed their Māra Design



4.2 Phase Two (2000–2001): Redesign and Extension

By 2000–2001, limitations in the initial design had become apparent, prompting a more explicit Hangarau process of site analysis, redesign, and extension. Detailed site analysis documents from this period show careful consideration of sun patterns, water flow, soil conditions, and plant relationships (see Figures 3–5). These analyses informed structural changes to the māra, including altered planting layouts and infrastructure improvements. Figures 3–5 illustrate the shift from initial design to analytical redesign, where student-generated data (wind, sun, and spatial mapping) informed technological decision-making.

This phase foregrounded systems modelling and feedback loops—core concepts in both Hangarau and permaculture. Tamariki learned that technological systems are iterative, requiring ongoing evaluation and adaptation. Failure and revision were not treated as shortcomings, but as integral components of technological practice.

Figure 2

Students' Letters to the School Governance Structure (Board of Trustees) Regarding the Māra Re-design, February 2000

Newton Central School
 Monmouth St
 Newton
 Tāmaki Makaurau

20 Huitangura 2000

Tērā koutou te poari Whakakāere,
 Kei te tūhī ākōu ki a koutou ki te pātari
 Wēhe meā ka taea wātau te Whānau o te
 Uru Kāwaka, ki te tipu he Wāro Kōiroti i
 te kura. Kei nōkō ngā pūkenga tipu kōi, i ngā
 tihanga Māori me te maki o wātau tapua
 Kua Riki wātau te wāhi ki muri i te
 tavi o Whaea Susan Wēhe meā he poi
 ang ki a koutou.

Figure 3

Site Analysis: In Groups, Students Measured Wind and Sun From Magnetic North Twice Daily Over a Week

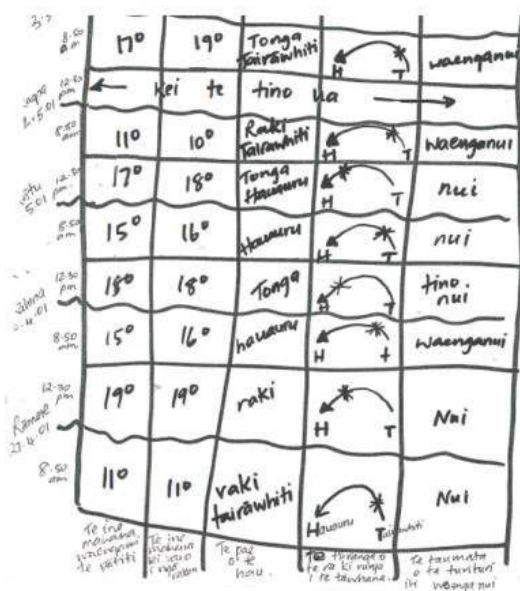


Figure 4

Forming a Concept Map for the Permaculture Garden with Permaculturist, Daniel Nepia, June 2001



4.3 Phase Three (2002–2010): The Māra as Curriculum Infrastructure

From 2002 onward, the māra functioned as a permanent learning site embedded within everyday classroom practice. Rather than being revisited as a ‘project,’ it became an always-available context for inquiry across curriculum areas. Seasonal cycles, soil regeneration, composting systems, and planting schedules provided authentic contexts for scientific investigation, mathematical reasoning, language development, and social learning. Successful applications for contestable funding supported this development and contributed to the māra expanding into a whole-school curriculum infrastructure (see Figures 6-7).

Crucially, the māra absorbed successive curriculum changes without losing coherence. The comprehensive rewrite of the curriculum in 2008 resulted in a changed structure for the curriculum, but the learning mapped to the new structure. Hangarau continued to function as the organising discipline, enabling new learning emphases to be integrated without dismantling the system itself. Over time, the māra supported shifts in curriculum emphasis, including increased focus on sustainability, systems thinking, and language revitalisation, without requiring structural redesign of the learning environment.

Figure 5

Completed Site Re-design

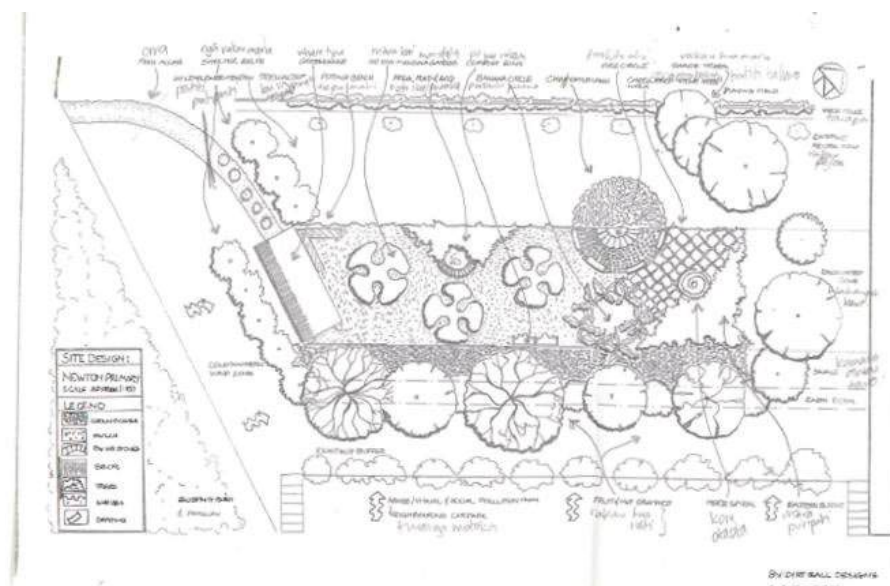
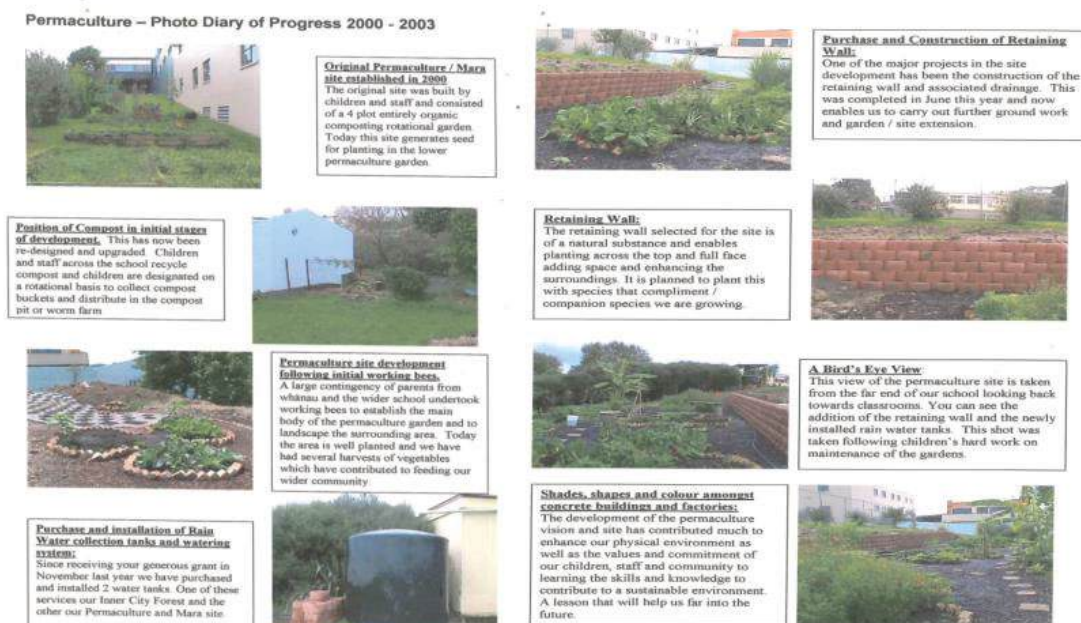


Figure 6

From a School Report about the Permaculture/Māra Development 2002-2003



4.4 *Language, maramataka, and knowledge reclamation*

Language acquisition was fundamental to the māra initiative. As an Indigenous community engaged in ongoing language revitalisation, the māra provided a rich, authentic context for developing specialised vocabulary, procedural language, and ritual registers in te reo Māori. Language learning was embedded in purposeful activity, supporting noticing, rehearsal, and consolidation through repeated use over time.

Maramataka Māori [traditional seasonal calendars] played a central role in structuring learning and decision-making within the māra. Rather than serving as background cultural knowledge, maramataka informed planting, harvesting, and observation practices, positioning Indigenous science as contemporary, relevant, and authoritative. In doing so, the māra offered alternatives to Western time markers and calendars, reinforcing Indigenous ways of understanding time, environment, and human responsibility.

5 DISCUSSION: SUSTAINING INTEGRATED CURRICULUM THROUGH LIVING SYSTEMS

These findings extend existing models of curriculum integration. While Jacobs (1989) and Capraro et al. (2013) emphasise organising centres and problem-based learning, the māra demonstrates how integration can be sustained through enduring systems rather than discrete units. Similarly, Rennie et al.'s (2012) conditions for effective STEM integration are not only enacted but embedded within the physical and social infrastructure of the māra. Fogarty's (2009) integration lenses are evident simultaneously, rather than sequentially, suggesting that long-term sites enable multiple forms of integration to coexist.

While this case is grounded in a Māori-medium context, the findings have broader relevance. In systems where curriculum is tightly structured, long-term integrated sites can function alongside existing frameworks by acting as recurring contexts rather than replacements for subject-based teaching. The māra did not replace curriculum areas; it provided a site through which they could be meaningfully enacted over time. This alignment can occur through timetabled rotation, where the māra functions as a recurring interdisciplinary context, or through subject-based planning that draws on the site for authentic application.

The māra case study demonstrates that curriculum integration can be sustained when learning is anchored in designed, living systems rather than time-limited units. Place mattered as an active participant in learning, not merely a backdrop. Hangarau functioned as the stabilising discipline that allowed integration to endure, providing conceptual tools for managing complexity, change, and uncertainty.

This work challenges short-term, unitised approaches to STEM education that prioritise novelty over depth. By contrast, the māra supported long-term engagement with scientific and technological ideas, fostering identity, agency, and ethical responsibility. Students learned about sustainability within a system that demanded care, observation, and collective effort.

5.1 *Design heuristic: Sustaining integrated curriculum through living systems*

The design heuristic presented below synthesises the integration lenses discussed earlier (Fogarty, 2009) with the longitudinal findings of the māra as a Hangarau system. Rather than operating as separate planning approaches, these lenses are enacted simultaneously within a designed environment. The heuristic therefore represents a consolidation of curriculum integration as both a pedagogical and technological design process.

- (i) Design for **permanence**
Establish physical and conceptual systems that endure beyond a single unit or cohort.
- (ii) Use technology education to **stabilise integration**
Position Hangarau as the organising discipline that holds together scientific, social, and ecological learning.
- (iii) **Anchor learning** in living systems
Design contexts where change, feedback, and interdependence are intrinsic (e.g. gardens, waterways, energy systems).
- (iv) Design for **iterative redesign**
Treat failure, breakdown, and inefficiency as expected features that drive further technological inquiry.
- (v) Allow knowledge to **accrue over time**
Build environments where learning deepens through repeated engagement rather than repeated novelty.
- (vi) **Embed language and knowledge systems** as infrastructure
Treat language, maramataka, and tikanga as structuring elements of the system, not as contextual additions.
- (vii) Design for **curriculum elasticity**
Ensure the system can absorb changing curriculum priorities without requiring redesign of the whole.

This heuristic shifts curriculum integration from a planning strategy to a design problem in technology education.

6 LIMITATIONS

This study is based on a single, long-term case within a specific Māori-medium educational context, and findings may not be directly transferable to all settings. The analysis draws on retrospective artefacts and author involvement, which may privilege certain interpretations over others. Future research could include comparative case studies, student voice, and quantitative measures of learning outcomes to further test the applicability of the proposed design heuristic.

7 CONCLUSION

This paper has argued that curriculum integration can be designed to endure when it is grounded in place, guided by Hangarau, and informed by Indigenous knowledge systems. The māra functioned as both a technological system and a living curriculum infrastructure, demonstrating how integrated learning can be sustained across time, reforms, and pedagogical shifts. For international educators concerned with technology education, sustainability, and equity, this case study offers a model for designing curriculum that is coherent, participatory, and deeply connected to the worlds learners inhabit.

8 DISCLOSURE STATEMENT

Generative artificial intelligence (GenAI) tools (e.g., ChatGPT, OpenAI) were used during the development of this article as part of a human-led collaborative writing process, primarily to support drafting, editing, and critical reflection on structure and argumentation. The tool functioned as a 'critical friend' in refining clarity and coherence. All substantive ideas, theoretical framing, analysis, and interpretations are the authors' own

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10 GLOSSARY

Aotearoa	One of the names for New Zealand, used more commonly in the North Island. See Te Waipounamu
Hangarau	Māori-medium Technology education within Te Marautanga o Aotearoa (Ministry of Education, 2017). Hangarau encompasses technological practice, systems thinking, design, and the purposeful transformation of materials, environments, and processes. In Māori-medium contexts, Hangarau is informed by mātauranga Māori and emphasises relational, ethical, and environmental considerations alongside technical knowledge.
Kaiako	Teachers, educators
Kaitiakitanga	Conservation, looking after the environment (in the widest sense of the word, including language and ancestral treasures handed down the generations) and managing resources carefully
Kaupapa Māori	A Māori-centred approach to knowledge, practice, and research that affirms Māori worldviews, aspirations, and authority. Kaupapa Māori positions Māori as the starting point for design and decision-making, rather than as an “addition” to dominant Western frameworks
Māra	A garden. In this paper, māra refers specifically to a permaculture garden designed and maintained as a learning system and curriculum infrastructure

Māori	The indigenous people of New Zealand
Maramataka	Māori lunar and seasonal calendars that guide activities such as planting, harvesting, fishing, and ritual practice. Maramataka integrate environmental observation, astronomical knowledge, and cultural understanding of time
Mātauranga Māori	Māori knowledge systems, including ways of knowing, being, and doing that have been developed, transmitted, and adapted over generations. Mātauranga Māori is dynamic and contemporary, encompassing environmental knowledge, technological practice, language, philosophy, and cultural values
Orangaukauka	Permaculture is a design philosophy and ecological framework focused on creating sustainable, regenerative systems that work with natural processes. In this paper, permaculture is treated as a knowledge system parallel to curriculum theory, aligning closely with systems thinking in Hangarau and mātauranga Māori. The term more commonly used now is ‘ahutoitū’
Taiao	The natural environment, inclusive of ecological systems, living beings, and human relationships with them
Te Marautanga o Aotearoa	The national curriculum framework for Māori-medium education in Aotearoa New Zealand. It is underpinned by mātauranga Māori and supports learning through te reo Māori across curriculum learning areas
Tikanga	Customs, protocols, and practices that guide appropriate behaviour and relationships. Tikanga are context-specific and grounded in cultural values
Tikanga Māori	Māori practices and protocols
Whānau	Family and extended family networks. Whānau includes caregivers and wider community members who contribute to learning
Whenua	Land, also understood as placenta, reflecting deep relational connections between people and place. In educational contexts, whenua signifies more than physical location; it is a source of identity, knowledge, responsibility, and learning

Establishing an International Comparative Framework for Design and Technology Education: A Multi-Jurisdiction Curriculum Analysis Methodology

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Abstract

Design and technology (D&T) education reflects diverse educational purposes across jurisdictions, variously emphasised as engineering and technology education, vocational preparation, or general education. Yet curriculum developments often occur in isolation, with limited systematic comparative analysis. This paper presents the methodological framework for the initial documentary analysis phase of a multi-year international comparative project examining D&T curricula across 18 jurisdictions.

The project adapts the Umalusi curriculum benchmarking framework—originally developed by South Africa's Council for Quality Assurance for international curriculum comparison—for systematic documentary analysis. This validated framework provides rigorous analytical instruments while allowing flexibility across diverse cultural contexts. The methodology focuses on D&T within general (non-elective) lower secondary education (approximately ages 11–14) in jurisdictions with published national curricula.

Analysis encompasses eight core dimensions: curriculum design and format; aims and philosophical orientation; content coverage and breadth; time allocation and pacing; cognitive depth; curriculum integration; pedagogical guidance and assessment frameworks; and contemporary elements. Data collection uses an online survey integrating Likert scale items, open responses and document uploads, supported by Excel based analysis templates. A secure SharePoint workspace enables shared document storage and distributed ethical governance across participating institutions.

The methodology's key contribution lies in establishing a replicable, validated framework for international curriculum comparison in D&T education. It supports the participation of additional jurisdictions in subsequent project phases while offering a reusable structure for future independent studies. By adapting a proven benchmarking instrument, this approach provides baseline comparative data essential for evidence-informed curriculum review and policy development, while building

sustainable international research capacity through collaborative analysis and knowledge exchange among teacher educators and early-career researchers.

Key Words: Comparative Education, Curriculum Analysis, Design and Technology Education, International Benchmarking, Documentary Analysis

1 INTRODUCTION

Design and technology (D&T) education reflects diverse educational purposes across jurisdictions globally, variously emphasised as engineering and technology education, vocational preparation, or general education. Yet curriculum developments often occur in isolation, with limited systematic comparative analysis (Bray et al., 2014). Existing global measures such as PISA do not include D&T, focussing instead on core subjects (OECD, 2019), and available datasets are too coarse to offer subject-level insight into design and technology curricula or their practical requirements (OECD, 2023). While bilateral collaborations and professional networks exist, there remains a lack of systematic, subject-specific frameworks for international comparison of intended design and technology curricula. This highlights the need for a structured method for comparing D&T curricula internationally.

The scope of the project is design and technology education within general education (not elective) at lower secondary level, typically for learners aged 11-14, in jurisdictions with published national curricula. The methodological framework described in this paper is used in Phase 1a of the multi-year International Design and Technology Education Comparative Research Project. This wider project comprises three phases: (i) curriculum analysis and comparison, including intended, enacted and hidden curricula and sub-foci such as curriculum ideology, underpinning values, entrepreneurship and 21st-century skills; (ii) teacher preparation; and (iii) contextual issues. This paper reports on the first step of Phase 1a, focusing specifically on the intended curriculum.

To support systematic comparative analysis, the project adapts the Umalusi curriculum benchmarking framework, originally developed by South Africa's Council for Quality Assurance for international curriculum comparison (Umalusi, 2015). Using this adaptation, we present in this paper a methodological framework for documentary analysis of intended D&T curricula across multiple jurisdictions.

The paper is structured in five parts. First, we outline the benefits of comparative education and limitations of global measures for D&T. We then provide an explanation of the Umalusi curriculum benchmarking framework. The main section of the paper describes each dimension of the adapted analytical framework. This is followed by an update on the project's progress and, finally, a discussion of the anticipated contribution of Phase 1a.

This paper therefore addresses the following research question:

How can a validated international benchmarking framework be adapted to enable systematic, rigorous comparison of intended design and technology curricula across diverse jurisdictions?

2 COMPARATIVE STUDIES OF EDUCATION SYSTEMS

Comparative studies of education examine how different jurisdictions organise curriculum, schooling, learning and related policies, shaped by context, cultural and economic considerations (Bray et al., 2014). Comparative studies help researchers and policy writers to identify how other curriculum content is structured, what their aims are, and how they are organised (Marshall, 2024). This can identify similarities, differences, priorities and assumptions. It highlights good practice, reveals gaps and informs education policy. However, it must be sensitive to oversimplification and uncritical adoption in different contexts (Bray et al., 2014).

Global comparative measures tend to emphasise core domains such as literacy, numeracy and, increasingly, digital competence, which are seen as foundational indicators of system performance (OECD, 2019). Major comparative programmes such as PISA focus primarily on these core subjects, with creativity assessed only when jurisdictions opt into additional testing cycles; for example, PISA measured creative thinking for the first time in 2022, but participation was optional and coverage variable (OECD, 2024). Even where creativity data exist, they remain centred on broad cognitive processes rather than subject-specific capabilities such as design and technology. Although the OECD has undertaken analyses of instructional time across secondary education systems, these datasets are too coarse to offer subject-level insight into design and technology curricula or their practical requirements (OECD, 2024). Systematic international comparisons specific to D&T remain limited, with most available literature emerging from individual jurisdictions for research or teacher-facing purposes (Banks & Williams, 2022) rather than large-scale cross-national studies. In some cases, national curriculum reviews have compared subjects through the lens of “knowledge-rich” models; for example, work in Northern Ireland suggested that D&T appeared less knowledge-heavy than subjects in some high-performing jurisdictions (Nijlunsing et al., 2025). This raises questions about whether D&T is marginalised because it is undervalued, unmeasured in comparative studies, or simply misaligned with the narrow parameters used in such reviews.

These gaps underline the need for a structured comparative framework that can capture the distinctive features of D&T curricula, which we address through our adaptation of the Umalusi curriculum benchmarking framework (Umalusi, 2015).

3 UMALUSI CURRICULUM BENCHMARKING FRAMEWORK

Umalusi is South Africa’s quality assurance body in general and further education. It is responsible for ensuring the standards of the South African curriculum (the Curriculum and Assessment Policy Statements, CAPS). Umalusi (2015) created a multi-dimensional analysis framework to enable evaluators to compare CAPS with international qualifications in a structured, consistent way. They wanted evidence to support national conversations about curriculum reform

drawing on international comparisons of curriculum design, content breadth and depth, pacing, progression, pedagogy, assessment, and integration. Umalusi designed the framework to be repeatable across multiple subjects (Du Toit & Gaotlhobogwe, 2017a; Du Toit, 2021; Umalusi, 2018). The framework has been used to compare technology curricula in Botswana and South Africa (Du Toit & Gaotlhobogwe, 2017b) and consumer studies curricula in Botswana, Eswatini, Lesotho, Namibia and South Africa (Du Toit, 2021). We have adopted the Umalusi curriculum benchmarking framework for this project because it is adaptable internationally, has been validated through multiple subject applications, and provides a comprehensive set of dimensions for systematic curriculum comparison.

4 FRAMEWORK FOR COMPARATIVE ANALYSIS OF DESIGN AND TECHNOLOGY EDUCATION

This section describes the dimensions of the benchmarking framework for analysing the published curricula in each participating jurisdiction. The framework is an adaptation of the Umalusi curriculum benchmarking framework tailored to compare published D&T curriculum. The analysis uses a JISC online survey for dimensions 1-4 and 6-8 and an Excel-based analysis template to collect each jurisdiction's analysis of their own documentation (content depth - dimension 5). The online survey includes Likert-scale items, categorical questions, and open responses, and facilitates uploading relevant curriculum documents. The Excel template collects details of specific topics in the curriculum with a corresponding rating of cognitive complexity. Curriculum documents are uploaded to a SharePoint site to maintain a central, accessible record of all files for future reference. This approach helps establish transparency, document provenance, and national context for comparing the data analysis. Together, these eight dimensions and the associate analysis enable a systematic and rigorous comparison of international D&T curricula.

It should be noted that the framework does not seek to normalise or resolve differences in national subject traditions. Instead, it is designed to make such differences visible through analysis of intended curriculum documentation, allowing variation in purposes, emphases and structures of design and technology education to be systematically identified and compared.

4.1 Curriculum Design and Format

In the first section, we are examining the overall design principles and format of the curriculum documents. This will capture how the curriculum is organised, what design principles guide its structure, and how accessible the documentation may be for teachers. This is identified by analysing its “user-friendliness” and the accessibility of language. For some government websites there is a requirement for this that is determined by the reading age of the documents [ref gove.co.uk website]. The design principles focus on the driver for the curriculum design, including whether the curriculum is content, skills, outcomes or competency based or if there is a balance between content and skills. The final question in this section records how well different curriculum documents work together as a coherent set. For example, whether terminology is consistent across all documents.

4.2 Curriculum Objectives

Next, we analyse the subject aims whether stated or implied - or if there are any. Where there are aims, we are comparing the aims of each curriculum with common international themes in design and technology education to understand the curriculum's philosophical orientation. These themes include (but are not limited to) developing technological literacy, creative thinking, develop 21st century skills (collaboration, communication, etc.), knowledge-rich, and offer authentic problem-solving opportunities.

4.3 Content Coverage and Breadth

This section examines what content areas and topics are included in each curriculum and how they are distributed across different year groups. We want to understand what content and skills are specified, how they are organised, and how extensively different areas are covered. The subject content knowledge is specific to design and technology, for example, structures, mechanisms, food, textiles and so on. The skills topics are subject-specific (design skills, making skills) and generic skills that may be relevant to other school subjects (critical thinking and problem-solving skills).

4.4 Time Allocation and Pacing

This dimension examines how teaching time for design and technology is specified and organised within the curriculum. We record whether formal allocation of time is specified, and if it is, we capture the teaching hours per week and per annum. If no time is stipulated, this absence is noted as part of the comparative analysis, as it reflects the level of autonomy given to schools. In addition to total teaching time, the questionnaire captures whether the curriculum requires extended or uninterrupted practical lessons—such as double periods or block sessions—to support workshop-based activities. These details help us understand the pacing expectations placed on teachers and whether the curriculum acknowledges the practical nature of design and technology.

4.5 Content Depth and Specification

Here the analysis uses a systematic approach using a template to examine how deeply content is treated and how clearly it may be specified for teachers. We are interested in understanding the cognitive demands the curriculum places on learners, how clearly content is defined - if at all, and whether there may be evidence of progression in complexity within and across year groups. Although the cognitive depth scale resonates with established learning taxonomies (e.g. Bloom), it was developed as a bespoke analytical tool for curriculum document analysis rather than as an instructional or assessment taxonomy. This is done by analysing each component of the curriculum content in turn using a four-point scale:

- (i) Introductory level: superficial treatment, mainly definitions and descriptions or no real understanding expected (e.g. Name three types of structures)

- (ii) Basic understanding: definitions with some detail, requires basic level of understanding or simple relationships between concepts (e.g. Describe how gears work)
- (iii) Detailed knowledge: requires detailed knowledge of concepts, deep understanding of concepts or understanding relationships between concepts (e.g. design a stable structure for given constraints).
- (iv) Complex understanding: conceptually challenging treatment, complex understanding of relationships and or application in novel/challenging contexts (e.g. analyse structural failure and propose solutions).

4.6 *Integration and Connections*

In this dimension we are capturing detail about how the curriculum makes connections. We ask about three different types of connection: first, connections within the D&T curriculum; next, connections made with other subjects and finally connections with pupils' experiences outside school and future careers. The level of explicitness may vary between curricula and may not be mentioned at all – this is also captured in the survey. This reveals how the curriculum is oriented, whether it is isolated, interdisciplinary, or experiential.

4.7 *Pedagogical Approach and Assessment*

This dimension examines the extent to which the curriculum provides explicit guidance on teaching approaches and assessment in design and technology. Its purpose is to identify how clearly teachers are directed in the pedagogical practice they are expected to use. This includes whether the curriculum specifies approaches such as project-, design-, inquiry- or content-based learning, and where guidance is provided, how detailed or prescriptive that guidance is. Similarly, whether specific assessment methods are required - such as portfolio, practical or written assessment - and whether pupils are expected to engage in peer or self-assessment. Finally, it considers how prescriptive the assessment guidance is overall, noting whether they allow for local adaptation.

4.8 *Contemporary Elements and Context*

The final dimension captures whether the curriculum explicitly mentions contemporary issues and contextual factors. Curricula may vary in how they incorporate current global challenges, emerging technologies, cultural considerations, and societal issues. Some curricula may explicitly feature topics such as sustainability, digital technologies, or entrepreneurship, whilst others may mention these themes briefly, or may not address them at all. This helps us understand how different educational systems respond to current challenges and opportunities in design and technology education.

5 INTERNATIONAL COMPARATIVE PROJECT

The project began in July 2025 with recruitment of 17 jurisdictions: Asia–Pacific (Australia, New Zealand, South Korea, Japan); Europe (UK, Ireland, Finland, Sweden); Latin America

(Argentina, Chile) and Southern Africa (South Africa, Botswana, Namibia, Zimbabwe, Lesotho, Eswatini). Each jurisdiction has a lead representative who has experience of conducting research and has an interest in a comparative project. These representatives also have knowledge of teacher education, which will be relevant for later phases of the project. The framework is being applied to published national or jurisdictional curricula for lower secondary pupils, commonly aged between 11 and 14 years.

Collaboration agreements have been established, with a Memorandum of Understanding (MoU) in place. All institutions have obtained ethical approval and have uploaded evidence of this to the central project SharePoint site. Nottingham Trent University is the lead institution; although ethical clearance is not strictly necessary for documentary analysis, approval has been secured as a foundation for consistent project governance. All participating jurisdictions have been required to complete ethical approval and sign the MoU before beginning the data analysis.

As noted earlier, data analysis is conducted using a JISC survey and an Excel spreadsheet, ensuring a consistent approach that supports transparency and repeatability. All curriculum documents are uploaded to the project SharePoint site, along with the completed JISC and Excel analyses, to create a traceable and auditable record. We have encouraged jurisdiction leads to work with teachers and teacher educators to double-code the curricula to support reliability. We also view this as an opportunity to involve, and thereby strengthen, the international D&T research community.

Alongside the data analysis, we are sharing our project design with government organisations, such as departments or ministries of education, and international bodies, such as OECD. These organisations have expressed interest, and we will share findings as the project progresses. Now that a clear process has been established for adding new jurisdictions, we are open to expanding the comparative project. We anticipate refining the framework further as the project develops and more jurisdictions participate.

6 CONTRIBUTION

This international collaborative research project is the first comprehensive comparative analysis of design and technology education curricula across multiple jurisdictions, focusing on learners in lower secondary school where the subject is part of a compulsory education within general education contexts (to our knowledge; cf. Jones et al., 2013). The project addresses the gaps mentioned earlier in comparative education: the global focus on literacy, numeracy and digital skills, and the limited nuance within existing international measures. The findings from the intended curriculum analysis (Phase 1a) offer ministries and curriculum agencies a structured lens for reviewing breadth, depth, progression and assessment, supporting more evidence-informed curriculum reviews (Bray et al., 2014).

For the research and teacher education communities, the framework establishes shared terminology and analytical categories, easing collaboration across jurisdictions and helping address assumptions or oversimplified adoption of D&T curricula, pedagogy and assessment. It

builds capacity for collaborative analysis and supports international knowledge exchange in the D&T education research community.

Built on established partnerships between the UK and South Africa, the project has expanded to 17 jurisdictions across Europe, Asia-Pacific, Africa and the Americas. This broad participation strengthens the international relevance of the framework and positions the work as a foundational contribution to future comparative studies in design and technology education.

7 AI DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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What Constitutes an 'Authentic' Project Context in D&T Education?

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Abstract

Authenticity is widely referenced in Design and Technology (D&T) education, yet the term is used inconsistently and rarely defined in ways that reflect the realities of lower secondary school teaching and learning. This paper addresses this gap by conducting a structured literature analysis across D&T, STEM and wider educational fields to examine how authenticity is conceptualised, enacted and constrained in school-based design contexts. This paper addresses this gap through a structured literature analysis conducted in January 2026, involving searches across four major databases (Scopus, ERIC, Web of Science and the British Education Index) and the systematic screening of more than 41,000 records. Using an inductive–deductive iterative coding process, approximately 38 relevant studies were analysed to examine how authenticity is conceptualised, enacted and constrained in school-based design contexts. Through screening, selection and synthesis, we develop a six-dimension analytical framework that captures three interconnected strands of authenticity: the external features of tasks, users and practices; the internal, learner-centred dimensions of relevance and agency; and the practical constraints that shape what teachers can design and pupils can do in lower secondary settings. The framework highlights how authenticity emerges not from any single feature but from the interaction of context, learner experience and classroom feasibility. This work provides researchers, curriculum designers and teachers with clearer criteria for analysing and designing authentic D&T project contexts, supporting more coherent discourse and more meaningful design experiences for 11–14-year-olds.

Key Words: Authenticity, Design and Technology, Lower Secondary, Authentic Contexts, Learner Agency

1 INTRODUCTION

1.1 *Why authenticity matters in Design and Technology*

In design and technology (D&T), terms like *authentic contexts* and *real-world tasks* are widely used yet rarely defined in ways that are either specific to a study or commonly agreed within the field. Researchers, teachers and curriculum designers often treat the terms as if their meanings are obvious, uncontested or established elsewhere. When authenticity *is* defined, it tends to be light-touch, surface-level, or inconsistent. This lack of clarity can limit both research quality and classroom practice: researchers do not build on or critique existing work, and teachers lack clear criteria for designing learning experiences that can genuinely be considered “authentic”.

Much of the deeper conceptual work on authenticity has been developed outside school-level D&T, particularly in fields such as engineering, science, mathematics and early years education. Recent work by Hallstrom and colleagues (2023), for example, has used a Delphi approach to propose a shared definition of authentic contexts but this is in the field of STEM education, where any overlap with D&T is only partial. At present, there is no lower-secondary, D&T-focused conceptualisation of what makes a design project context genuinely authentic. This situation leaves teachers and researchers reliant on assumptions or borrowed frameworks when designing or judging authentic contexts.

The aim of this paper is to develop an analytical framework for authenticity in lower secondary school D&T project contexts, informed by authenticity theory and D&T literature. This framework will support researchers, curriculum designers and teachers in making more coherent, defensible judgements about what constitutes authentic contexts and learning in D&T for Key Stage 3 (KS3) pupils.

2 LITERATURE REVIEW

2.1 *How authenticity is conceptualised across education*

Several authors identify authenticity as a multidimensional construct, rather than a single feature of a task or context. Herrington et al. (2014) propose nine elements of authentic learning, many of which emphasise external dimensions such as situating learning in real-life problems, providing access to expert or professional practice, and encouraging collaboration. These aspects focus on how learners interact with real-world contexts and practices. Others highlight internal dimensions of authenticity, including identity, personal meaning, and learner autonomy, as seen in Strobel et al. (2013) work. Together, these perspectives suggest that authenticity involves an interplay between what learners *do* (the task, the context, the practices) and how learners *experience* that work (their identity, agency and sense of purpose). This distinction is important because studies often emphasise one side or the other, contributing to inconsistencies in how authenticity is understood across education.

This argument of the multidimensional nature of authentic learning appears in other fields including early childhood, and science literature. Wu et al. (2025), focussing on early years

settings, identifies six dimensions including authentic assessment (cf Herrington and colleagues), contexts for learning, authentic self, diversity and cultures. Anker-Hansen & Andree (2019), researching in science education, highlight a key tension: tasks can be culturally authentic but not personally authentic (meaningful to students) and recommends balancing both via careful design.

While multidimensionality is well recognised in research, D&T curriculum designers draw on these ideas unevenly.

2.2 *How authenticity is used in D&T research*

Herrington et al. (2014) authentic learning model and Strobel et al. (2013) engineering-based authenticity framework are used or referenced in D&T research (e.g. Engström & Lennholm, 2025; Svård et al., 2024) even though both were developed for other sectors. Herrington's model treats authenticity as a pedagogical approach, not a curriculum design principle, and focuses mainly on external features of learning rather than internal ones such as identity or autonomy. Although the wider literature conceptualises authenticity as involving both internal and external dimensions, D&T research tends to emphasise the external features that appear most prominently in the frameworks it borrows.

Several studies within D&T have attempted to conceptualise authentic learning in subject-specific ways. Snape & Fox-Turnbull (2013) distil a substantial body of technology education research—primarily from the New Zealand context—into four aspects: rich contexts, social construction, meaningful connections and student engagement. Hill & Smith (2005) identify ten interlinked factors in their theory of authentic learning in technology education, and these include both external and internal dimensions.

Attempts to implement authenticity in D&T frequently remain light touch or focus primarily on the external dimensions. Teachers face constraints that lead to simplified tasks (Stein et al., 2001); curriculum-scale initiatives show uneven implementation (Levande et al., 1998); and even situations where more focussed aspects of authentic contexts are included - such as domain-expert involvement (Kangas et al., 2011) – they are difficult to sustain.

Many D&T studies and projects imply authenticity without defining it clearly—for example through references to “authentic tasks,” “real-world contexts,” or “user-centred design”. In these cases, authors rely on an assumed shared understanding of authenticity rather than offering explicit criteria. Within lower-secondary research, some studies frame authentic contexts as a strategy for increasing pupil motivation (e.g. Jones, 2024; Twiner et al., 2022) or for providing workplace realism (e.g. Twiner et al., 2022), but these accounts typically lack theoretical underpinning. A notable exception is Nicholl and colleagues' (2013) *Designing Our Tomorrow* project, where the pedagogical approach is explicitly grounded in two frameworks—authentic learning and authentic teaching—giving greater conceptual clarity than is found in most KS3-focused studies.

The literature shows that authenticity is treated inconsistently in D&T and is often reduced to external features, with only a few studies offering sustained, theory-led enactment, which includes

the internal features. To address this, our next section outlines a structured search and screening process to identify relevant work on authenticity in lower-secondary D&T, followed by a transparent extraction of definitions and enactments. We then explain our analytic procedure (mapping against external and internal dimensions and KS3 feasibility) that generates the criteria used in our findings.

3 METHODOLOGY

3.1 *Research Approach*

A structured literature analysis was adopted that enabled the systematic identification, comparison, and synthesis of definitions and conceptualisations of authenticity in relation to authentic learning, authentic contexts, and design-based tasks. The process combined elements of a structured review with analytical coding to identify recurring characteristics, dimensions, and criteria relevant to authentic contexts in school-based design projects.

3.2 *Search Strategy and Data Sources*

Between 14–18 January 2026 four major scholarly databases were searched for their relevance to education, technology, and design research:

- Scopus
- ERIC (Education Resources Information Center)
- British Education Index
- Web of Science

Search activity was documented in a search log (date, database, search terms, filters, and results).

3.3 *Search terms*

Search strings combined 3 keywords groups:

- (i) Domain terms:
“design and technology”, “technology education”, “design education”, D&T, KS3, “lower secondary”, “11–14”
- (ii) Authenticity terms:
authentic*, “authentic learning”, “authentic context”, “authentic task”, “real-world”, “industry-inspired”, “situated learning”
- (iii) Task/context terms:
context*, task*, brief*, problem*, project*, “design challenge”, “design process”, “design thinking”

Where supported, filters were applied for English-language publications, educational context, and secondary or middle school level. Publication dates were typically limited to 2010–2026, although earlier foundational theoretical works were included where they were frequently cited or conceptually influential.

3.4 *Screening and Selection*

Across all databases, searches produced 41,739 records. Screening occurred in three stages.

3.4.1 *Stage 1: Title and abstract screening*

Studies were retained if they met at least one of the following criteria:

- explicitly defined or examined authenticity, authentic learning, or authentic contexts
- related authenticity to D&T, design education, design thinking, or technological practice
- focused on real-world contexts, user-centred design, or industry-linked tasks.

3.4.2 *Stage 2: Eligibility checking*

Full texts were consulted where abstracts indicated potential relevance. Papers were excluded if they:

- addressed authenticity solely in higher education without transferable theoretical models
- focused exclusively on early childhood without conceptual relevance
- explored authenticity in non-educational fields
- used the term “authenticity” rhetorically without definition or analytical contribution.

Where a paper lacked a definition but offered strong insight into authentic D&T practice (e.g., design-based learning, real-user engagements, inclusive design) it was retained.

3.4.3 *Stage 3: In-depth coding*

Approximately 40 papers were retained and coded into a structured literature review matrix. For each source, the matrix recorded:

- bibliographic details
- educational context (country)
- KS3 applicability (11–14)
- major themes
- theoretical models or framework used
- conceptual contribution and key notes (criteria, dimensions, critiques, constraints)

This matrix provided the analytical basis for identifying crosscutting themes and for distinguishing between conceptualisations of authenticity, characteristics of authentic contexts, and common challenges such as tokenism or superficial “real-world” framing.

3.5 *Analytic Procedure*

The retained studies were analysed using an iterative coding approach designed to surface patterns in how authenticity is defined and operationalised.

- Deductive coding was applied using categories derived from dominant frameworks represented in the dataset (e.g., authenticity of context, task, value beyond school, learner agency/meaningfulness, and assessment alignment)
- Inductive coding allowed additional themes to emerge organically from the D&T-specific literature, such as real-user engagement and inclusive design, learner “buy-in” and perceived authenticity, tokenistic “real-world” framing, and the need for coaching/scaffolding to manage complexity.

Codes from both approaches were synthesised into a set of preliminary dimensions of authenticity, which were then refined by cross-referencing findings from:

- KS3 specific empirical studies
- D&T conceptual and pedagogical literature
- authenticity models from broader education domains
- papers critiquing pseudo-authentic contexts.

This process culminated in the development of a multi-dimensional analytical framework presented in the Findings section of this paper.

3.6 *Limitations*

This review did not aim to be exhaustive; rather, it sought to capture sufficient breadth to support conceptual clarity and develop evaluative criteria. Some relevant literature may not have been indexed in the selected databases or may use terminology adjacent to authenticity (e.g., meaningful learning, real-life learning). However, the structured search combined with systematic coding enabled the identification of strong conceptual foundations and D&T specific insights needed to build the analytical framework.

3.7 *AI disclosure*

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

4 FINDINGS: ANALYTICAL FRAMEWORK

In this section we present our findings from the literature to describe the [six] dimensions that includes a clear definition of each. Although these are presented as separate there is overlap between the dimensions, which is highlighted in the definitions and summary.

4.1 *Dimension 1: Relevance to learners' lives*

The first dimension refers to the extent to which learning activities, tasks, and contexts are meaningful and accessible to learners by connecting with their existing experiences, interests, and everyday lives. Anker-Hansen & Andree (2019) show that authenticity is about ensuring that learning becomes personally meaningful and grounded in the learners' worlds, experiences and interests, rather than as abstract tasks detached from what they value or encounter beyond school. Similarly, Vos (2018) highlights the importance of situating learning within contexts that learners find familiar and intelligible, enabling them to access and interpret tasks without relying on specialist prior knowledge beyond their experience. She argues that students engage more effectively when tasks arise from contexts, they can genuinely make sense of, as opposed to artificially constructed or pseudo-realistic scenarios (for an example see Djepakhija, 2012) study.

Two examples where this is seen in practice are the DOT project (Nicholl, et al., 2013) and work by Nachtigall & Wirth (2024). Both reinforce the idea that relevance is constructed through learners' interpretations and is heightened when activities allow personal experience, empathy, and meaningful choice to shape understanding.

4.2 *Dimension 2: Task and problem authenticity*

Task authenticity refers to pupils tackling a design problem with a genuine purpose, rather than—for example—a brief created simply to rehearse a skill or deliver a concept (Strobel et al., 2013). Authentic design problems are typically ill-structured, with competing constraints and multiple plausible solutions (Herrington et al., 2014). Svärd et al. (2024) agree with this and suggest that ensuring the problem has or replicates real variables and constraints is an aspect of authenticity. Several authors argue that authentic tasks should allow to pupils experience a degree of uncertainty as they design and explore possible solutions. Snape and Fox-Turnbull (2013) argue that real design and technology tasks require learners to iterate and respond to shifting or competing variables rather than following a predetermined pathway. When teachers simplify or over-structure a task – often to fit curriculum time or to ensure that all pupils reach a 'successful' outcome – the complexity that makes a task authentic can be lost. As Strobel et al (2013) note, pupils readily recognise these tightly specified problems as inauthentic. These become pseudo-authentic tasks, where over-specified constraints remove meaningful decision-making and ultimately collapse the authenticity of the problem.

4.3 *Dimension 3: Real users / stakeholders*

A third recurring dimension of authenticity in the literature concerns the presence of real or identifiable users and stakeholders within design tasks. This dimension emphasises that projects

gain authenticity when they are framed around the needs, values, or constraints of a recognisable user, group, community, or stakeholder, rather than a hypothetical or generic audience. In some situations, the authenticity of the task comes from an external source, such as a business, competition or community group (Svård et al., 2024). However, authenticity can also arise when pupils recognise that the problem addresses a need in their community or has a personal meaning (Stein et al., 2001). This overlaps with dimension 1 – relevance to learner’s lives - but differs in that the user is not necessarily the learner.

When design activity is oriented towards an explicit user or client, it needs to be genuine involving engagement with ethical considerations, empathy, population diversity, and the social consequences of design decisions, rather than treating the user as a superficial theme (Nicholl, et al., 2013). There is evidence that when students actively interact with users that learner engagement increases (Jones, 2024; Kangas et al., 2013); although there is no strong evidence to say that engagement with users directly is a crucial factor in learner engagement.

4.4 *Dimension 4: Connection to real practice*

This dimension concerns the extent to which pupils engage in designing and making practices that resemble those used by professional designers, engineers, or makers, rather than simplified or school-based routines. Authenticity, in this sense, is achieved by enabling pupils to participate in meaningful aspects of disciplinary practice that are appropriate for their age and context. Anker-Hansen and Andree (2019) argue that mirroring external practices is fundamental to an authentic task.

Kangas et al. (2013) demonstrate that authenticity is strengthened when pupils engage in processes drawn directly from professional design practice, such as iterative prototyping, modelling and responding to real constraints and feedback. Engström & Lennholm (2025) similarly show that when students work with real data, technologies and expert input, they participate in workflows that more closely mirror engineering practice than typical teacher-directed school projects. Snape and Fox-Turnbull (2013b) offer a clear conceptualisation of this, arguing that authenticity arises not from real-world themes but from enabling pupils to engage in the socially and materially situated practices of technologists—drawing on diverse knowledge sources, making decisions under constraint, and refining prototypes iteratively.

4.5 *Dimension 5: Learner agency*

This dimension focuses on pupils’ freedom to make real decisions during the design task. Authentic agency involves decisions that carry consequences: pupils choose approaches, materials or design directions that may lead to unexpected outcomes, including the possibility of failure. This mirrors the uncertainty and judgement that characterise real design practice. When choices are tightly controlled so that pupils cannot deviate or risk failure, agency becomes pseudo-authentic.

Research on authentic learning emphasises that autonomy and decision-making are central features of authenticity (Herrington et al., 2014; Strobel et al., 2013), while studies of creative

authenticity highlight that learners' ideas and interpretations must meaningfully shape the work (Vernon & Paz, 2023). In D&T, Snape & Fox-Turnbull (2013) note that authentic technological practice requires pupils to iterate, test, and respond to shifting or competing variables, rather than follow a predetermined sequence. Identifying where genuine decision-making is possible, and supporting pupils to justify and reflect on those decisions, is therefore a crucial part of planning for authenticity in KS3 D&T.

4.6 *Dimension 6: Feasibility within KS3 constraints*

This dimension recognises that the authenticity of a D&T task is shaped by three categories of resources.

The first—teacher subject knowledge—includes both conceptual understanding and procedural skill. Stein et al. (2001) identified that gaps in subject knowledge restricts teachers' confidence when designing authentic D&T activities. This influences the extent to which teachers can support pupils through open, uncertain and iterative design processes. When teachers lack confidence with materials, processes or modelling techniques, they may unintentionally narrow the task to reduce risk or ensure predictable outcomes, which then impacts on learner agency. Next, authenticity is shaped by the materials and tools pupils can access. If pupils are restricted to materials that differ significantly from those used in real-world design contexts—because of cost, safety or accessibility—this can limit the realism of modelling, testing and prototyping (Jones, 2024). Finally, timetabling constraints, including short or infrequent lessons, reduces opportunities for iteration, experimentation and failure, all central to authentic design practice (Twiner et al., 2022). If one or more resource elements are limited, lacking or inaccessible, authenticity can collapse, regardless of how well-designed the task or context may have been.

4.7 *Summary*

Although each dimension is described separately, the six dimensions of authenticity are deeply interconnected. Authenticity does not emerge from any single feature of a task or context, but from the way these dimensions interact during the teacher's design of the activity and the pupils' design activity. For example, pupil agency (5) depends on the openness and uncertainty of the task (3), but both are shaped by the resources and time available in KS3 settings (6). Likewise, relevance (1), real users (2) and authentic practices (4) reinforce one another: a task can only feel genuinely authentic to pupils when the context, the decisions they make, and the practices they engage in align. Understanding authenticity as a multidimensional and interdependent construct is therefore essential for analysing and designing KS3 D&T project contexts.

5 DISCUSSION AND CONCLUSION

This paper set out to address the lack of a KS3-specific conceptualisation of authenticity in D&T, where the term is frequently used but rarely defined. The six-dimension framework developed here responds to this gap by distinguishing between external/contextual features, internal/experiential features, and the practical constraints that shape how authenticity is enacted in classrooms.

Authenticity is often reduced in practice to external features such as real-world problems, users and professional practices. Our analysis shows that these are necessary but not sufficient: authenticity also depends on how pupils experience the work—its relevance to their lives and the degree of genuine agency they are afforded. Crucially, teachers play a central role in mediating this agency through the way they plan, scaffold and judge the openness of tasks. Learner agency, therefore, cannot be separated from teacher expertise and pedagogical choices.

The framework provides KS3 D&T teachers with a practical tool to plan and evaluate project contexts more intentionally. It could help teachers strengthen external features (authentic tasks, users and practices), while also ensuring internal features such as relevance and meaningful pupil decision-making are built into tasks rather than added superficially. It also supports teachers in recognising how resources, time and subject knowledge shape what authenticity can look like in their context, helping them make informed adjustments that maintain complexity and agency within realistic classroom constraints.

Finally, authenticity is shaped by system-level constraints, including available materials, resourcing and timetabling. Although these sit outside the task itself, they directly influence what teachers feel able to design and pupils are able to do. When these constraints narrow the scope for iteration, uncertainty or meaningful decision-making, the authenticity of even well-intentioned tasks can be compromised.

By bringing these dimensions together, the framework offers a clearer way to analyse and design authentic project contexts for KS3 D&T. It highlights that authenticity emerges not from any single feature, but from the interaction between context, learner experience and the practical realities of school settings. Future work will apply the framework to live KS3 curriculum projects to examine how these dimensions operate in practice and how authenticity can be strengthened within real classroom constraints.

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Exploring Generative Artificial Intelligence in Upper Secondary Art and Design Education: Developing Digital Competence and Critical Reflection

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Abstract

This project investigates how generative artificial intelligence (AI) can be integrated into upper secondary art and design education, to enhance students' digital competence, critical reflection, and digital judgment. The study is set within a contemporary context where generative AI is increasingly shaping education, work, and society. The Norwegian curriculum emphasizes digital skills as a core competency, highlighting this project's relevance for today's educational landscape. The aim of this project is to explore how teaching and learning with generative AI, can foster creative, ethical, and reflective practices in design education. By embedding AI tools into the classroom, the project seeks to investigate how this technology can serve as a resource to spark students' creativity, while also addressing ethical challenges and encouraging critical evaluation of AI-generated outputs. Methodologically, the project applies educational design research (EDR), combining theoretical development with practical interventions. We designed an assignment where students use generative AI to create an advertising poster, focusing on visual devices, target audience, content and meaning. We used the qualitative methods unstructured classroom observation, semi-structured interviews and analysis of student work. 22 students, in two groups, and one teacher take part in two iterative design cycles. Thematic analysis is used to identify patterns in interaction, reflection, and learning among the participants. This project contributes to a further understanding of how generative AI can be adapted to educational contexts to strengthen students' digital skills and critical thinking. It also sheds light on how teachers can facilitate meaningful learning experiences in response to a rapidly evolving digital world. By sharing insights from this research, we aim to contribute to broader discussions on how AI can be integrated in education in ways that promote creativity, ethical and critical reflection.

Key Words: AI Literacy, Generative AI, Digital Competence

1 INTRODUCTION

Generative artificial intelligence (AI) is an emerging technology in today's education, shaping how students learn, create, and make decisions. This places new demands on their abilities in critical evaluation and influences which competencies they may need in their future education, work, and participation in society. In educational contexts, generative AI tools that produce visual content challenge established understandings and raise new questions about creativity, authorship, and critical evaluation, highlighting the need for reflective and responsible approaches to AI supported tools.

As generative AI increasingly enters educational settings—intentionally or otherwise—there is a growing need to examine how students develop an understanding of how these technologies function, how they may be used as creative resources, and which ethical and critical considerations are involved. This need extends beyond individual competencies to include how students negotiate meaning, make decisions within iterative processes, and engage in collaborative reflection when working with AI-supported tools.

Drawing on research conducted for our master's thesis within a Norwegian upper secondary art, design, and architecture programme, this paper examines how students develop AI and digital literacy through the use of generative AI and collaborative group work, where AI functions as a shared reference point for dialogue, evaluation, and learning.

2 LITERATURE REVIEW

Building on Vartiainen et al.'s research on co-creation with generative AI and peer interactions (Vartiainen et al., 2023), this study extends their work through a practical educational design that emphasizes dialogic teaching, iterative prompting and ethical reflection to evaluate its impact on students' AI and digital literacy. In line with research on AI in education, Heaton et al. (2024) argue for pedagogical approaches that position students as active and reflective participants in AI-supported creative processes, rather than passive users of generative technologies. Together, this perspective informs the educational design in the present study, with a focus on students' development of AI knowledge and critical reflection on data use, consent, privacy, and responsibility.

3 THEORETICAL FRAMEWORK

3.1 *Pragmatism*

The project draws on John Dewey's pragmatist concept of knowledge, which conceptualises learning as developing through practice, controlled experience, action, and reflection (Dewey, 1916). Dewey regarded experience as the basis for all knowledge, and this experience comes from a constant transaction with the environment (Dewey, 1929, 1938). From this perspective, learning emerges through active engagement with concrete situations and reflection on the consequences of one's actions. This perspective underpins the research project's iterative process, where

teaching is continuously adapted based on empirical experiences to support students' development of digital skills and critical thinking. The link between experience and knowledge is also reflected in the teaching design, where the students shift between working with generative AI and reflecting on what they have experienced.

Dewey worried that students would learn subject matter isolated from real life (Dewey, 1916) and stressed that education should provide experiences relevant outside of educational institutions, that can be connected to further experiences and arouse the learner's curiosity and desire to learn more (Dewey, 1938). The design is therefore grounded in current and societally relevant issues that students encounter in contemporary society and is structured to facilitate collaboration, exploration, evaluation, and problem-solving. This approach aligns with Dewey's understanding of learning as a problem-solving process that emerges in response to challenges and develops through active participation, dialogue, and collaboration (Bailey et al., 2010).

3.2 *AI literacy and digital literacy*

This study is grounded in AI-literacy, understood as the ability to collaborate and communicate with AI while engaging with it critically and ethically (Long & Magerko, 2020). The design for the project was also anchored in the Norwegian Directorate of Education and Trainings framework for students' digital literacy, which emphasizes privacy, source evaluation, ethics, and copyright when using digital media (Norwegian Directorate for Education and Training, 2017). By embedding these frameworks into classroom activities, the project investigates how generative AI can function as a resource in students' creative processes, while also addressing ethical challenges and encouraging critical evaluation and AI-generated outputs.

4 METHODOLOGY

4.1 *Participants*

The participants were students from the Norwegian upper secondary art, design, and architecture program, which grants general university entrance qualifications. The program focuses on creative work and developing skills in visual art, design, and architecture. One teacher carried out the educational design by facilitating dialogue during presentation and guided students as they worked with the assignment. We did not focus on the teacher's implementation, as the focus was on the students.

A total of 22 students participated in the study. They were split into two groups, the first intervention had a group of 10 students, and the second intervention had 12 students.

4.2 *Ethical Considerations*

This research project has been approved by Sikt – Norwegian Agency for Shared Services in Education and Research (SIKT, n.d.). This ensures students and teachers privacy, anonymity, and data protection. The teacher and students have signed to declare informed consent to participate.

4.3 *Educational design research (EDR)*

This study's methodological approach is educational design research (EDR), which aims to address and develop solutions to challenges in educational practice, while contributing to theory development (McKenney & Reeves, 2018). We conducted the educational design research project through two iterative cycles of design, implementation, evaluation and re-design before trying it again, collecting data during the implementation phase.

4.3.1 *The Components of the educational design*

The design consisted of:

- Presentation material: A PowerPoint introduced generative AI, technical use, privacy considerations, and contemporary applications of AI in advertising. It addressed strategies for identifying AI-generated content and ethical issues related to responsibility, transparency, misinformation, labelling, and applicable legal regulations, supported by integrated questions to promote critical discussion.
- Assignment and worksheet: students collaborated in pairs to design an advertising poster, combining analogue sketching with AI-based image generation (first text-to-image and then image-to-image). Their design process, including ideas, sketches, prompts, and outcomes, was documented in a worksheet.

4.4 *Data collection and analysis*

Educational design research commonly employs qualitative methods for collecting and analysing data (McKenney & Reeves, 2014). We have chosen the qualitative methods observation and interview, presented in the following sections.

4.4.1 *Observation*

Observation was chosen as a method to examine how the design worked, what could be improved, and if it fostered students' digital literacy, and AI-literacy, through observing interactions and practical work. We observed one instructional week per intervention and had an unstructured approach. The first intervention totalled 8 school hours (45 min. each) and the second 9 school hours, both spread across the week. Our observational roles were non-participant (Bryman, 2016). Right after the lessons, we made field notes describing what we had observed.

4.4.2 *Interview and group discussion*

Two types of interviews were conducted with the students to collect data:

- Semi-structured interviews (Brinkmann & Kvale, 2015): Focused on assessing the educational design, including what functioned well and what could be improved.

- Group discussion: Explored students' experiences, the technical skills they developed, their ethical reflections on AI, and their perceptions of artefacts, bias, and limitations in AI-generated outputs. Both part of the design and as a way to gather data.

Drawing on the group discussion, this paper primarily examines students' ethical reflections on AI, with particular attention to privacy, copyright, and misinformation, which are commonly understood as key components of AI literacy and digital literacy.

4.4.3 *Thematic analysis*

We used thematic analysis based on Braun and Clarke's (2006) framework as our qualitative approach, due to its focus on identifying recurring themes across the dataset. This framework was used to analyse meaning in interview transcriptions, fieldnotes, and students' work sheets. Themes were developed with the research question in mind. The analysis involved familiarizing with the data, generating initial codes, developing, reviewing and defining themes, and reporting the results in relation to theory.

The analysis was conducted inductively, and four themes developed:

- Digital literacy
- Student engagement
- Technical skills with AI
- Redesign

In this paper we will present and elaborate on the results from the themes *Digital literacy* and *Redesign*. Due to word limitations, the themes are not fully explored.

4.5 *Disclosure on the use of Generative AI*

The data analysis and text production for this paper is done entirely by the authors, but GenAI-tools have been used in translations from Norwegian to English and for copy editing.

5 RESULTS

Here we are presenting results from intervention 1 and 2, focusing on Digital literacy and what had to be redesigned between and after each intervention.

5.1 *Results from first intervention: Digital literacy*

5.1.1 *Students' reflections on copyright*

Copyright emerged as a key theme in intervention 1. Observations indicated that several students raised questions regarding copyright during the lessons and engaged in discussions concerning

the ethical frameworks governing the use of AI for image production, as well as whether such practices comply with established guidelines.

During the group discussion, concerns and considerations emerged regarding the origins of the images generated by AI and copyright infringement in the training material. One student (Student 3) expressed uncertainty about whether all images used to train AI systems have been used with consent from the original creators and questioned the ethical implications of such use. This statement may indicate that the student is reflecting on potential issues related to ethical use of generative AI.

The student groups approached copyright issues differently in their own work. One group attempted to generate a well-known brand logo in their advertisements. After initial challenges, they succeeded, which may indicate that the AI systems enforce copyright protection and trademarks only to a limited extent. The group commented on their submission, which may be interpreted as an awareness of copyright issues and as emerging understanding of the limitations and potential workarounds within the AI system.

In contrast, another group described a conscious effort to uphold copyright in their work. They refrained from using copyright-protected images from existing brands and instead drew inspiration from a magazine cover, while deliberately avoiding providing the AI with photographs taken by others. These reflections are also articulated in their submitted work.

5.1.2 Students' reflections on privacy

During the group discussion, students reflected on privacy issues in AI use and whether they had considered privacy when completing the task. An analysis of the submitted task sheets revealed no prompts that raised privacy concerns. Several students also reported deliberately avoiding the use of images of themselves or others, as well as personal data. This suggests that the teaching design adequately addresses privacy issues and that students demonstrated awareness of privacy considerations when using generative AI.

Although the students took privacy considerations into account, they also expressed concerns regarding the training material, and whether this may include images of individuals who have not given consent. One student group noted that they had generated a face that appeared familiar. Another student highlighted children's privacy as a particular area of concern, pointing out that publicly available images may potentially be misused as AI training data.

5.1.3 Students' reflections on misinformation in AI-generated content

In both the observation and the group discussion, students explained why and how the use of AI should be labelled, and how unlabelled AI images may affect consumers' trust and perceived value. Several students were surprised that clear regulations for AI-generated advertising have not yet been established, particularly given existing requirements for labelling digital retouching in advertising. They emphasised that distinctions between what is real and artificial can be

blurred, potentially leading to uncertainty and unrealistic expectations, especially in contexts such as cosmetic advertising.

5.2 *Redesign after the first intervention*

5.2.1 *Including copyright*

We initially removed slides on copyright from the first intervention per the teachers' advice, but students repeatedly raised questions on AI and ethics on copyright. We therefore reinstated a copyright component within the AI and ethics module in the PowerPoint.

5.2.2 *Instructional design: Assignment execution and Structure*

Many students generated before ideating or sketching and underinvested in sketch development, which hindered Assignment 2 and caused frustration. We emphasized that stronger sketches lead to better outputs and implemented a phased workflow:

- (i) Idea and design development with sketching, documented in assignment sheet
- (ii) Assignment 1: Prompting based on sketches (text-to-image) + documenting process.
- (iii) Assignment 2: Using sketch image as input in the prompt (image-to-image) + documenting process.

5.3 *Results from the second intervention: Digital literacy*

5.3.1 *Students' reflections on copyright*

In contrast to the first intervention, several students wanted to design advertisements for well-known brands using trademarked brands and logos. During image generation, Microsoft Co-pilot sometimes refused to generate content due to copyright restrictions, while at other times it allowed protected logos to be generated. This inconsistency triggered several students to discuss what is acceptable and how one should relate to copyright if AI does not enforce it. In group work, one student said it felt wrong that one person had access and another didn't, the same group continued, reasoning that: 'AI doesn't care about copyright anyway', and therefore it was fine to continue. However, two of the other groups chose to reconsider their design choices and their prompting strategies during their design process, to maintain a certain originality. Asked what they could do to uphold copyright after experiencing the AI tool's inconsistency, the students expressed different strategies. One student stated that to use generative AI ethically, one must create entirely new designs and steer clear of existing names or logos and reported doing so. Another student favoured changing the name while keeping the look but later switched to an original design to avoid copyright risk.

5.3.2 *Students' reflections on privacy*

In the group discussion, the students were asked whether they had adhered to established privacy guidelines. They confirmed that they had consciously avoided privacy violations, which was supported by the prompt histories in the task sheets, showing no privacy-related content. This suggests that students demonstrated awareness of privacy considerations in their assignment work. To further elaborate on this, students were also asked whether they reflect on privacy beyond this assignment. Several students expressed that they generally relate to privacy issues, but that these are not necessarily considerations they reflect on extensively in their everyday use of digital services, such as AI tools and social media. One student stated that they would not want their face stored in an AI database, while another student added that during the introductory phase of new applications or social media platforms, users often do not reflect on the fact that uploaded images may be used as training data for AI systems. Students stated that using one's own face in AI-generated images, in principle, is an individual choice. However, several students pointed out that such choices are not always fully informed, partly due to insufficient or inaccessible information about terms of use. Some students also expressed that they were unaware of the existence of settings in various AI tools and social media platforms that allow users to control or limit how their personal data are used.

5.3.3 *Students' reflections on misinformation in AI-generated content*

A central topic of discussion throughout the period was misrepresentation and misinformation in using AI for advertising and other forms of content, particularly in cases where AI-generated material was not clearly disclosed. There was general agreement among the students that AI-generated advertising should be clearly labelled, for example in cases involving clothing and AI-generated models, as they perceived that a lack of disclosure could contribute to uncertainty and confusion among audiences. Students argued that regulatory frameworks should require the labelling of AI-generated content, partly because consumers may develop unrealistic expectations, products may not correspond to the quality portrayed, and not all users are able to recognise that the content has been generated.

Another highlighted aspect concerns instances in which deepfakes are used to spread misleading information or fraudulent activities targeting vulnerable groups. One student noted having seen several videos in which celebrities were represented through deepfakes, and that it may be difficult to distinguish these from authentic videos. The student expressed particular concern about the potential consequences of using such technology towards children.

5.4 *Redesign after the second intervention*

5.4.1 *Instructional design: Assignment execution and structure*

After observing students work and what the students requested to be redesigned, these are what had to be revised:

- Clarity: A clearer walkthrough to be confident in the execution and some parts being too vague.
- Structured timeframes: more structured time frames to plan and outline their process.
- Extended time: More time for ideation and sketching to improve image generation outputs.

6 DISCUSSION

The aim of this study was to explore how the educational design, employing collaborative work with generative AI, enhanced students' development of AI and digital literacy, rather than measuring learning development across the interventions. The results indicate that students engaged actively with ethical and critical dimensions of AI use, particularly related to privacy, data use, and consent. Students' strong consensus around privacy suggests that the topics introduced in the design may function as an entry point for ethical reflection, aligning with core dimensions of AI-and-digital literacy frameworks (Long & Magerko, 2020; Norwegian Directorate for Education and Training, 2017).

Working with the assignment to design AI-generated advertisements facilitated discussions of image origins, consent, copyright, as well as strategies for responsible use. Through problem-solving and discussions, students demonstrated competencies in ethical AI use, source evaluation, and copyright awareness (Long & Magerko, 2020; Norwegian Directorate for Education and Training, 2017). Students' differing views on responsibility in AI generated advertising highlight that ethical judgement in this context is complex. These tensions can be understood as productive, as they indicate active engagement with ethical dilemmas rather than uncritical acceptance.

Students engaged extensively in peer discussion and collaborative reflection, often extending discussions beyond what was explicitly addressed in the educational design. The group discussions appeared to support understanding of AI-related issues, particularly when students were given space to articulate perspectives and build on one another's contributions.

Students' reflections were especially notable when discussing AI-related issues connected to relatable experiences from their digital everyday lives, such as misinformation, deepfakes, and unlabelled AI-generated content on social media and advertisements. This supports Dewey's understanding of learning as emerging through experience, inquiry, and problem-solving in response to real and relevant challenges (Dewey, 1916, 1938). When AI-generated outputs failed to meet students' expectations, peer discussion and iterative adjustments of prompt strategies became part of the learning process, indicating that reflection was embedded in the activity itself rather than occurring only after the task completion.

Overall, the results suggest that the educational design supports key aspects of AI and digital literacy by combining ethical reflections, peer interactions, and practice-based assignments with generative AI. The design aligns with dialogic co-creation approaches (Vartiainen et al., 2023), pragmatist views of learning through experiences and iteration (Dewey, 1916, 1938), active

participation (Heaton, et al. 2024) and the iterative logic of EDR (McKenney & Reeves, 2018). However, given the limited scope of the study, continued interventions are needed to further test and refine educational designs that support students' AI-and-digital literacy across educational practices to keep up with the ongoing technological development.

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Learning Value in Participating in a STEAM Competition: An Example of iSTEAM-PowerTech

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Abstract

Expanding on the three types of value in science, technology, engineering, art and mathematics (STEAM) competitions, namely value in radical, social and cognitive constructivism, this study developed more types of value of participating in a STEAM competition, specifically: (1) Physical growth, (2) STEAM knowledge building, (3) Career self-efficacy, (4) Learning attitude enhancement, (5) Thinking skill development, (6) Social-Emotional Development, and (7) Sustainable Development Goal (SDG) concept building. This study surveyed 56 teachers who have long mentored students taking part in the iSTEAM-PowerTech competition to explore students' multifaceted learning values. The results indicated teachers' strong value of students' participation. Among the value constructs, Physical growth scored the highest ($M = 4.51$), showing students' improvement in motor control and coordination. STEAM knowledge building and Career self-efficacy followed, reflecting that participating in iSTEAM-PowerTech can enhance interdisciplinary STEAM knowledge learning, and career self-efficacy in STEM works. Although SDG concept building scored slightly lower, it revealed emerging awareness of sustainability and resource reuse. Overall, the iSTEAM-PowerTech competition effectively promotes students' hands-on skills, cognitive thinking, emotional development, and sustainability awareness, embodying the STEAM pedagogy of learning by creating and doing through the design processes of iSTEAM-PowerTech. (see <https://www.youtube.com/watch?v=rHnoNlnTHYM>).

Key Words: STEAM Knowledge, Radical Constructivism, Cognitive Constructivism, Social Constructivism

1 INTRODUCTION

1.1 *The Study Purpose*

The core concept of constructivism is that knowledge and thinking skills are not passed from the teacher to the learner; rather, they are actively constructed through interaction with project-based learning (Sayaf, 2023). Based on constructivist theory, learners actively build their understanding

through interaction with their environment (Piaget, 1970). All knowledge is constructed through one's perception and senses (von Glasersfeld, 2001), aligning with the principles of embodied cognition with physical engagement (Shapiro & Spaulding, 2021), which can increase the contextual, social, and radical values, for example, in hands-on STEAM project design (Hong et al., 2025). Besides, hands-on activities contribute to the development and cultivation of motor skills, in shaping physics learning (Ajibudiarta et al., 2025). Moreover, Okeke and Ramaila (2025) explored the concept of psycho-productive competency to capture the interplay between psychomotor skills and cognitive–affective dimensions of learning in a science, technology, engineering, art and mathematics (STEAM) activity and found that by highlighting hands-on, embodied, and creative approaches to problem-solving can develop project design skill. Accordingly, this study is to understand types of learning values of participating iSTEAM-PowerTech from their supervisors' perspectives.

1.2 Research Question

Psychodynamic theory explains the interrelation between conscious and unconscious processes in subjective engagement in learning where all hands-on events are considered as inevitable consequences of antecedent sufficient causes that show learning concern for positive growth (Kennedy & Sundberg, 2025). For example, design-based learning (DBL) is recognized as a unique and promising approach in STEM education due to its ability to engage students in mastering subject content while fostering creative thinking skills in cross-disciplinary environments (Siva et al., 2025). Participating in STEM-related competitions (e.g., Robot competitions) can promote student' cooperative motivation and learning attitude (Graffin et al., 2025). Moreover, the multiple intelligences theory provides many approaches through which the learning task could be presented to facilitate effective science, technology, engineering and mathematics (STEM) learning (Kennedy & Sundberg, 2025). Those studies indicated that there are many types of learning value from engaging a STEM activities can be classified, thus, this study is to develop different learning value for those supervisors to identify learning values of a STEAM competition, iSTEAM-PowerTech.

In iSTEAM-PowerTech competition, in order to ensure that participants design their own miniature models to compete speed independently, the contest requires students to complete three miniature models in the morning and participate in competitions in the afternoon. Prior to on-site model design, participants may design and repair their models at school and ensure functional operation successfully. During this pre-training process, teachers as the supervisors can observe students' performance and give suggestions to continuous quality improvement. From activity theory, who join a STEAM activity will always learn knowledge, attitude and psychomotor skills (Okeke & Ramaila, 2025), where pre-training of iSTEAM-PowerTech can facilitate students to enhance various learning value, but what kind of learning value they can learn from this activity observed by supervisors has rare discussed, thus a research question is proposed as follow:

What kind of learning value of participating iSTEAM-PowerTech students can acquire most?

2 METHOD

2.1 Procedure and Participants

This study targeted teachers who have long guided students in participating in the PowerTech competition as the research sample. To assess the learning value, based on ground theory, we first asked 15 iSTEAM-PowerTech supervisors who have ever led teams to participate the competition for at least 5 years to list the learning value they observed from students' engagement, then we listed 48 items for them to classify. Finally, seven types of learning value were proposed: (1) psychomotor growth, (2) STEAM knowledge building, (3) Career self-efficacy, (4) Learning attitude enhancement, (5) Thinking skill development, (6) Social-emotional development, and (7) Sustainable Development Goal (SDG) concept building. Moreover, a questionnaire was delivered to 56 supervisors to rank value of each item. Consequently, the value of each items and constructs of the essentiality of participating in iSTEAM-PowerTech was explored in this study. A total of 56 valid responses were received, resulting in a 100% valid return rate. Among the respondents, 39 were male (69.6%) and 17 were female (30.4%). Regarding age distribution, 11 participants (19.6%) were under 40 years old, 26 (46.4%) were between 41 and 50 years old, and 19 (33.9%) were above 51 years old.

3 RESULTS

3.1 Overall Analysis

The mean scores of all items ranged from 3.98 to 4.77, indicating that the respondents generally held positive perceptions in each item. Based on the mean scores, the top three items were: (1) My students have learned to correctly use various hand tools during creation ($M = 4.77$), (2) My students demonstrate stable movements when using hand tools ($M = 4.66$), and (3) My students continue to improve in visual and spatial awareness and moving ability ($M = 4.63$); all of these three items are related to psychomotor development.

In contrast, the lower mean items were: (1) I believe that the low cost of competition materials ensures affordability and equality for general students ($M = 3.98$), and (2) My students can plan material use in advance to maximize efficiency, such as how many objects can be made from a single board ($M = 4.00$), which are related to ESG practice, and (3) My students' competition experience and performance contribute to their advancement in further education ($M = 4.04$) which is related to value-added efficacy, indicating that these areas still have room for improvement. Overall, all constructs presented moderately high positive evaluations, showing that learners were generally satisfied with the activity content and their learning outcomes (see Table 1).

Table 1*Item Analysis*

No.	Construct	Item	<i>N</i>	<i>M</i>	<i>SD</i>	<i>FL</i>
1	Psychomotor development: Handling hand-tools	My students have learned to correctly use various hand tools during creation.	56	4.77	0.63	0.83
2	Psychomotor development: Action stability	My students demonstrate stable movements when using hand tools.	56	4.66	0.48	0.70
3	Psychomotor development: Visual-spatial ability	My students continue to improve in visual and spatial awareness and moving ability.	56	4.63	0.52	0.79
4	Career self-efficacy: Personal growth	The students I mentor experience a sense of accomplishment and personal growth as a result of engaging in hands-on practice.	56	4.57	0.54	0.82
5	Attitude: Initiative	My students are willing to take the initiative to divide work and coordinate tasks with teammates.	56	4.55	0.54	0.73
6	Psychomotor development: Hand-eye coordination	My students can coordinate hand–eye movements to complete delicate tasks.	56	4.55	0.54	0.71
7	Career self-efficacy: Hands-on career	I observed that students have developed greater interest in hands-on career paths.	56	4.54	0.54	0.80
8	STEAM learning: Engineering knowledge	My students understand optimization in engineering production through practice, such as tightening screws properly—not too tight or too loose.	56	4.48	0.74	0.88
9	Thinking skills: Metacognition	My students can identify errors from failures and propose improvement strategies.	56	4.48	0.6	0.72

10	Psychomotor development: Flexible bodily response	My students have developed more flexible bodily responses through hands-on operation.	56	4.48	0.63	0.77
11	Social-emotion: Self-management	My students demonstrate self-management by putting away tools and materials after practice.	56	4.45	0.63	0.80
12	Psychomotor development: Motor coordination	My students maintain stable and coordinated movements during prolonged practice sessions.	56	4.45	0.57	0.88
13	Social emotion: Emotional regulation and positive engagement	The students I mentor are able to sustain positive engagement even when working under group pressure.	56	4.45	0.54	0.73
14	Thinking skills: Analytical reasoning	My students can infer and analyze possible causes of problems encountered in creation.	56	4.43	0.57	0.78
15	Psychomotor development: Fine motor control	My students can effectively control strength and perform fine motor operations.	56	4.43	0.66	0.86
16	Attitude: Pursuing efficiency and quality	My students have improved their efficiency and quality in other tasks through competition experience.	56	4.43	0.68	0.85
17	STEAM learning: STEAM integration	My students enhance their ability to integrate and apply STEAM knowledge during the competition.	56	4.41	0.73	0.87
18	Thinking skills: Design thinking	My students can generate creative ideas and designs under limited resources and conditions.	56	4.41	0.68	0.56
19	Thinking skills: Inductive reasoning	My students demonstrate the ability to generalize principles from experience.	56	4.41	0.65	0.84
20	Attitude: Continuous improvement	My students show a continuous improvement attitude by repeatedly refining their work.	56	4.41	0.57	0.78

21	Career self-efficacy: Transfer of learning	My students can apply the procedures and methods learned from competition to other tasks.	56	4.41	0.63	0.83
22	Attitude: Knowledge sharing	My students are willing to share their experiences and approaches with others.	56	4.39	0.62	0.78
23	Attitude: Engaging in team work	My students encourage teammates and demonstrate active interaction.	56	4.39	0.68	0.84
24	Social-emotional: Empathy	My students show empathy and take the initiative to assist others.	56	4.39	0.56	0.77
25	Career self-efficacy: Skill acquisition	My students demonstrate practical skills that can be applied to future competitions.	56	4.39	0.59	0.89
26	Career self-efficacy: Confidence & motivation	I observed that students' sense of achievement through creation enhances their confidence in learning other subjects.	56	4.38	0.65	0.83
27	Psychomotor development: Bodily/tactile development	My students demonstrate the strengths of tactile development.	56	4.36	0.72	0.72
28	STEAM learning: Knowledge application	My students can integrate the STEAM knowledge they have learned into the creation process.	56	4.34	0.72	0.86
29	Attitude: Craftsmanship	My students pursue accuracy and efficiency during production.	56	4.34	0.58	0.79
30	Attitude: Responsibility	My students take responsibility and make improvements when problems occur.	56	4.34	0.67	0.66
31	Social emotion: Listening	My students can listen to and respond to others' opinions in teamwork.	56	4.32	0.64	0.75
32	Thinking skills: Flexible thinking	My students have the ability to identify and adjust the direction of their designs.	56	4.30	0.69	0.84

33	Social emotion: Tool self- management	My students show self-management by organizing and storing tools and materials after practice.	56	4.30	0.69	0.56
34	SDG: Using materials	I believe that the effective use of competition materials contributes to promoting the Sustainable Development Goals (SDGs).	56	4.27	0.84	0.74
35	Thinking skills: Critical thinking	My students demonstrate critical thinking and problem-solving skills in design issues.	56	4.25	0.69	0.87
36	Social emotion: Stress resilience	My students can handle problems calmly when facing setbacks.	56	4.25	0.67	0.70
37	SDG: Using recycled materials	My students actively recycle reusable materials.	56	4.25	0.77	0.72
38	Thinking skills: Proactive thinking	My students can anticipate possible unexpected situations during the competition and take responsive actions.	56	4.23	0.69	0.83
39	STEAM learning: STEAM disciplines	My students understand the importance of the STEAM disciplines for design work.	56	4.23	0.81	0.82
40	STEAM learning: Domain knowledge comprehension	My students learn mathematical and scientific concepts through designing in practice.	56	4.20	0.8	0.84
41	Social-Emotion: Emotional awareness and expression	My students can recognize and appropriately express both their own and others' emotions.	56	4.20	0.7	0.81
42	SDG: Equity & accessibility	I observed that students with lower academic performance can also participate in this competition.	56	4.16	0.97	0.71
43	Attitude: self- demanded	My students demonstrate a high level of self-demand for design quality.	56	4.16	0.6	0.78
44	SDG: Reducing material usage	My students try to reduce material waste during production.	56	4.07	0.78	0.84

45	SDG: Reusing materials	My students consider the reusability of materials during creation.	56	4.04	0.83	0.76
46	Career self-efficacy: Advanced education	My students' competition experience and performance contribute to their advancement in further education.	56	4.04	0.93	0.77
47	SDG: Resource use	My students can plan material use in advance to maximize efficiency, such as how many objects can be made from a single board.	56	4.00	0.85	0.69
48	SDG: Equal accessibility	I believe that the low cost of competition materials ensures affordability and equality for general students.	56	3.98	1.12	0.69

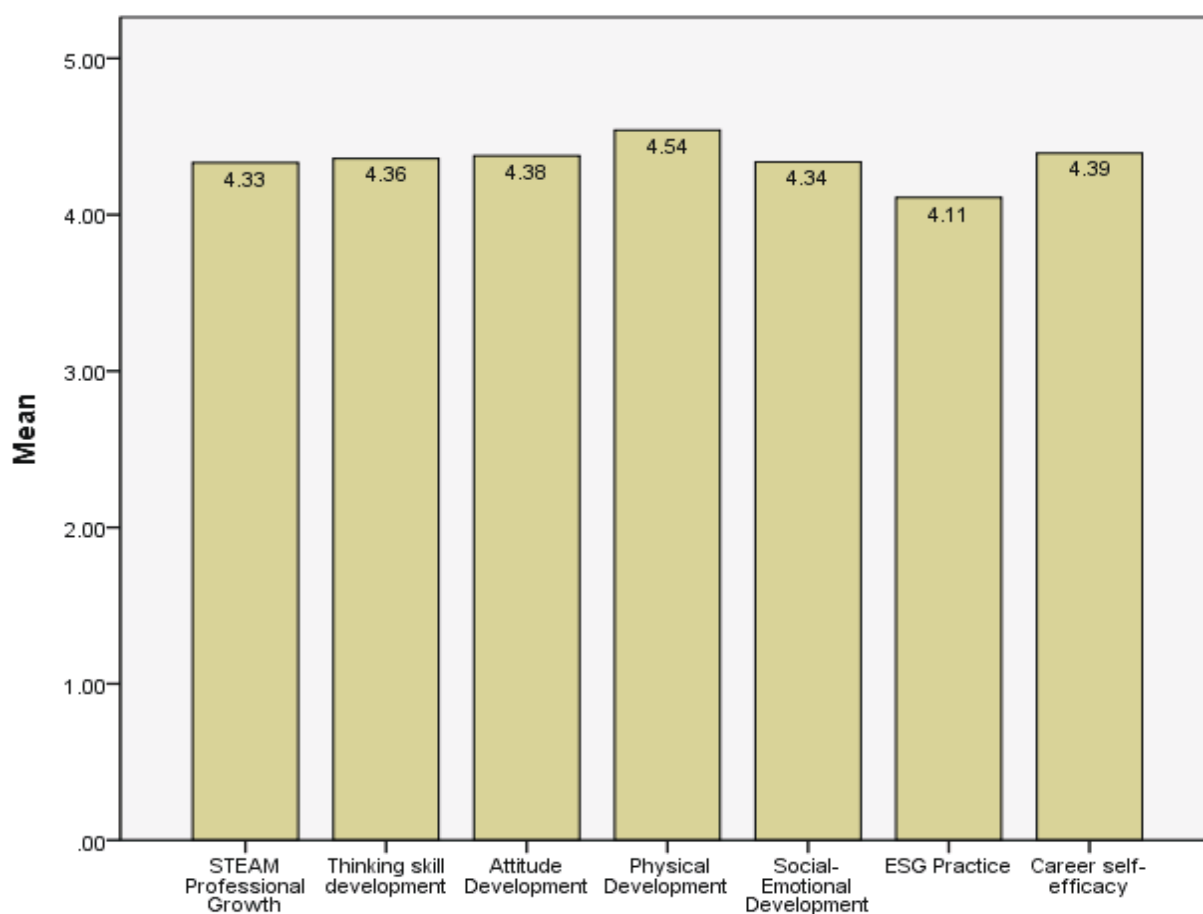
4 FINDINGS

4.1 *Construct Comparison*

The mean scores of each construct, arranged from highest to lowest, were as follows: Psychomotor development ($M = 4.54$, $SD = 0.43$), STEAM Professional Growth ($M = 4.33$, $SD = 0.67$), Career Self-Efficacy ($M = 4.39$, $SD = 0.54$), Attitude Development ($M = 4.38$, $SD = 0.46$), Thinking Skill Development ($M = 4.36$, $SD = 0.55$), Social-Emotional Development ($M = 4.34$, $SD = 0.48$), and ESG Practice ($M = 4.11$, $SD = 0.65$). Overall, the teachers perceived students' performance in psychomotor development to be the most prominent, while ESG Practice received relatively lower ratings (see Figure 1).

Figure 1

Construct Comparison



4.2 Analysis of Each Construct

4.2.1 Item Comparison in STEAM Knowledge

In the construct of STEAM Knowledge, the average score was $M = 4.33$. Among all items, the highest-rated statements were “My students understand optimization in engineering production through practice, such as tightening screws properly—not too tight or too loose” ($M = 4.48$) and “My students enhance their ability to integrate and apply STEAM knowledge during the competition” ($M = 4.41$). These results indicate that teachers generally agree the PowerTech competition helps students develop operational skills and integrate engineering knowledge through hands-on experiences. Overall, such activities effectively facilitate learning through practice, fostering students’ engineering thinking and interdisciplinary application abilities.

4.2.2 Thinking Skill Development

In the construct of Thinking Skill Development, the average score was $M = 4.36$, indicating that teachers generally perceived students to possess strong reflective and adaptive thinking skills.

The highest-rated item was “My students can identify errors from failures and propose improvement strategies” ($M = 4.48$), showing that students demonstrated effective metacognitive awareness through the process of trial and error. Overall, students performed well in inductive reasoning, creative design under resource constraints, and proactive thinking, demonstrating the PowerTech competition’s effectiveness in terms of cultivating critical and creative problem-solving abilities.

4.2.3 *Attitude Development*

The construct of Attitude Development had an average score of $M = 4.38$, suggesting that students exhibited positive attitudes and interpersonal engagement in teamwork. The highest-rated item was “My students are willing to take the initiative to divide work and coordinate tasks with teammates” ($M = 4.55$), followed by “My students are willing to share their experiences and approaches with others” ($M = 4.45$). These findings imply that students demonstrated strong collaboration, communication, and responsibility, highlighting that the competition positively contributes to students’ attitude formation and cooperative learning spirit.

4.2.4 *Psychomotor Development*

In the construct of Psychomotor development, the average score was $M = 4.54$, the highest among all constructs. This indicates that students exhibited excellent performance in movement coordination, operational stability, and body control. The top-rated items were “My students demonstrate stable movements when using hand tools” ($M = 4.66$) and “My students continue to improve in spatial awareness and movement coordination” ($M = 4.63$). These results reveal that students not only strengthened their sensory awareness through practice, but also developed steady and precise operational abilities. Overall, PowerTech effectively enhances students’ sensory integration and tactile learning strengths.

4.2.5 *Social-Emotional Development*

The construct of Social-Emotional Development showed an average score of $M = 4.34$, indicating that students demonstrated good emotional regulation, empathy, and teamwork ability. The highest-rated items were “My students maintain positive participation under group pressure” ($M = 4.45$) and “My students encourage teammates, demonstrate active interaction, and show empathy by assisting others” ($M = 4.39$). These findings show that students can engage positively in teamwork and maintain stable emotional management, suggesting that the PowerTech competition effectively fosters social-emotional learning and interpersonal growth.

4.2.6 *ESG Practice*

The construct of ESG Practice had an average score of $M = 4.11$. The highest-rated items were “I believe that the effective use of competition materials contributes to promoting the Sustainable Development Goals (SDGs)” ($M = 4.27$) and “My students actively recycle reusable materials” ($M = 4.25$). These results indicate that the PowerTech competition design emphasizes both economic affordability and educational sustainability. Students showed steady performance in

recycling, reusability, and waste reduction, suggesting that the competition gradually cultivates students' awareness of environmental responsibility and sustainable practices

4.2.7 *Career Self-Efficacy*

In the construct of Value-Added Effectiveness, the average score was $M = 4.39$, reflecting positive outcomes in students' self-development and future application. The highest-rated items were "My students find a sense of personal accomplishment through hands-on practice" ($M = 4.57$) and "My students find a sense of personal accomplishment through hands-on practice" ($M = 4.54$). These results indicate that PowerTech not only enhances students' motivation and self-confidence but also supports career self-efficacy. Although "My students' competition experience and performance contribute to their advancement in further education" ($M = 4.04$) scored relatively lower, the overall findings suggest that the competition enriches students' confidence, learning transfer, and long-term development potential.

5 DISCUSSION AND CONCLUSION

The complex challenges of the 21st century have necessitated the integration of traditionally discrete disciplines, leading to the emergence of STEAM. STEAM integration seeks to dismantle disciplinary boundaries while fostering creativity and innovative practices to address complex, context-specific problems (Kennedy & Odell, 2023). From activity theory, who join a STEAM activity will always learn knowledge, attitude and psychomotor skills (Okeke & Ramaila, 2025). Design-based activities, according to Windschitl (2002), are complex and meaningful. They involve obtaining students' ideas on specific topics and organizing suitable learning experiences to help them improve their current knowledge, attitude and skills. To explore the learning values of iSTEAM-PowerTech, this study used grounded theory to identify the values recognized by senior teachers who have led teams to join iSTEAM-PowerTech. More teachers were then asked to rate the essentiality of each item. By comparing major constructs, the results indicated that: (1) Physical growth was ranked as having the most value to students, followed by (2) STEAM knowledge building, (3) Career self-efficacy, (4) Attitude enhancement, (5) Thinking skill development, (6) Social-Emotional Development, and (7) SDG concept building. Among all of the constructs, physical growth was perceived as having the greatest value.

The article is primarily extended interpretation from several theories, for example, multiple intelligence, to reframe the various domains beyond its traditional association with manual or technical skills. While these learning values were identified by supervisors' observation, it lacks empirical testing in classroom or shop settings. Future research should explore how the proposed reconceptualization translates into experimental outcomes across different stages of pre-training contexts.

Most courses for K-12 students are taught by lecturing in Taiwan, which may be beneficial for students with visual and audio learning styles, but not for those with a kinesthetic learning style. Therefore, some students lose interest in attending school, and may even drop out. Therefore, it is recommended that focusing on schools providing the information about the learning value of iSTEAM-PowerTech-related courses and competitions, then future study may compare if the

providing can enhance those different learning styles students to perceive learning value of iSTEAM-Power different.

6 ACKNOWLEDGEMENTS

6.1 *Funding Statement*

This project is supported by National Science and Technology Council of Taiwan and Institute for Research Excellence in Learning Sciences, National Taiwan Normal University from The Featured Areas Research Center Program within the framework of the Higher Education Sprout Project by the Ministry of Education (MOE) in Taiwan.

6.2 *Declaration on the Use of Generative AI*

The authors confirm that no generative artificial intelligence (AI) or AI-assisted technologies were used in writing, data analysis, or the creation of this manuscript. The entire content was produced solely by the human researchers.

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Topics in Technology Education Textbooks from Germany

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Abstract

Over time, textbooks have undergone significant transformation through digital enhancements, yet they remain central instructional media that serve an orienting function for teachers. Consequently, textbook research can offer insights into subject-specific impacts, including the support of learning activities and practical work (Larsson & Stolpe, 2025, p. 1825). This study employs a qualitative content analysis to examine 14 technology education textbooks from Germany with regard to the technical topics they convey. The findings reveal that the institutional positioning of technology education, whether as a dedicated subject or as part of an integrated subject, has a substantial influence on the scope and thematic selection of textbook content. A comparison with the contexts of the international Standards for Technological and Engineering Literacy (ITEEA) shows that the areas of "Medical and Health-Related Technologies" and "Agricultural and Biological Technologies" are not present in the analysed textbooks. Instead, topics of a cross-cutting character are integrated ("Sustainability", "Vocational Orientation", "History of Mankind and Technology", and "Descriptions of Lesson Methodologies"), which can be explained by the German tradition of subject-specificity.

Key Words: Technology education textbooks, Topics in technology education, Qualitative content analysis

1 TEXTBOOKS AND THEIR RELEVANCE

Textbooks are educational media with a long-standing tradition, and despite the increased use of digital media in schools and classrooms, they continue to hold central importance as an educational resource. They are considered a "hidden curriculum" and serve as key reference points for educators in the preparation and delivery of instruction (Kaminski, 2017, p. 222; Kirchner, 2016, p. 343; Daus et al., 2004, p. 80). This is especially true for teachers instructing outside their primary subject expertise, who are often employed in the so-called 'minor' subjects (Kaminski 2017, p. 222), amidst the current and projected teacher shortages prevalent in Germany (Klemm 2020). The extent to which these results regarding the significance of textbooks can be directly transferred to technology education remains an area for further research. Teachers have discussed at length in which learning areas and subjects textbooks are either necessary or dispensable (Sandfuchs, 2010, p. 11). In technology education, the highly activity oriented

structure of the subject poses particular challenges for the design of school textbooks (Kirchner & Penning, 2024), and the medium has therefore already been the subject of critical discussion (Sachs, 2002a, 2002b).

1.1 *Definition of terms: Textbooks*

A precise definition of what a textbook is has been challenging to pinpoint, particularly because with the inclusion of various contemporary, increasingly digital, supplementary materials, it is unclear where the meaningful boundary of the textbook lies. In the present article, textbooks are defined, by four functions: as educational resources that structure and transmit officially valued knowledge, guide learning practices through instructional activities, convey cultural and ideological values, and provide documentary materials that support the development of students' critical thinking (Aguiar & Dias Garcia, 2020, p. 210). Textbooks have evolved from purely print media to hybrid media, combining digital elements with the traditional textbook format. Here, different media forms can be distinguished (Macgilchrist, 2017, pp. 226-228).:

- The *digitized version of printed textbooks* in the form of non-editable PDF files, serving as static e-books (Ulrich & Huwer, 2017, p. 65).
- *Multimedia-interactive digital textbooks*, which are designed and developed as digital products (Macgilchrist, 2017, p. 227). These include additional offerings such as text, audios, or videos, and digital applications such as quizzes that students can interactively engage with. However, the basic structure of the digital textbook remains unchanged.
- *Constructive-interactive digital textbooks* allow students to create or modify content themselves, thus independently constructing knowledge offerings. The content created by the students expands the textbook but does not alter the published textbook content (Macgilchrist, 2017, p. 227).

Moreover, adaptive textbooks are currently being developed, which, through activity recognition, tailor and deliver content individually to students, for instance, in the subject of physics (Dengel, 2023). The rapid developments in artificial intelligence in particular are therefore likely to have a major impact on the further development of school textbooks as a core medium of teaching and learning in schools.

The extent to which these digital textbook options are currently being used in general education, and specifically in technology education, remains unclear. Interesting findings are provided in the study by Glasnović Gracin and Trupčević (2025), who conducted an analysis of mathematics textbooks and the e-tasks contained within them, and noted that “digitalization was not being employed to its full potential. Classroom observations indicated that digital textbooks were primarily used to display static images on a smartboard screen” (Glasnović Gracin & Trupčević, 2025).

1.2 *Textbooks (for technology education) in Germany*

In many German federal states, textbooks must undergo a ministerial approval process. During this process, textbooks are specifically reviewed to ensure they cover the curricular requirements. Teachers in public schools are only permitted to use approved textbooks, although they are free to incorporate other educational media, including unreviewed resources published online.

Textbooks are developed and commercially distributed by educational media publishers in Germany. Therefore, publication by an established textbook publisher can be considered an additional formal, definitional criterion for school textbooks. Textbooks are subject to the principle of learning material freedom (also known as the free provision of learning materials) in many German federal states, meaning they are provided free of charge.

Kirchner and Penning explain that the market situation for textbooks in the German integrative subject of economics-work-technology for lower secondary school (cf. 2.1) does not indicate a particularly strong tradition of textbooks in schools (Kirchner & Penning, 2024). The potential demand for textbooks in minor subjects is lower than in major subjects, making production less lucrative for textbook publishers. The market for technology education textbooks is particularly small because the federal states position technology education differently (cf. Section 2), thus limiting the transferability of an already available textbook to other federal states.

2 TECHNOLOGY EDUCATION IN GERMANY

Germany consists of 16 federal states, each with its own educational sovereignty. Since the development of technology education in the 1970s, various approaches to teaching technology have emerged in Germany. These approaches significantly influence the curricular integration of technology education, whether as a standalone subject or as part of an integrated subject. In the subsequent textbook analysis, 14 textbooks from lower secondary education are included in a contrasting manner, encompassing half of those related to the standalone subject of technology as well as half of those developed for an integrated subject.

2.1 *Technology education within an integrated subject*

Technology education is taught within various integrated subjects in Germany. Particularly in primary education, this integration of technology education is almost entirely realized through its incorporation in general studies, where technology education represents one of five subject-specific perspectives. In secondary education, technology education is integrated into subject combinations alongside scientific education (science and technology) and is also incorporated into subjects like economics-work-technology, combined with economic educational objectives, nutrition, and consumer education, as well as career orientation.

Integrated subjects such as economics-work-technology particularly rely on work-oriented conceptualizations of technology education. This approach focuses on the societal dimension of teaching and technology (Schmayl 2019, p. 123). Technology is critically assessed in terms of its social impacts and its societal context. The emphasis is on technological emancipation, allowing

learners to question and engage with future technological-ecological developments in view of their diverse effects. In the work-oriented approach, the focus is less on the technological reference points (e.g., construction principles) and more on their applicability in the context of work (Zinn 2018, p. 66). Workplace analyses, product analyses, and projects are core teaching methods, and interdisciplinary teaching is preferred (Geißel 2018, p. 219).

2.2 *Technology education as a standalone subject*

When technology education is offered as a standalone subject, its curricular implementation is characterized by either the general technological approach or the multi-perspective approach. Since the curricular guidelines of many federal states do not explicitly reference subject-related didactic approaches, a speculative assignment can only be made based on the specific characteristics of the approaches. The general technological approach aims to enable learners to navigate a technology-driven world, drawing its contents and methods directly from engineering sciences (e.g. construction, production, system principles) (Zinn, 2018, p. 66; Binder, 2016). The multi-perspective approach seeks to shape technological literacy and, accordingly, responsible actions and critical thinking. One core background is the multi-dimensional view of technology according to Ropohl (2009) who outlines a natural, human, and social perspective.

The described fragmentation into different approaches to technology education also impacts its actual subject-matter content. Existing curricula for the subject of technology have consequently been criticized for exhibiting "(...) arbitrariness in the selection of teaching content (...)" (Höpken, 2009, p. 29). One reason for this is the problem of the lack of a direct reference discipline for the school subject of technology. Larger subfields such as mechanical engineering, electrical engineering, and civil engineering cannot be systematically prioritized in terms of their relevance (ibid.).

Proposals for structuring the content areas of technology education in Germany, such as those by Sachs (1979), date back several decades and therefore cannot account for more recent developments. Furthermore, although textbooks must align with curricular specifications through official approval processes, these specifications are often not sufficiently detailed to allow for direct conclusions about the specific subject matter of technology education. Existing international publications that address technology education topics, such as the Standards for Technological and Engineering Literacy (ITEEA, 2020), have presumably not been available in German long enough to have significantly influenced current curricula. Therefore, this analysis of technology education textbooks aims to identify which content areas are actually represented within them.

3 QUALITATIVE CONTENT ANALYSIS OF TEXTBOOKS

Textbook research constitutes a subfield of the broader domain of educational media research (Balcke et al., 2022, p. 17). These fields possess an explicitly interdisciplinary methodological background, a result of the wide variety of research questions and the diverse designs of educational media (Porges, 2014, p. 163). Methodologically, research in this area tends to follow either an open hermeneutical approach or a more strictly structured content analysis (Bramann &

Mierwald, 2025, pp. 207-208). Concerning research questions, Bölsterli Bardy (2015, p. 15) distinguishes three types. First are questions examining the process leading from textbook development to their use in schools. Second are the product-focused questions analysing existing textbooks. Third is the research investigating the effects of textbooks on teachers and students (ibid.).

3.1 *Target of the analysis*

Specifically for technology education in Germany only limited publications on textbooks are available (Sachs, 2002a, 2002b; Kirchner & Penning, 2024), in addition to a few older empirical studies (Grimm, 1990; Bönkost & Oberliesen, 1997). From an international perspective, further notable publications examine topics in Nigerian technology education textbooks (Adeoye & Olabiyi, 2011), the development of disciplinary literacy (Hurdelbrink & Engström, 2023), and how models are integrated into Swedish textbooks (Norström, 2019).

The aim of the conducted analysis is therefore to provide an overview of topics presented in German lower secondary school technology education textbooks. It seeks to answer the following research question: What topics are covered in German lower secondary technology education textbooks, and how does their prevalence differ between textbooks designed for dedicated subjects and those for integrated subjects?

The results are expected to show the quantitative distribution of topics across the different textbooks. This knowledge should enable the identification of the most prevalent topics in German technology education textbooks. Against the backdrop of the significant differences in implementing technology education across German federal states, the topics and content of different textbook types will be compared.

3.2 *Methodology and sample*

The sample consists of 14 textbooks selected from a total of 23 identified available textbooks. The selection criteria included formal approval for use in a federal state (or being specially developed for a state where formal approval is not required), publication after 2015, and current availability from the publisher. The structure of the books varies between textbooks designed to cover the entirety of lower secondary technology education (grades 5-10) and those intended for only one or two grades.

Table 1*Sample: Overview of the sample N=14 textbooks*

	Dedicated subject (N=7)		Integrated subject (N=7)	
Approved and developed for the listed federal states	Baden-Württemberg (1), Bavaria (3), approved for multiple German federal states (3)		Brandenburg (2), Saxony (5)	
Textbook series from various publishers	Prisma Technik; Auer Technik 7,8,9; Startklar! Technik; Starke Seiten Technik; Blickpunkt Technik		Praxis WTH-S 7,8,9; Startklar! WTH-S 7-9; #WAT 1,2	

Because of the systematic approach, which ensures the traceability of the procedure (Oberle et al., 2021, p. 23), the qualitative content analysis (Mayring 2022, pp. 49-50) was chosen. The analysis focused solely on core textual content conveying technology education subject matter. The content analysis was applied in two stages to develop a coding system and perform the analysis. First, a summarizing approach (Mayring, 2022) was used to condense the information from each page or relevant subpage of the three largest textbooks. These summaries were then grouped into categories to form an initial coding system. In total, categories were defined on three hierarchical levels. The 12 main categories (cf. fig. 1) were thus differentiated into 58 subcategories and 143 sub-subcategories. This system was then applied to the analysis of all 14 textbooks, resulting in a total of 1642 codings.

4 FINDINGS

Figure 1

Topics in technology education textbooks from Germany: Percentage of categorized main topics across every textbook (in total 1642 codings)

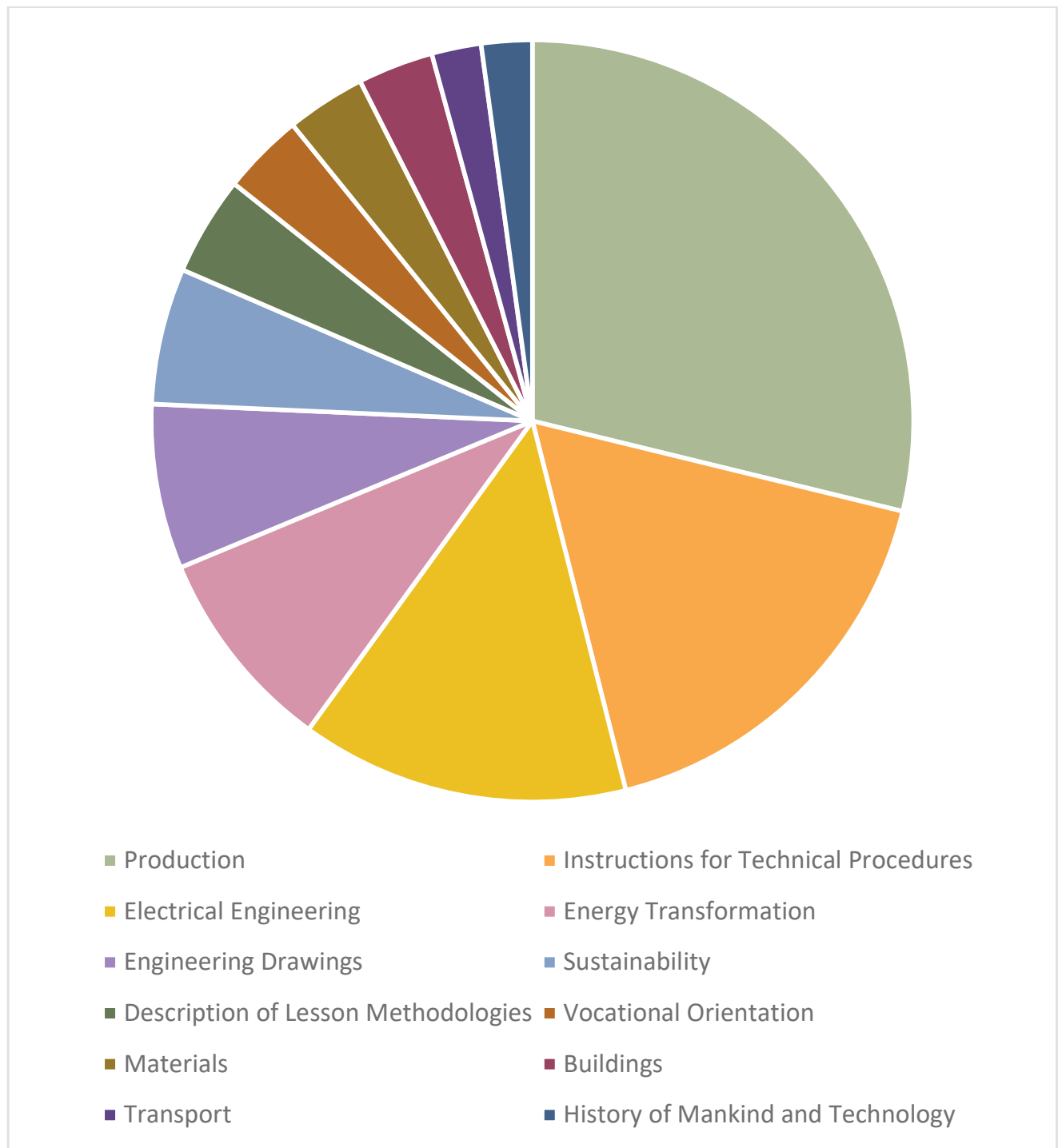
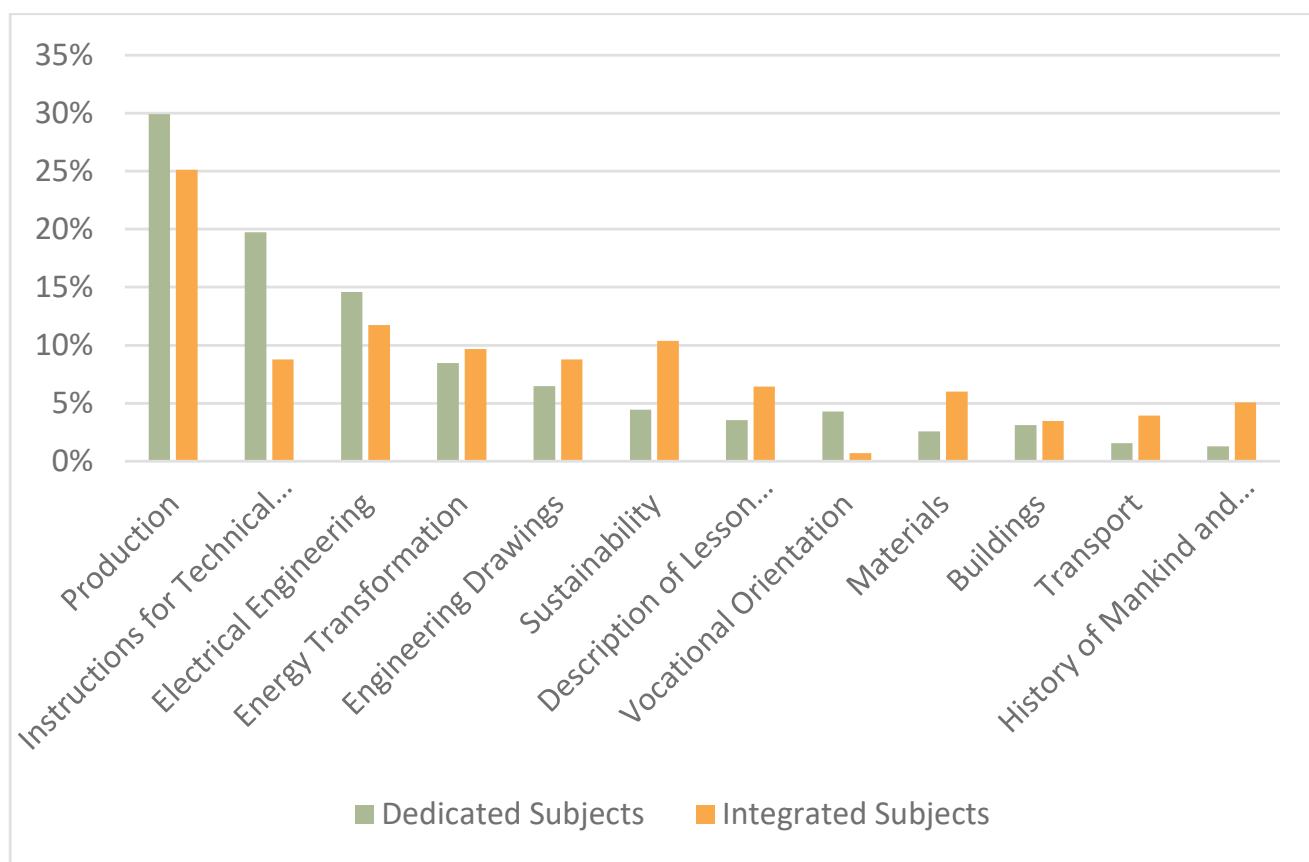


Figure 2

Topics in technology education textbooks from Germany by subject type: Percentage of categorized topics comparing dedicated and integrated subjects



As displayed in Figure 1, the qualitative content analysis yielded 12 major categories, to which vastly different total numbers of codes were attached for dedicated (1,284) and integrated (358) technology education subjects. This quantitative disparity indicates that significantly less textual space is devoted to technology education in textbooks for integrated subjects.

The revealed topics can be compared to the contexts outlined in the Standards for Technological and Engineering Literacy (STEL) (ITEEA, 2020). Apparent overlaps exist for most areas, while two STEL contexts were not observed. The following mappings and distinctions were identified:

- “Computation, Automation, AI and Robotics” is comparable to elements within the “Electrical Engineering” topic, as relevant aspects are present in its subcategories.
- “Material Conversion and Processes” encompasses the topics “Production”, “Materials”, and “Instructions for technical procedures”. The processes include individual instructions described in textbooks (e.g., marking, sawing) along with the

necessary background information on materials, which collectively lead to production processes.

- “Transportation and Logistics” finds its equivalent in the topic “Transport”, which includes automotive topics and other forms of transportation (e.g., trains, bicycles) but contains fewer logistical aspects.
- “Energy and Power” is similar to “Energy Transformation”, which thematizes renewable and fossil energy sources, as well as the transportation and storage of energy.
- “Information and Communication” includes aspects of the topic “Engineering Drawings” (as technical communication) and parts of “Electrical Engineering” (e.g., transmitter-receiver principles).
- “The Built Environment” corresponds to “Buildings”, which groups civil engineering content and aspects of modern living such as smart homes.

The STEL contexts “Medical and Health-Related Technologies” and “Agricultural and Biological Technologies” were not observed in the analysed textbooks. Furthermore, no direct connections were recognizable between the STEL contexts and the topics “Sustainability”, “Vocational Orientation”, “History of Mankind and Technology”, and “Descriptions of Lesson Methodologies”. A possible explanation for this is the cross-cutting character of these latter topics, which are likely integrated into the practices and core disciplines sections of the STEL framework, rather than being confined to specific content contexts. These topics are described as follows:

- “History of Mankind and Technology” indicates the use of historical examples, ranging from the Stone Age to steam engines.
- “Sustainability” forms a cross-cutting section encompassing connected topics like various forms of environmental pollution, as well as recycling and repairing.
- “Vocational Orientation” is often included via job descriptions and forms a distinct topic in integrated subjects; it may therefore be underrepresented when analysing only the technology education components.
- “Descriptions of Lesson Methodologies” refer to pedagogical instructions, which can be directly technology-related (e.g., approaches to workpiece production) or more general (e.g., creating mind maps).

When compared with the only identified international study on technology education textbook topics, certain similarities are evident (Adeoye & Olabiyi, 2011, pp. 155-164). Although the

textbooks analysed in that study are considerably older, they likewise cover themes including electrical energy usage, woodwork and metalwork production, and technical drawing (ibid.).

Besides the connections to the STEL contexts and the quantitative differences, relevant distinctions in topic distribution between the two textbook types are recognizable in Figure 1. The topic “Production” plays a major role in both textbook types. Descriptions of “Instructions for technical procedures” receive less space in integrated subjects. The topics “Energy Transformation”, “Engineering Drawings”, and “Electrical Engineering” are represented to a comparable extent across both kinds of textbooks. In proportion, cross-cutting and less extensive topics receive more attention in textbooks for integrated subjects. One exception is “Vocational Orientation”, which forms a separate, significant part of most integrated subjects and is therefore less extensive within the separate technology education components analysed here. Overall, the distribution shows that textbooks for dedicated subjects tend to deliver a more practical approach by including more descriptions of concrete instructions, while integrated subjects include, proportionally, more cross-cutting and less dominant topics.

5 CONCLUSION

Textbooks in technology education represent a significant research gap within the field. In Germany, textbooks generally require approval from the respective federal state's ministry of education. Their development is typically undertaken by educational publishers, which have a vested economic interest in successful sales figures. The market for textbooks in technology education, which in Germany is taught both as a dedicated subject and within integrated subjects, is relatively small. This also results in a rather limited data basis for textbook research, which, outside of technology education, is an established field of study.

This paper has examined German technology education textbooks concerning their thematic focus. It demonstrated that textbooks for dedicated subjects treat technology education topics considerably more extensively than those for integrated subjects. Regarding content areas, nearly all contexts from the ITEEA STEL are covered, with the exception of two contexts. This overview of topics forms the first part of an ongoing dissertation project. The project will extend to investigate how these technology education content areas are presented and didactically prepared. Insights from these subsequent research questions will then be combined to form a comprehensive view of each textbook, enabling more profound conclusions.

The findings can contribute to enriching the subject-specific pedagogical discourse and may also provide impulses for textbook development. It is desirable for this research field to attract more subject-specific interest in the future. This would enable, alongside the content-related study presented here, further insights into the subject-specific use and the development processes of textbooks, ideally in international comparison and including a wide range of (digital) textbook types (see Section 1.1). Such research could contribute to quality development in textbooks and their subject-specific use in teaching, thereby benefiting both students and teachers.

6 GENERATIVE ARTIFICIAL INTELLIGENCE DISCLOSURE

The authors employed generative artificial intelligence exclusively for specific translation tasks during the preparation of this manuscript.

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Observations as a Method in Practice-Based STEM Research

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Abstract

Strengthening the scientific foundation of schools increasingly requires involving student teachers in practice-based research, a priority highlighted in recent Swedish education policy. Although practice-based research is intended to bridge professional challenges with systematic inquiry, little is known about how student teachers can meaningfully participate during compulsory school placement (VFU). The aim of this study is to develop a method for involving student teachers in practice-based research through observations carried out in connection with their VFU.

The study was conducted over five years and involved student teachers, in-service teachers, VFU supervisors, and researchers collaboratively observing communication during laboratory activities. Direct, systematic observations were carried out using evolving observation protocols that included predefined categories and time spans. These protocols were iteratively refined across several cycles based on practical challenges, observer experiences, and theoretical grounding.

The findings show clear opportunities for involving student teachers in research. Structured observation increased students' awareness of classroom interactions supported course learning goals, and enriched teachers' reflections on their own practice. When the observations were well integrated into coursework and accompanied by preparation and discussion, student teachers perceived the work as valuable and sometimes continued using or developing protocols independently. Certain challenges emerged. Students did not benefit when the observations were insufficiently connected to course aims, and large numbers of observers made consistent interpretation difficult. Time constraints, coordination between teacher educators and researchers, and the dual roles of teacher educators also posed obstacles.

Across five cycles, the study identified key features of effective observation protocols: clearly defined terms, shorter time spans, theoretically grounded categories, and calibration among observers. The results demonstrate that thoughtfully designed

observation protocols can serve as a viable method for engaging student teachers in practice-based research during VFU.

Key Words: Laboratory Work, Observations, Practice-Based Research, Teacher Education, Compulsory School Placement

1 INTRODUCTION

The national pilot project ULF (Education, Learning, Research) was launched in 2017 to test different collaboration models between research, schools and teacher education (Ministry of Education and Research, 2017). The ULF project has been made permanent since 2025. The main objective is to strengthen the scientific basis and scientific approach in schools, and to bridge the perceived gap between theory and practice (ULF agreement, 2025). Another objective is to enhance teacher education by providing increased opportunities for students to participate in the school's research and development activities (ULF agreement, 2025).

The importance of involving student teachers in strengthening the scientific basis of schools is also emphasised in the 2021 Education Act for Teachers and Preschool Teachers (Ministry of Education and Research, 2021). It emphasises that student teachers should gain insight into practice-based research during their work-based training at so-called training schools. This aligns with the intention of the 2023 public service agreement for teacher education, which clearly states that practice-based research should be an integral part of teacher education at all levels, including compulsory school placement (Ministry of Education and Research, 2023).

This study was conducted within the framework of the K-ULF (Compensatory Teaching for Learning and Research) model (K-ULF, 2025), one of several collaboration models developed within ULF. K-ULF is a collaboration between KTH and several school authorities. Practice-based research within K-ULF is conducted in close collaboration between professional teachers, student teachers, teacher educators, doctoral students and researchers, with the aim of contributing to teaching development. The students are enrolled in KTH's teacher education programme, Master of Science in Engineering and in Education (CL) which leads to a double degree (KTH, 2025). As well as becoming civil engineers, the students also qualify as subject teachers in mathematics and either technology or a natural science subject.

Vetenskapens Hus (Stockholm House of Science) (Vetenskapens Hus, 2026) provides a platform and research environment for collaboration and practice-based research within K-ULF. Run by KTH and Stockholm University, Vetenskapens Hus works closely with researchers, schools, teachers and student teachers. It is involved in teacher education and provides a laboratory environment in which large numbers of school students and student teachers carry out activities in classroom-like laboratories with modern equipment under the guidance of university students and educators.

1.1 Practice-based research

According to Candy, Edmond, and Vear (2021) in the field of practice-based research “research and the practice operate as interdependent and complementary processes leading to new and original forms of knowledge”. At the same time the knowledge resulting from practice-based research varies and is not always straightforward and varies between different contexts (Vear, 2021).

Practice-based research within ULF is based on questions, needs and challenges identified by professionals. The resulting research contributes to improvements in teaching (Ministry of Education and Research, 2018; Candy, Edmonds & Vear, 2021). For example, by involving student teachers in observations as part of a practice-based research project, they can contribute to data collection. This enables teachers to conduct educational research in collaboration with universities. At the same time, student teachers gain insight into research during their studies and practise observing learning situations. This commitment from both teachers and student teachers in joint practice-based research projects makes the scientific approach more visible in the classroom

The aim of this study is to develop a method for involving student teachers in practice-based research through observations carried out in connection with their compulsory school placement (VFU). Based on challenges seen by teachers and school leaders in the classroom, observation protocols were developed. We investigate how these protocols can be used to include students in practice-based research projects. The observations were conducted partly at Vetenskapens Hus and partly at the VFU schools.

1.2 Research questions

This paper investigates the following research questions:

- How can observation protocols be designed to facilitate student teachers’ participation in practice-based research projects?
- What are the challenges and opportunities of involving student teachers in practice-based research projects?

2 METHODOLOGY

Over a five-year period, VFU students, VFU supervisors and researchers carried out a series of observations of teaching situations. These observations took place partly in schools and partly at Vetenskapens Hus, focusing primarily on communication in relation to laboratory activities. During the observations no personal data was gathered and therefore no ethical approvals were needed according to Swedish Research Council (2024).

2.1 Methods

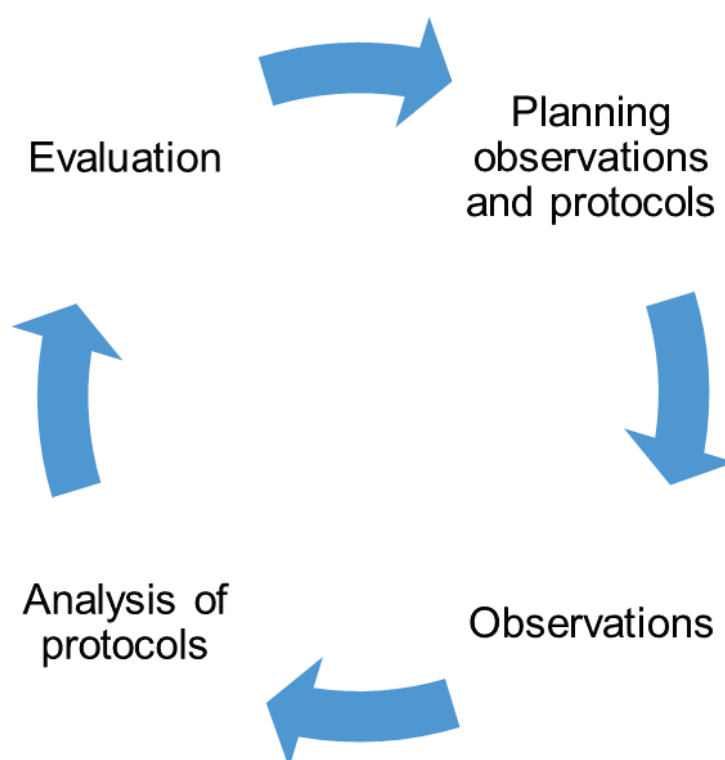
The observations in this study are direct (Denscombe, 2016) and were carried out by several observers. Direct observation involves observing events as they occur. In this study, the situations observed were students' communication during laboratory work. As an individual's understanding of a specific situation is unique, it is challenging to direct the attention of several observers towards the same focus. Therefore, the observations need to be systematised so that all observers have the same focus and documentation tools. Based on these conditions, we opted for systematic observations using observation checklists (Bjørndal, 2018; Denscombe, 2016). An observation checklist helps the observer to focus on specific events in the observed situation. To further assist the observers, the study's observation checklist includes predetermined categories and time spans (Bjørndal, 2018). The study's observation checklist will henceforth be referred to as the observation protocol, as this term has been used throughout the work.

2.2 Tools

Observation protocols were developed cyclically over five academic years, with each year corresponding to one cycle and each cycle consisting of four phases (see Figure 1).

Figure 1

The various stages of development of the observation protocol.



The design of the observation protocol was based on challenges experienced by the upper secondary school teachers participating in K-ULF. For each cycle, a group of teachers and

researchers planned the observations and protocols jointly. Within the framework of a VFU course, the observations were carried out differently in each cycle. The observation protocols and methods were evaluated and the results compiled before the next cycle began. Observers and teaching situations varied between cycles. An overview of the data collected can be found in Table 1.

Table 1

Overview of data collected during the various development cycles (years 1–5).

		Cycle				
Activity		1	2	3	4	5
Students observe	Laboratory work in an informal learning environment	X				X
	Lessons in school		X			
	Lessons online		X			
Teachers observe	Lessons led by student teachers	X				
	Laboratory work led by student teachers			X		
Researchers observe	Laboratory work led by student teachers	X		X	X	
	Online laboratory work led by student teachers	X				
Researchers interview	Teachers			X		
	Teacher educators					X

The common theme for all observations was communication in the classroom. The observations were developed based on previous observations, teachers' challenges and current events.

2.2.1 Cycle 1

During the first cycle, three different protocols were tested and used by student teachers, teachers and researchers in various situations (Table 1). The protocols addressed the following:

- (i) Speaking time for teachers and students

- (ii) Who asks and answers questions
- (iii) Role distribution among students in a laboratory situation.

The first two protocols focused clearly on quantitative questions, while the third was more qualitative.

Student teachers undertook an introductory exercise involving reflection on and identification of roles in a laboratory situation. This formed the basis for the third protocol. After a brief introduction, the students were asked to observe a laboratory activity at Vetenskapens Hus using one of the three protocols. Three to four students observed the same activity. Afterwards, they discussed in cross-groups and wrote a short reflection.

Towards the end of Cycle 1, the Covid 19 pandemic broke out, meaning that further on-site observations of practical activities could not be carried out as planned. Instead, the researchers observed online teaching led by student teachers.

2.2.2 *Cycle 2*

Cycle 2 took place in the midst of the Covid 19 pandemic, affecting both teachers' challenges and the conditions in which observations could be carried out. Based on lessons learned from the online observations in Cycle 1, a simplified protocol was developed. This protocol focused on who asked and answered questions, as well as providing opportunities to work in smaller groups in various teaching scenarios. Student teachers used this protocol for observations of teaching, either in school or online.

2.2.3 *Cycle 3*

The third cycle's protocol was based on the second cycle's protocol and focused on communication during laboratory experiments. Since the Covid 19 pandemic restrictions had been lifted, all the experiments were face-to-face. Teachers and researchers observed laboratory work led by student teachers. They observed the level of activity during practical work and the upper secondary school students' communication with each other. Teachers were also interviewed during this cycle about differences in their students' behaviour during laboratory sessions at school and at Vetenskapens Hus.

2.2.4 *Cycle 4*

Prior to the fourth cycle, the protocol was revised to provide a clearer theoretical framework. The observers collaborated to develop the protocol and establish shared definitions. The observations were now based on three types of conversation that take place between students (Mercer, 2008). *Exploratory talk* is characterised by mutual listening, while critical consideration of the dialogue drives joint work forward. In *cumulative talk*, students build on each other's statements without taking a critical approach. In *disputational talk*, students do not listen to each other's opinions and arguments, the conversation is characterised by brief contributions met with immediate disagreement (Mercer, 2008). With this change, the focus became more qualitative: how are

students' conversations affected by interactions with teachers, teaching assistants and other students during laboratory exercises? While teacher students conducted laboratory exercises with students, the observations were carried out by researchers.

2.2.5 *Cycle 5*

The protocol used in Cycle 5 was simplified and clarified based on the observations made in Cycle 4. During this cycle, VFU students observed laboratory work at Vetenskapens Hus. During their VFU course, the student teachers were introduced to the protocols and Mercer's conversation types (Mercer, 2008) at a seminar. At the end of the course, the students were given a summary of their observations. They were also asked to complete a questionnaire. Additionally, the course coordinator was interviewed.

3 FINDINGS

In this chapter, we summarise our findings focusing on the following topics: opportunities to involve student teachers in practice-based research projects, challenges to involve student teachers in practice-based research projects, and design of observation protocols

3.1 *Opportunities to involve student teachers in practice-based research projects*

Combining student teachers' observations with practice-based research enables more than just the individual students to learn from the observations. For example, teachers who participated in the observations became aware of classroom phenomena that made them reflect on their own practice. Compiling different observers' perspectives on the classroom situation has the potential to provide a more complex picture and enable overall conclusions to be drawn.

The themes for the observations were determined based on teachers' questions about their practice, as described in section 2.2.1. Teachers, teacher educators and researchers collaborated to design observation protocols and evaluate observations, sparking fruitful discussions about teaching and student learning.

Using observation protocols helps to focus attention on specific events in a given situation, enabling them to be observed in a structured way. Observing teaching is an important part of practical training for student teachers and is used as a tool by both students and supervisors.

Over the years, the design of the protocols and their introduction to students have evolved, influencing how students experience working with observations.

Student teachers found the use of observation protocols most rewarding when they were contextualised and preceded and followed by discussions and reflections.

I thought the protocol worked well, but I remember that it was also helpful to have it explained beforehand. It probably would have been difficult to understand or use it correctly on my own. (Student teacher)

Teacher educators could see that students chose to continue using and developing some of the protocols for other tasks in the VFU course.

One of the course objectives was for students to design lab experiments and evaluate whether the learning objectives they set were being met through these observations, we gave the students a tool to assess this. To observe learning, to see if their goals were met. And for several of the students, we saw that the answer was yes, they took it to heart. They used those tools later in the course to conduct the evaluation they needed to complete the course objectives, so I definitely think that's what contributed to their learning. (Teacher educator)

The teacher educator also reflected on the importance for student teachers' future studies and work to meet practice-based research in their education.

But some students became particularly interested in the research project itself, they wanted to hear more about the results afterwards. And then, a few years later, we've seen that several of them have come back when it was time to write their master thesis, so that's another way.

And even after they've started working as teachers, they've reconnected, and now some of them are part of [a] research project ... (Teacher educator)

3.2 *Challenges to involve student teachers in practice-based research projects*

At the beginning of the project, the students' observations were incorporated into the VFU course in a way that made them feel it was relevant and valuable. However, in later cycles, although we had a more detailed protocol, fewer students felt that the observations were valuable, as they felt that they were an additional, rather than integral, part of the course.

I feel like I couldn't take anything away from this. I feel a bit exploited because I had to do it but couldn't get anything out of it. (Student teacher)

But when they don't benefit from it, it's precisely because they don't see that it has a connection to their own learning. They need to see the benefit of it. It needs to be clear to them that it, that it's not just the research project, it also has a purpose for their learning, so that's why it's there. That connection is very important to make. (Teacher educator)

From this, we learned that it needs to be clear to students why they are making the observations, and that the observations must be well integrated into the course. Students also need to be properly introduced to the protocol and given the opportunity to practise using the protocol and discuss their observations with other students.

An important prerequisite for practice-based research in schools is that teachers are given time to work with it. In projects that include VFU, teachers who are VFU supervisors and teacher educators also need to have routines for communication and close collaboration.

So, time would need to be set aside for both teacher educators and researchers so they can sit down well in advance and develop both a plan and a framework.

And for it to work for students, researchers, and everyone else, it needs to be planned well in advance. So you need to set aside time for it ... (Teacher educator)

One challenge in combining VFU with practice-based research is the large number of observers. In the final version of the protocol, it was still difficult to achieve a consistent interpretation of the different types of conversations, and a consistent understanding of how the protocol should be used. The information provided by the observers ranged from sparse to very rich in content.

Another challenge is finding strategies to separate the role of teacher educator from that of researcher. One advantage of having the teacher educator involved in the research project is that it is easier to incorporate the observations into teaching, but it is important to ensure that students feel confident that the observations will not affect their course assessment.

Well, I do think it's important for the teacher educator to be involved in the research project by helping to formulate research questions related to the course's learning objectives. Then, of course, there's also the challenge that the teacher educator shouldn't be too involved in the actual data collection, to ensure that it doesn't influence the assessment in the course. But the teacher educator should be involved so that we can ensure that what we're looking at benefits both the research project and the students. (Teacher educator)

3.3 *Design of observation protocols*

In this study we have developed a method to engage student teachers in practice-based research during their compulsory school placement (VFU). The tool used in the study is an observation protocol. As the study has been ongoing for several years, the observation protocol has been refined for each VFU period. This makes the development process iterative.

During the first phase of the study, it quickly became clear that people interpret observation protocols differently. For example, during the first cycle, groups and subgroups of students were observed. It transpired that the different observers had different ideas about what constituted a group and who its members were. This could refer to the entire teaching group (half a class), students sitting at the same table (four students), or two students working together. This lack of clarity meant that the seemingly simple quantitative data collected could not be compiled meaningfully.

During the Covid-19-pandemic, not all observations could be carried out on site. During Cycle 2, around half of the observations were conducted on site and the other half online. Depending on

whether the teaching was conducted in a classroom or online, the observation protocols needed to be adapted.

One lesson learned is that, when several people are to use the same protocol, it is important to define terms and reach a consensus on how the questions in the observation protocol are to be interpreted, so that the observation data can be used for research compilations. When there are several observers, it is necessary to calibrate and carefully review the protocols prior to the observations in order to ensure a consistent interpretation. During later observation cycles, different methods were tested to ensure agreement among all observers on the interpretation of the protocols. The most effective method was to involve the observers in designing the protocol, and to have all observers read through and discuss each other's compiled observations, ensuring consensus on the interpretation of the protocols. However, this approach is best suited to small groups of observers and is difficult to implement when a larger group is involved.

Another lesson learned is that it is easier to compile quantitative than qualitative data when there are many observers. Observation protocols for collecting quantitative data are also easier for students to use than more qualitative protocols with free text fields. The early versions of the protocols were therefore largely quantitative. However, the results from the qualitative questions were considered more valuable, leading to more qualitative observations in later iterations.

From Cycle 4 onwards, the protocol underwent a fundamental revision and restructuring to focus on different types of conversation. A key insight from this work was the need for a clearer theoretical basis, resulting in the integration of more theory into the protocol. We also opted for shorter time spans to facilitate the recording of events during each observation period. By focusing on conversation types, it also became clearer what the observer should pay attention to. This made it possible to categorise the conversations that occurred instead of writing extensive personal notes. A key insight was that these conversation types enabled observers to focus their observations on the same aspects more easily. In addition to Mercer's three conversation types (Mercer, 2008) we also recognised a need to distinguish between quiet and passive students. The protocol was therefore adjusted during the observation cycle. Following this adjustment, the protocol was considered sufficiently clear to be used by students.

Another difficulty in interpreting the protocols is that the observed laboratory work had different content and target groups. During Cycle 5, for instance, 21 observations were made of nine different school programmes at Vetenskapens Hus. These included one mathematics experiment (one observation), two technology experiments (four observations), two physics experiments (eight observations) and four chemistry experiments (eight observations). The youngest students who carried out and were observed in the experiments were in Year 6, and the oldest were in Year 3 of upper secondary school. Such diverse material made it difficult to draw general conclusions.

4 CONCLUSIONS

This study shows that involving student teachers in practice-based research during school placement (VFU) offers significant potential for enriching both teacher education and school development. When observation tasks are clearly connected to teachers' authentic questions and

embedded within course objectives, student teachers, teachers, and teacher educators all benefit. Collaborative design of observation protocols not only sharpens focus during classroom observations but also stimulates meaningful reflections about teaching and learning. For many students, the structured use of protocols supported by preparation, discussion, and reflection, enhanced their ability to observe learning processes and even informed later academic and professional engagements with research.

However, the work also highlights important challenges. Observations must be transparently integrated into the VFU course; when students do not see their relevance, they perceive the tasks as burdensome or disconnected from their own learning. Large numbers of observers, limited time for collaboration, and the dual role of teacher educators as both instructors and researchers introduce further complexity. Ensuring that protocols are interpreted consistently, and that students feel secure that participation will not affect assessment, are essential conditions.

Overall, the findings demonstrate that student teacher involvement in practice-based research is both feasible and fruitful, provided that the activities are well integrated, clearly motivated, and supported by robust observation tools. The results underscore the importance of thoughtful protocol design, careful preparation of student teachers, and strong collaboration between schools and teacher education institutions to ensure meaningful learning and reliable research outcomes.

This paper used generative AI for translation and grammar improvement.

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An International Modified Delphi Study on Validating the Concept and Components of Digital Literacy

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Abstract

This study aims to systematically conceptualize and validate a comprehensive digital literacy (DL) framework through an international modified Delphi process. In the field of technology education, DL has been defined in diverse ways by scholars worldwide, highlighting the growing need for a shared and consensus-based understanding at the global level. To address this issue, the study systematically analyzed prior research conducted worldwide since 1995 to derive an initial conceptual framework of DL. Subsequently, three rounds of Delphi surveys were conducted with experts from South Korea's academia and school sectors to refine the framework, followed by two rounds of international Delphi surveys with 14 experts from four continents—Asia, Europe, Africa, and the Americas—to examine cross-cultural validity.

The final outcome of this study presents a DL framework supported by cross-cultural expert review, comprising six interrelated components organized across developmental stages (basic–intermediate–advanced): technological competence; digital content understanding, search and evaluation; digital content application and creation; digital communication; computational thinking (CT)-based problem solving; and social contribution and ethical responsibility. Each component is further specified through a total of 64 subcomponents, systematically articulated to reflect developmental progression and educational applicability. This framework clarifies the concept of DL within technology education and offers an internationally applicable standard for curriculum design, assessment, and policy development across diverse educational contexts.

South Korea demonstrates a high level of information and communication technology (ICT) capacity, and digital transformation is rapidly advancing across industries, including education. In particular, technology education is closely linked to this digital shift. By integrating international expert perspectives into a framework initially shaped by the insights of South Korean researchers, this study broadens understanding of DL by incorporating multi-perspective insights and deepens international connectivity and mutual understanding in technology education, thereby informing ongoing global discourse in technology education.

1 INTRODUCTION

As digital technologies permeate all areas of modern life, digital literacy (DL) has become a core competency for citizens globally. Governments, educational institutions, and international organizations increasingly regard DL as essential for learning, problem-solving, and participation in a rapidly changing society. South Korea, for example, has integrated DL across the national curriculum and introduced new elective subjects to strengthen students' digital and analytical abilities. Beginning in 2025, AI-based digital textbooks have been introduced as instructional materials in South Korea, reflecting the expanding role of DL in education. Similar developments appear worldwide: Canada's MediaSmarts (2015) emphasizes critically engaging with digital media; the European Commission (2018) highlights the need to reinforce digital competence; and OECD positions DL as foundational for future learning. Collectively, these initiatives demonstrate a shared recognition of DL as an indispensable competency in the digital age.

Despite this widespread attention, DL remains inconsistently defined. Since its early conceptualizations by Lanham (1995) and Gilster (1997), the field has expanded to encompass cognitive, technical, socio-emotional, communicative, and ethical dimensions. Influential frameworks and theoretical perspectives—including the European Commission's DigComp framework (2018), UNESCO's Digital Literacy Global Framework (2018, 2019), conceptual models proposed by Eshet-Alkalai (2002, 2004), critical perspectives articulated by Buckingham (2003, 2015), and institutional frameworks developed by JISC (2011, 2014)—offer diverse perspectives, yet the lack of unified terminology and structure contributes to conceptual fragmentation. Cultural and contextual differences among countries further complicate the establishment of a common global understanding.

In response, this study aims to construct and cross-culturally validate a digital literacy framework through a modified Delphi process. The guiding research questions were:

- (i) How was the DL framework constructed through the South Korean Delphi study?
- (ii) To what extent is the framework validated by international experts?
- (iii) What cross-cultural differences emerge?

2 THEORETICAL BACKGROUND

2.1 The Concept of Literacy

The concept of literacy has evolved from its original meaning—the ability to read and write—to a multidimensional construct shaped by social, cultural, and technological change. From the perspective of New Literacy Studies, literacy is understood not merely as a set of technical skills

but as a form of social practice embedded in particular contexts and enacted through participation, communication, and meaning-making (Street, 1984; Barton & Hamilton, 1998). The multiliteracies framework further expanded this view by emphasizing multimodality, collaboration, and the production of knowledge across diverse media environments (New London Group, 1996; Cope & Kalantzis, 2009). In contemporary digitally mediated societies, literacy therefore involves not only accessing and understanding information but also creating, communicating, and participating as responsible members of a community, which connects literacy to the ethical and civic dimensions highlighted in discussions of digital citizenship (Ribble, 2015; Choi, 2016).

These theoretical developments also point to a conceptual distinction between competence and literacy. While competence-based approaches tend to focus on functional and measurable performance, literacy-oriented perspectives stress socially situated meaning-making, critical engagement, and transformative participation (Biesta, 2009; Lankshear & Knobel, 2008). From this standpoint, DL can be conceptualized as a holistic and context-sensitive construct that integrates technological, cognitive, and socio-cultural dimensions rather than as a collection of discrete technical skills. This literacy-oriented perspective provides the theoretical basis for structuring the proposed digital literacy framework in relation to technology education.

2.2 *The Concept and Components of Digital Literacy*

DL has been conceptualized from multiple perspectives. Early studies emphasized the ability to interpret digital information and use digital tools effectively (Lanham, 1995; Gilster, 1997), while later work expanded the concept to include multimodal understanding, critical evaluation of information, online collaboration, and ethical awareness (Eshet, 2004; Hobbs, 2010; Rheingold, 2012). Institutional frameworks such as DigComp (European Commission, 2018) and UNESCO's Digital Literacy Global Framework (2018, 2019) further structured DL as a set of interrelated competence areas, including information and data literacy, content creation, communication and collaboration, safety, and problem solving. In order to identify the core domains of DL, this study conducted a comparative analysis of twelve major prior studies and frameworks. Each framework was examined using a common analytical scheme, focusing on the competence areas and conceptual domains proposed in the literature. Despite differences in terminology and emphasis, six recurring domains were consistently identified: the use of digital technologies, understanding and handling digital information and content, communication and collaboration, creative production, problem solving, and ethical and social responsibility.

Based on this synthesis, the present study reorganizes these recurring domains into six components and reinterprets them from the perspective of technology education. Technological competence reflects the technological capability emphasized in the field, while digital content understanding, search, and evaluation represents the cognitive and critical dimension of DL. Digital content application and creation highlights productive participation in digital environments, and digital communication emphasizes collaborative and socio-emotional interaction. CT-based problem solving was included to align DL with the design-oriented and problem-solving tradition of technology education, and social contribution and ethical responsibility extends DL toward digital citizenship. This synthesis provides the theoretical basis

for the development of the DL framework and conceptualizes DL as a multidimensional structure prepared for cross-cultural validation.

Table 1 illustrates the convergence of domains identified across twelve prior studies on digital literacy. The six core components proposed in this study were synthesized based on these recurring conceptual domains.

Table 1

Comparison of Core Domains Derived from Prior Studies on DL

Prior Studies	Technological Competence	Digital Content Understanding, Search, and Evaluation	Digital Content Application and Creation	Digital Communication	CT-based Problem Solving	Social Contribution and Ethical Responsibility
ALA (2011)	x		x	x	x	x
Buckingham (2003)	x	x	x	x	x	x
Belshaw (2014)	x		x	x	x	x
Eshet-Alkalai (2004, 2005)		x	x	x	x	
European Commission (2018)	x	x	x	x	x	x
Rheingold (2010)	x		x	x		
JISC (2011–2013)	x	x	x	x	x	x
Martin (2008)		x	x	x	x	x
MediaSmarts (2015)	x	x	x	x	x	x
Gilster (1997)	x	x	x			
Hobbs (2010)	x		x	x	x	x
UNESCO (2018)	x	x	x	x	x	x

3 METHODS

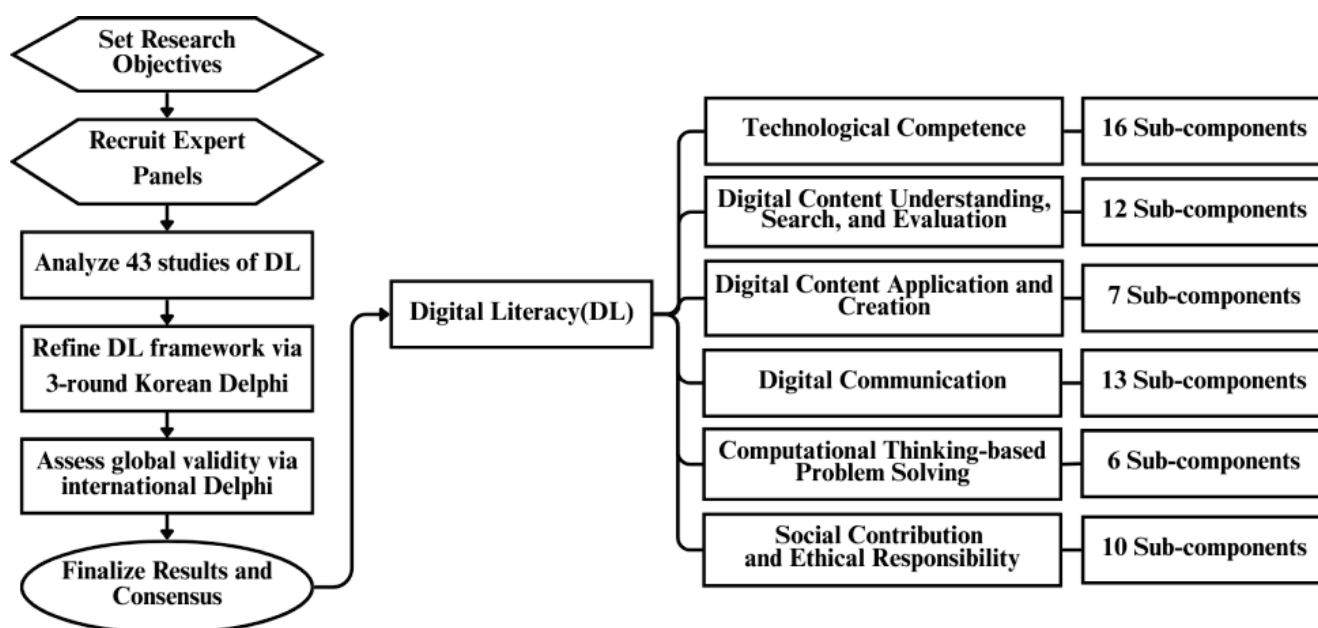
3.1 Research Design

This study adopted a modified Delphi design (Murry & Hammons, 1995) comprising three rounds of a South Korean Delphi study, followed by two rounds of international Delphi review. The overall purpose was to construct a contemporary framework for the concept and components of DL and to validate its relevance through iterative expert consensus.

To achieve this objective, the research was conducted in three sequential stages, as illustrated in Figure 1. Through the procedures outlined in Figure 1, the study proceeded in three stages: (1) identification of preliminary DL components through a review of prior studies, (2) refinement through a three-round Delphi study with South Korean experts, and (3) cross-cultural validation through a two-round international Delphi process.

Figure 1

Research Model



3.2 Expert Selection Criteria

Experts were selected following established Delphi methodological guidelines emphasizing expertise, scholarly recognition, and contextual diversity (Okoli & Pawlowski, 2004; Hsu & Sandford, 2007; Skulmoski et al., 2007; Keeney et al., 2011). To operationalize these guidelines, potential experts were identified from publicly available editorial and reviewer boards of peer-

reviewed international journals in education and educational technology and subsequently screened using publicly accessible institutional profiles, curriculum vitae, and publication records.

Candidates were required to meet the predefined eligibility criteria summarized in Table 2, including a doctoral degree in a relevant field, demonstrated scholarly contributions in digital literacy or closely related areas, and substantial professional or academic experience. Academic rank and institutional affiliation were verified through official university or research institute websites, while practitioner expertise was confirmed through documented involvement in digital literacy or ICT education. Only individuals who satisfied all criteria were invited to participate in the Delphi panel. The detailed selection criteria are presented in Table 2.

Table 2

Selection Criteria for the International Delphi Panel

Criteria	Description
Expertise	Doctoral degree in education, computer education, technology education, or educational policy
	Demonstrated research achievements in DL, AI education, CT, EdTech, or technology-enhanced learning.
Academic Position & Recognition	Faculty members at the rank of assistant professor or higher, or senior researchers.
	Experienced practitioners (e.g., school teachers with experience in DL or ICT education)
International Representation	Experts from global regions.
	Ensured cross-cultural perspectives on DL conceptualization.

3.3 *Panel Composition and Recruitment*

The South Korean Delphi panel consisted of 10 experts from academia and school-based digital education. The international panel ultimately comprised 14 experts representing four continents: Asia, Europe, Africa, and the Americas.

To recruit experts who met the predefined selection criteria, a systematic process was conducted between January 26 and July 29, 2025. The second-round Delphi survey began on August 22, 2025. Five of the original participants responded, and after limited replies despite reminders, additional recruitment was carried out between October 14 and 27. In total, 14 experts who met all selection criteria participated across both rounds, ensuring an internationally diverse and credible Delphi panel.

Table 3*International Delphi Panel by Round*

Round	Participants	Withdrawn	Newly Added	Country (Region) Distribution	Major Fields of Expertise
1st Round	10	-	-	Ethiopia, South Africa, Georgia, Spain, Malawi, Singapore, Kyrgyzstan, Saudi Arabia, Italy, Netherlands	Education, Educational Policy, Mathematics Education, Cognitive Science, ICT
2nd Round	9	5	4	Georgia, Netherlands, Spain, Italy, Singapore, Czechia, United States	Education, Technology Education, Computer Science, Mathematics Education

3.4 Data Collection & Analysis

Data analysis procedures are summarized in Table 4, including criteria for the Content Validity Ratio (CVR), which was calculated using Lawshe's (1975) method based on Schipper's minimum acceptable values. Consensus indicators included Standard Deviation (*SD*), Interquartile Range (*IQR*), and agreement rate, and sensitivity analysis was conducted using changes in mean (Δ Mean) and standard deviation (Δ *SD*) to examine stability between rounds (Keeney et al., 2011; von der Gracht, 2012).

3.5 AI disclosure

Artificial Intelligence (AI) technologies (e.g., chat GPT) were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

Table 4*Summary of Data Collection and Analysis Procedures*

Category	Description
Rating Scale	5-point Likert scale (1 = Completely inappropriate → 5 = Highly appropriate).
CVR Criteria	Minimum values: 0.62 (n=10); 0.78 (n=9).
Consensus Indicators	Mean, <i>SD</i> , <i>IQR</i> , Agreement Rate. $SD \leq 1.0$, $IQR \leq 1.0$, Agreement $\geq 75\%$
Sensitivity Indicators	Δ Mean, Δ SD applied to identical items. Δ Mean = $ \text{Mean}_2 - \text{Mean}_1 $ Δ Mean < 0.5 (Stable), 0.5–1.0 (Slight change), ≥ 1.0 (Significant change)

4 RESULTS**4.1 Final Concept and Components of Digital Literacy**

Through three rounds of the South Korean Delphi process and two rounds of the international Delphi review, the DL concept and six-component framework were supported through expert agreement. The South Korean experts demonstrated strong agreement on the DL concept and components, and international experts similarly confirmed their global relevance. Although the component related to computational thinking (CT)-based problem solving showed relatively lower agreement among some international participants, the final framework—revised into a developmental structure of Basic, Intermediate, and Advanced levels—reflects cross-cultural feedback and represents the finalized version derived through this multi-stage Delphi process.

Table 5*Final Concept and Six Components of DL*

Category	Content
Concept of DL	Digital literacy refers to the ability of individuals, as digital citizens, to effectively understand, utilize, and communicate various technologies and content necessary in the digital age to solve diverse problems in everyday life.
Technological Competence	The ability to understand and use various digital technologies to solve problems.
Digital Content Understanding, Search, and Evaluation	The ability to understand various content in digital environments, devise search strategies, and critically evaluate the results obtained.
Digital Content Application and Creation	The ability to creatively use and produce various digital content.
Digital Communication	The ability to collaborate and communicate within society and communities by utilizing digital content and technologies.
CT-based Problem Solving	The ability to logically solve real-life problems using CT.
Social Contribution and Ethical Responsibility	The ability to understand and adhere to social contributions and ethical responsibilities as a digital citizen.

Han-ul Jang. (2024). A Study on Development of Concept and Components of Digital Literacy using Modified Delphi Techniques. p. 144.

4.2 *Validation of the Finalized Framework of DL*

Table 6 presents the validity results for the DL concept, its six components, and the revised developmental framework. The South Korean Delphi panel demonstrated high levels of agreement across all elements, with CVR values ranging from 0.80 to 1.00. International Delphi Round 1 showed similarly high agreement for most components, although “CT–Based Problem Solving” received a comparatively lower CVR value (0.40). Analysis of the international experts’ open-ended responses indicated that this component was perceived by some panellists as a context-specific competency rather than a universally applicable DL skill.

Based on expert feedback, the DL framework was reorganized into a developmental structure consisting of Basic, Intermediate, and Advanced levels. In the second round of the international Delphi, the revised developmental DL framework was evaluated as a whole, yielding a CVR of 1.00 and a mean score of 4.70 (SD = 0.50).

Table 6*Validation Results of DL Concept, Components, and Revised Framework*

Category	South Korean Delphi(3 rd)		International Delphi(1 st)		International Delphi(2 nd)	
	CVR	Mean (<i>SD</i>)	CVR	Mean (<i>SD</i>)	CVR	Mean (<i>SD</i>)
Concept of DL	1.00	4.70 (0.48)	1.00	4.50 (0.53)	-	-
Technological Competence	0.80	4.50 (0.71)	1.00	4.40 (0.52)		
Digital Content Understanding, Search, and Evaluation	1.00	4.60 (0.52)	1.00	4.50 (0.53)		
Digital Content Application and Creation	1.00	4.70 (0.48)	1.00	4.50 (0.53)	-	(<i>Framework-level only</i>)
Digital Communication	1.00	4.60 (0.52)	0.80	4.40 (0.97)		
CT-based Problem Solving	0.80	4.40 (0.70)	0.40	4.10 (0.88)		
Social Contribution and Ethical Responsibility	0.80	4.50 (0.97)	0.80	4.50 (0.71)		
Revised DL Framework (Basic-Intermediate-Advanced)	-	-	-	-	1	4.70 (0.50)

Table 7 summarizes the aggregated validity statistics for the subcomponents across the six DL components. As shown, the number of subcomponents changed from the first to the second Delphi draft (69 → 64) due to systematic revisions made during the restructuring of the framework. These changes resulted from multiple refinement procedures, including clarification of ambiguous statements, consolidation of overlapping items, deletion of subcomponents with consistently low CVR values, reorganization into developmental levels (Basic–Intermediate–Advanced), and conceptual refinement to ensure cross-cultural coherence. Consequently, some components saw reductions in the number of subcomponents (e.g., CT-based problem solving), while others expanded (e.g., digital communication), reflecting a more balanced and educationally applicable structure.

Across components, the South Korean Delphi panel demonstrated consistently high validity (CVR range = 0.80–1.00; mean $\approx$ 4.73). In contrast, the first round of the international Delphi

exhibited greater variability in validity ratings (CVR range = 0.00–1.00), with particularly lower values observed for the CT-based problem-solving component. In the second round, the reorganized developmental framework received consistently high evaluations across components.

Notably, eight subcomponents in the second-round international Delphi did not meet the minimum CVR threshold. Rather than viewing these results as deficiencies, they indicate meaningful cross-cultural variations in how certain DL competencies are interpreted. The eight items are currently undergoing qualitative analysis based on experts' open-ended comments. Drawing on these insights, revisions will be made—such as refining terminology, adjusting categorization, or recalibrating specificity—before conducting a follow-up Delphi round. Through this iterative process, the framework is expected to achieve stronger international applicability and enhanced educational validity.

Table 7

Aggregated Statistics for Subcomponents by DL Component

DL Component	No. of Sub-components 1 st → 2 nd	South Korean Delphi(3 rd)		International Delphi(1 st)		International Delphi(2 nd)	
		CVR	Mean (<i>SD</i>)	CVR	Mean (<i>SD</i>)	CVR	Mean (<i>SD</i>)
Technological Competence	18 → 16	0.80-1.00	4.68 (0.56)	0.20-1.00	4.28 (0.78)	0.56-1.00	4.65 (0.49)
Digital Content Understanding, Search, and Evaluation	11 → 12	0.80-1.00	4.68 (0.49)	0.60-1.00	4.53 (0.64)	0.56-1.00	4.56 (0.63)
Digital Content Application and Creation	7 → 7	0.80-1.00	4.67 (0.56)	0.40-1.00	4.47 (0.67)	0.56-1.00	4.61 (0.67)
Digital Communication	11 → 13	0.80-1.00	4.81 (0.43)	0.20-1.00	4.48 (0.65)	0.33-1.00	4.54 (0.70)
CT-based Problem Solving	9 → 6	0.80-1.00	4.78 (0.44)	0.00-0.80	4.18 (0.99)	0.78-1.00	4.52 (0.72)
Social Contribution and Ethical Responsibility	13 → 10	0.80-1.00	4.81 (0.43)	0.20-1.00	4.20 (0.82)	0.56-1.00	4.60 (0.60)
Overall	69 → 64	0.80-1.00	4.73 (0.49)	0.00-1.00	4.34 (0.76)	0.33-1.00	4.58 (0.62)

4.3 Consensus and Sensitivity Analysis Across Delphi Rounds

During the Delphi process, several panelists withdrew due to time-zone differences and delayed communication. To maintain methodological rigor, replacement experts who met all predefined selection criteria were recruited. To examine whether these changes influenced the outcomes, consensus indicators (Mean, *SD*, *IQR*, Agreement Rate) and sensitivity indicators (Δ Mean, Δ *SD*) were analyzed across Rounds 1 and 2. As summarized in Table 8, consensus levels improved in the second round, and sensitivity results suggested that the framework remained stable despite partial panel turnover.

Table 8

Comparison of Consensus Across Delphi Rounds

Index	1 st Round	2 nd Round	Δ (R2–R1)	Interpretation
Mean	4.35	4.58	0.23	Increased consensus
<i>SD</i>	0.75	0.62	-0.13	Reduced variability
<i>IQR</i>	1.18	0.88	-0.30	Higher agreement
Agreement Rate (%)	88.02	93.33	5.31	Strengthened consensus
Δ Mean	-	-	0.24	Stable (Δ Mean < 0.5)
Δ <i>SD</i>	-	-	-0.13	Improved consensus

5 DISCUSSION

The DL framework developed through the South Korean and international Delphi processes achieved a relatively high level of expert consensus, suggesting that the proposed concept and six-component structure may be applicable across diverse educational and cultural contexts. The framework conceptualizes DL not merely as a set of functional skills, but as a multidimensional construct encompassing technological, cognitive, and social dimensions.

At the same time, it is noteworthy that the inclusion of CT-based problem solving within the DL framework reflects the perspective of technology education, where CT is increasingly recognized as a core approach to understanding and shaping digital systems. In this study, CT is not treated as an independent disciplinary competence but as a cognitive problem-solving strategy that supports meaningful engagement with digital technologies. From this perspective, CT complements other DL components by enabling individuals to analyze digital problems, design logical solutions, and apply technological knowledge in real-world contexts. The relatively lower agreement observed among international experts may also reflect disciplinary differences in how digital literacy is conceptualized across educational traditions.

The reorganization of DL subcomponents into basic, intermediate, and advanced levels was intended to enhance the framework's educational applicability by aligning it with learners' developmental progression. This developmental approach is consistent with discussions in technology education that emphasize conceptual understanding, design-oriented thinking, and problem-solving capabilities. In this respect, the proposed framework may be interpreted as aligning DL with core educational aims of technology education, as highlighted by de Vries (2018).

Finally, this study reflects the evolving role of technology education as it intersects with digital education, citizenship education, and ethical education. By incorporating international expert perspectives into a framework initially developed within a national context, the study offers empirical insight into how DL can be discussed beyond disciplinary and curricular boundaries. In particular, the eight subcomponents that did not meet the minimum CVR threshold are currently being refined based on qualitative analysis of expert feedback and will be re-evaluated through a third round of the international Delphi process at PATT43. Through this iterative procedure, the framework is expected to achieve greater cross-cultural validity and educational applicability. The proposed framework may therefore serve as a reference point for ongoing discussions on the role of technology education in the era of digital transformation, while remaining open to further refinement.

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Authentic Users as Catalysts for Human-Centred Design Inquiry in Key Stage 3 Design and Technology

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Abstract

Design and Technology (D&T) education in England has been criticised for privileging procedural making over authentic design inquiry. Design Thinking Integrated Learning (DTIL) offers a promising pedagogical response; however, classroom practice frequently relies on hypothetical users or teacher-constructed briefs. This study investigates how embedding real end-users within a DTIL-based Key Stage 3 (KS3) D&T curriculum reshapes students' design activity and perceived 21st-Century Skill development. An embedded multiple case study was conducted across ten student teams ($n=40$) undertaking twelve weeks of DTIL-structured design projects with different adult end-users from the school and local community. Data included group presentations, classroom observations and a post-intervention focus group. Reflexive thematic analysis examined how authentic user engagement influenced design reasoning and collaboration. Findings indicate that real users acted as pedagogical catalysts through three interdependent mechanisms: empathetic reframing of problem spaces, social accountability that drove iterative persistence and collaborative negotiation of meaning. These mechanisms transformed classroom design tasks from procedural activity into socially situated inquiry, making skills visible and meaningful to students. The study contributes empirical evidence that authentic user engagement is an epistemic condition for human-centred design learning. As a bounded case study, the research offers analytically generalisable insights and proposes authentic user collaboration as a transferable design principle for strengthening inquiry-driven D&T curricula.

Key Words: Design and Technology, Design Thinking Integrated Learning, Authentic Users, Human-Centred Design, 21st-Century Skills

1 INTRODUCTION

Design and Technology (D&T) education in England claims to have a distinctive role in cultivating creative problem-solving through designing and making (McLain, 2022), however research indicates that classroom D&T practice frequently becomes dominated by procedural tasks, limited problem framing and constrained user awareness (Demetriou & Nicholl, 2022;

Design and Technology Association, 2023; Nicholl & Spendlove, 2016). National inspection evidence indicates that these conditions have persisted for over two decades. Ofsted (2008) identified fragmentation in KS3 D&T, where students complete loosely connected projects that stifle creativity and encourage formulaic thinking. In England, accountability pressures and curriculum compression have further narrowed opportunities for open-ended design exploration (Atkinson, 2023; McLain et al., 2019).

International policy frameworks increasingly focus on 21st-Century Skills, particularly creativity, collaboration, communication and critical thinking (Thornhill-Miller et al., 2023). D&T is widely recognised as a natural disciplinary space for developing these competencies because of its epistemological grounding in iterative, abductive and socially mediated design practice (Cross, 2011; McLain, 2022; Morrison-Love, 2017), however, questions remain regarding how classroom pedagogies concretely cultivate such competencies rather than claiming them as outcomes.

Design Thinking Integrated Learning (DTIL) has emerged as a pedagogical approach that adapts professional design thinking into structured classroom sequences that involve empathy, ideation, prototyping and testing (Koh et al., 2015; Li & Zhan, 2022; Park et al., 2023). DTIL has been shown to promote engagement and creative reasoning (Henriksen et al., 2020; Razzouk & Shute, 2012), although critiques highlight that empathy activities often become procedural exercises when detached from authentic stakeholders (Demetriou & Nicholl, 2022) and its model can be viewed as oversimplified and fixed in a technē paradigm (Lee, 2021).

Authentic end-users have been proposed as a means of reintroducing genuine human-centred inquiry into classroom design (Morrison-Love, 2022), but empirical evidence in D&T within schools remains limited (Bosch et al., 2022; Klapwijk & van Doorn, 2015). This study addresses this gap by examining how real user collaboration can reshape design activity within a DTIL-based Key Stage 3 (KS3) intervention at the lower secondary level.

Research question: how does authentic user engagement influence students' design activity and perceived 21st-Century Skill development within DTIL-based KS3 Design and Technology?

The study isolates authentic user collaboration as a specific pedagogical mechanism. The aim is analytical generalisation in identifying transferable design principles for technology-education curriculum development (Yin, 2018).

2 THEORETICAL FRAMING

2.1 Design learning as inquiry-driven and socially situated practice

Contemporary design-education scholarship conceptualises learning as an inquiry-driven practice in which knowledge emerges through interaction, negotiation and material engagement (Atkinson, 2023; Cross, 2011; Kimbell, 2011; Rusmann & Ejsing-Duun, 2022). From this perspective, design learning moves away from linear problem-solving and becomes abductive

reasoning under the conditions of uncertainty, where students frame and reframe problems through dialogue with others and artefacts (Cross, 2006; Dorst, 2011).

Within D&T education, collaboration, empathy and reflection function as epistemic rather than affective features of design activity (McLain, 2020; Morrison-Love, 2017), however, classroom studies repeatedly show that inquiry conditions are often reduced by tightly prescribed briefs and assessment routines that limit opportunities for genuine negotiation of meaning (Griffin & Care, 2015; Mawson, 2003; McLellan & Nicholl, 2013; Nicholl & Spendlove, 2016). Ofsted observed that teachers frequently retain tight control over students' activities, giving insufficient opportunity to "make decisions, plan, analyse and evaluate", which "gives a poor foundation for studying at Key Stage 4" and limits independent design reasoning (Ofsted, 2008). Despite this prolonged issue, the subject still lacks the 'human' element of design (Design and Technology Association, 2023).

Interaction with real people anchors design activity in lived contexts and ethical responsibility, which aligns classroom practice with participatory and relational traditions in design research (Morrison-Love, 2022; Sanders & Stappers, 2008).

2.2 *DTIL and human-centred pedagogy*

DTIL adapts professional design thinking into structured classroom learning cycles (Koh et al., 2015; Li & Zhan, 2022). Studies indicate that DTIL can promote engagement and creative reasoning (Henriksen et al., 2020), although empathy activities risk becoming procedural when detached from authentic stakeholders (Demetriou & Nicholl, 2022). Participatory design traditions position users as co-creators of meaning instead of passive informants (Sanders & Stappers, 2008), which suggests that authentic user collaboration could develop D&T pedagogy.

Within this study, empathic design is understood as engagement with users' lived experiences to inform problem framing, meanwhile user-centred design positions users as active contributors in shaping design outcomes.

2.3 *Authentic users and the relational turn in design education*

Design is considered as relational, where knowledge emerges through interaction between people, artefacts and contexts (Kimbell, 2011; Rusmann & Ejsing-Duun, 2022). From this perspective, users become participants in meaning-making who shape how problems are framed, values are prioritised and solutions are justified.

Within D&T, users are often represented through fictional personas or teacher-developed briefs. Although these can simulate professional processes, studies indicate that they frequently reduce empathy to a procedural step and limit opportunities for genuine engagement with lived experience (Bosch et al., 2022; Demetriou & Nicholl, 2022; Kaygan & Yargin, 2019; McLellan & Nicholl, 2013). This constrains students' exposure to authentic uncertainty and competing needs.

When participatory practices are translated into educational settings, authentic user collaboration introduces external perspectives that disrupt pre-specified problem spaces and redistribute authority for defining success, which reflects the shift from designing *for* users to designing *with* them in contemporary professional practice (Björgvinsson et al., 2012; McDonagh, 2015). Interaction with real users deepens contextual understanding and aligns classroom practice with contemporary design epistemologies (Demetriou & Nicholl, 2022; Kaygan & Yargın, 2019; Morrison-Love, 2022).

This study therefore conceptualises authentic users as relational partners who introduce epistemic uncertainty and accountability into classroom design activity. Examining how these dynamics unfold within DTIL cycles provides insight into how school D&T can move towards inquiry-driven and human-centred practice.

3 METHODOLOGY

3.1 *Research design*

An embedded multiple case study design was adopted (Stake, 2006; Yin, 2018). The overarching case was a DTIL-based KS3 D&T curriculum intervention. Ten embedded cases were defined with each comprising of a team of four Year 8 students (aged 12-13 years) collaborating with a different adult end-user. This structure enabled examination of how distinct user interactions shaped the design processes under shared curricular conditions.

The study is positioned within interpretivist and social-constructivist traditions that examine how knowledge and meaning are co-constructed through collaborative design activity (Schwandt, 2000).

3.2 *Participants and context*

Forty students participated in one single-sex (girls) secondary school. Teams were heterogeneously grouped and the end-users were school staff and community members who presented genuine needs that required design solutions. The projects ran across twelve weeks of curriculum time following DTIL cycles of empathising, defining, ideating, prototyping and testing. As an example, one of the contexts was provided by an audiologist who found it challenging to provide a simple but engaging means of supporting hearing tests with 2–5-year-olds. The group considered all the constraints, including hygiene and safety, to produce a simple pick and place activity when the child hears certain sounds. Another example was a way of reminding students where to place certain ingredients in the fridge for their cooking classes. The group produced an encased electronic system that activated when the fridge door was opened, and an audio message was played aloud.

3.3 *Data collection*

Data sources included:

- Group oral presentations documenting design decisions and user feedback
- Classroom observations and researcher field notes
- A post-intervention photo-elicitation focus group (Leonard & McKnight, 2015)

This paper focuses on qualitative data that reveal how authentic users shaped design reasoning and collaboration.

3.4 *Data analysis*

Reflexive thematic analysis followed Braun and Clarke's (2022) approach. Coding progressed iteratively from descriptive accounts of user interaction towards interpretive themes that explained how authentic users functioned as pedagogical mechanisms. Cross-case comparisons identified recurring patterns.

3.5 *Trustworthiness and reflexivity*

Prolonged engagement across the twelve-week intervention enabled familiarity with classroom dynamics. Data triangulation across observations, presentations and focus group discussion strengthened the interpretive credibility, and the reflexive thematic analysis acknowledged the researcher's role in meaning-making.

3.6 *Enactment of DTIL within the curriculum intervention*

The DTIL curriculum intervention was structured around iterative cycles of empathising, defining, ideating, prototyping and testing, which was adapted for KS3 classroom conditions. Each team met their end-user to explore needs and challenges. Students conducted informal interviews, recorded their observations and produced initial problem statements. This empathising phase was followed by group discussion to define user needs and generate early concepts.

During ideation, the teams used sketching, annotation and low-fidelity modelling to explore alternative concepts. Teacher facilitation focused on prompting justification of decisions instead of directing any solutions. Prototyping involved constructing physical artefacts using workshop tools and digital modelling software. Testing cycles included presenting prototypes to end-users, gathering feedback and identifying necessary refinements.

These DTIL cycles were repeated across the twelve-week project. Although the sequence provided structural guidance, the teams retained autonomy in design direction and interpretation of the user feedback. This combination of structured cycles and authentic external interaction created conditions for emergent inquiry instead of the completion of tasks in a linear fashion. The intervention therefore provided a consistent pedagogical framework that allowed for variability in user interaction to shape each embedded case.

3.7 *AI Disclosure Statement*

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

4 FINDINGS

Three interdependent themes were identified: empathetic reframing of problem spaces, social accountability that drove iterative persistence and collaborative negotiation of meaning.

4.1 *Empathetic reframing of problem spaces*

Encountering real end-users prompted the students to reconceptualise design tasks around lived needs rather than teacher-constructed briefs.

“At first I thought it was just making something to store things. But when she explained how she struggles to reach things, we realised the problem was much more about accessibility.” (Group 3)

“After talking to him, we changed our idea completely. What we thought was helpful actually wouldn’t work in real life.” (Group 7)

Observations noted sustained questioning and interpretation of user narratives:

“We had to really listen because if we misunderstood her, the design wouldn’t actually help.” (Group 1)

Analytically, this reflects abductive reasoning, which is central to design cognition (Cross, 2011; Dorst, 2011) and aligns with design as knowledge creation through interaction (Grönman & Lindfors, 2021). Authentic users introduced epistemic uncertainty and inquiry conditions that are often absent from routine classroom D&T tasks (Mawson, 2003; McCormick, 2004).

4.2 *Social accountability that drove iterative persistence*

Students described a sense of responsibility towards producing functional outcomes for real users.

“When it didn’t work the first time, we couldn’t just leave it because someone was actually depending on it.” (Group 5)

“If it was only for an assessment, we probably would’ve stopped. But because she was going to use it, we kept fixing it.” (Group 9)

Authentic users redistributed evaluative authority away from teacher assessment to external stakeholders. This transformed evaluation towards a personal commitment, which aligns with accounts of design learning as inquiry that is sustained by social consequence (Rusmann & Ejlsing-Duun, 2022).

4.3 Collaborative negotiation of meaning

Authentic users introduced external perspectives that required collective interpretation.

“She said she liked both ideas, so we had to decide which actually solved her problem better.” (Group 6)

“We didn’t all agree on what he meant at first, so we had to talk it through.” (Group 4)

Focus-group reflections explored this more intensive collaborative dialogue:

“We had to explain our ideas properly to each other so we could explain them to the user.” (Focus group)

This reflects collaborative knowledge construction where uncertainty that is introduced by external perspectives stimulated shared reasoning and the articulation of assumptions (Care et al., 2016).

5 DISCUSSION

5.1 Authentic users as epistemic catalysts in DTIL

Existing DTIL research demonstrates that structured design thinking cycles can promote engagement, creativity and collaboration (Henriksen et al., 2020; Li & Zhan, 2022), however, classroom-based studies caution that when empathy and ideation activities are detached from real stakeholders, design thinking risks becoming another routine pedagogical procedure (Demetriou & Nicholl, 2022). The findings show how authentic user engagement reintroduced epistemic uncertainty, responsibility and negotiation into DTIL cycles.

Empathetic reframing that was observed in this study illustrates how real users altered students’ initial assumptions and prompted abductive problem framing. This supports arguments that design competence in schools depends on opportunities to encounter authentic complexity rather than simplified tasks (Mawson, 2003; Mawson & Maor, 2001; Rusmann & Ejlsing-Duun, 2022). Authentic users functioned as external reference points that required the students to iterate their interpretations of the problem space rather than accepting teacher-defined briefs.

Social accountability extended DTIL’s iterative stages beyond compliance with assessment criteria, which aligns with claims that meaningful design learning requires consequences that

matter beyond the classroom (McLain, 2022, 2023). The presence of real users therefore altered motivational structures and sustained persistence through iterative refinement.

Collaborative negotiation of meaning demonstrates how user feedback became a shared interpretive object around which teams articulated their assumptions, justified their decisions and co-constructed knowledge. This resonates with collaborative learning research that positions group dialogue as a shared practice of sustained thinking and co-construction of meaning (Mercer & Littleton, 2007). DTIL cycles became sites of collective reasoning instead of a task that “masquerades as design and make” (McLain, 2020, p. 79). These mechanisms indicate that the authentic users improved DTIL’s inquiry potential.

5.2 *Repositioning classroom D&T practice*

Persistent critiques of D&T in England describe classroom activity that is dominated by procedural making, limited problem framing and constrained student agency (Demetriou & Nicholl, 2022; Nicholl & Spendlove, 2016). This study provides empirical evidence that embedding real users can address these tendencies by re-establishing design as relational inquiry.

Instead of adding an extra activity, the inclusion of authentic users reorganised the structure of classroom authority. Evaluative judgement was no longer held exclusively by the teacher because it was distributed across the user, team and artefact. This redistribution of authority is significant because it created conditions for the students to experience design as negotiated, value-laden and socially accountable practice that is consistent with contemporary professional design epistemologies (Kimbell, 2011; Morrison-Love, 2022).

These findings therefore suggest that authentic user collaboration is not an optional enrichment to DTIL but is a structural condition that enables DTIL cycles to function as genuine inquiry. For curriculum designers, this highlights the importance of embedding external stakeholders where the aim is to cultivate human-centred reasoning.

5.3 *Analytical generalisation and transferability*

As a bounded case study in one school context, the study does not claim any statistical generalisation, although by identifying mechanisms through which authentic users shaped design activity, the findings support analytical generalisation (Stake, 2006; Yin, 2018). The mechanisms of empathetic reframing, social accountability and collaborative negotiation represent transferable pedagogical design principles that have the potential to inform curriculum development beyond a single school context.

Although contextual factors such as school culture, resources, timetable structure and teacher expertise inevitably mediate its implementation, the identified mechanisms offer theoretically grounded insights into how authentic user collaboration can support inquiry-driven D&T. Future research could examine how these mechanisms function across different age groups, assessment regimes and contexts, but this study provides a starting point for evidence-informed curriculum design.

6 CONCLUSION

This embedded multiple case study examined how authentic user collaboration reshaped DTIL-based design learning in KS3 D&T. Reflexive thematic analysis identified empathetic reframing, social accountability and collaborative negotiation as mechanisms through which real users transformed classroom design tasks into inquiry-driven and human-centred practice.

Although it is bounded to one school context, the study offers analytically generalisable insights into how authentic users function as epistemic conditions for meaningful design learning. Authentic user collaboration could be viewed as a transferable design principle for strengthening inquiry, collaboration and visible 21st-Century Skill development in technology education curricula. At a time when D&T curricula face increasing performativity pressures, authentic user engagement offers a practical means of protecting space for uncertainty, empathy and dialogue at the heart of D&T education.

6.1 *Limitations and future research*

The study is limited to one school context and a single twelve-week intervention. Although the embedded case study design supports analytic depth, the findings are shaped by local curriculum conditions and the availability of adult end-users. Additionally, the presence of the researcher as teacher may have influenced classroom dynamics, although reflexive analysis sought to account for this.

Future research could examine authentic user collaboration across diverse school settings, different age phases and alternative DTIL structures. Longitudinal studies could further explore how repeated exposure to authentic design inquiry may influence students' developing design identities and sustained development of 21st-Century Skills.

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Can a Bestiary of Metaphors Help us to See Ourselves in Relation to Sustainability?

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Abstract

This paper explores how we may see ourselves as technology educators and how we see technology education in the world of education by the playful but earnest use of animal metaphors. The paper focuses on the relationship between technology education and sustainability education, and on how metaphors can encourage new ways of thinking.

Inspiration for the paper draws on several threads. First, there is the circumstance that technology itself is often described as the elephant in the room – ever-present but never talked about. This phenomenon contributes to a general lack of ‘seeing’ technologies for the fullness of their effects on our worlds. Second, the multi-faceted (and, at times ephemeral) nature of technology education indicates a range of species struggling to co-exist harmoniously. Third, for a sustainable world, all species should to be protected. Thus, a fourth thread suggests dilemmas around whether some species of technology education are actually compatible with sustainability education.

Metaphors can help us comprehend one concept in the light of another concept even when the two concepts seem outwardly quite different. A metaphor can change our conceptual system and can radically modify our perception of a particular situation. The paper explores a range of animal metaphors (species, traits, behaviours, needs, etc) to reflect on the nature and role of technology education in relation to sustainability; to ask questions about our technology education practices; and, to imagine alternative paths to the future. In order to address the central question of ‘Which animal(s) are we?’, the paper invites consideration of four Vs: vanity, victims, vision, and volition.

Key Words: metaphors, technology, sustainability, technology blindness, education, Blindspot Declaration

1 INTRODUCTION

Bestiary: A treatise on beasts, as written during the Middle Ages. (Onions, 1983)

This paper has as its background, the recently developed Blindspot Declaration (The Blindspot Group, 2025) – an attempt by a group of concerned academics to address perceived educational shortcomings around sustainability and technologies – a phenomenon we call technology blindness (See also Svensson et al., 2026; Svensson & Keirl, 2026). We invite colleagues in the professional technology education community to reflect on their practices, their thinking and, from the paper’s title, how they see themselves in relation to sustainability. This is not to say that there is not a reciprocal need for sustainability educators to (re-)consider their own positions regarding technologies – that is a core concern of the Declaration.

The paper begins with some clarification of terms and of the use of metaphors. From the arch-metaphor of Technology-as-Elephant, we extend the use of animal metaphors in a bestiary to, in one way, celebrate the diverse nature of our field. However, such an approach also serves to create spaces to invite colleagues to consider how they are positioned, or position themselves, on the matter of technology blindness. Following the metaphors, we raise a pair of difficult questions for consideration. The paper concludes with two cautionary notes on vanity and victimhood and, two affirmative notes on vision and volition in support of the Declaration’s orientation towards action.

2 CONCERNING THE USE OF ‘US’, ‘WE’ AND ‘SEEING’

When we refer to ‘us’ and ‘we’ in the paper’s title and content we are thinking of ourselves in three possible ways: first, as persons (individuals, teachers, educators); second as possible groups (special interest, primary, secondary, tertiary, subject, etc); and, third, as the collective PATT community or the (Design and) Technology professional community more broadly. Also, when we use the idea of ‘see/ing’ in this paper, there is the sense of seeing ‘ourselves’ in all the identities just described but we also in how we look at Technology Education (in which we are players) and how we look at Sustainability Education (in which, we suggest, we should be players). Thus, we argue that in order to see technologies for what they really are, and to help others to do so, it might be helpful to look at ourselves and our own practices first.

Seeing is not necessarily understanding. The blindness we are talking of is not about simply seeing a technological object. For example, we may *see* a car, but we don’t necessarily know, understand or question its existence, its workings or its full environmental, social or political implications. Cars are systems operating within systems (Svensson, 2021). Generally, we know ‘It’s a car’ and we ‘get into the car’ and such statements need little or no critical-conscious effort or attention. Our technologies become a part of the backgrounds of our lives – they drop out of sight. Collectively, our technologies constitute our lives, yet we can easily be blind to them.

3 ON METAPHORS

Using metaphor/s is an established linguistic practice – not least in the use of rhetoric, the art of persuasion. A metaphor is often used to help illustrate the characteristics or nature of one phenomenon by making links to the characteristics of another phenomenon - usually when there’s nothing outwardly similar between the two phenomena. By this linking, the metaphor takes the place of a literal equivalent. Thus, in north European settings, people are sometimes described as

being owls or larks. The owl is a bird active at night while the lark is a bird which rises early in the morning: people are not *actually* larks or owls, but they may show the waking characteristics of them.

An important note: metaphors tend to be culturally located and may not readily transfer between cultures or languages.

Metaphors can be used for effect to illustrate a point or to support an argument, but they do not constitute evidence of fact or truth – not least because a metaphor may not be understood in exactly the same way by different hearers or readers. There is rich literature about terms similar to metaphor as well as about its relatives such as extended, dead and mixed metaphors (see, e.g. Blamires, 2000). For this paper, metaphors are used as ‘imaginative substitutions’ in order to help ‘see things otherwise’. We begin with the macro-metaphor for our field, that of the elephant.

4 TECHNOLOGY AS THE ELEPHANT

The phenomenon of Technology has long been described as ‘the elephant in the room’; the idea being that everyone in the room knows it’s always there, but no one really wants to talk about it. This circumstance both comes from, and contributes to, a general inability to ‘see’ technologies fully for their effects on our worlds.

Sclove (1995) introducing his text on democracy-technology relationships, addressed the way in which we unquestioningly accept technologies into our lives. He illustrates well the lack of participation we have in the decision-making around the design or desirability of technologies and how we are complicit in perpetuating their development and impacts.

This complicity in technological decisions that haphazardly uproot established ways of life is as perplexing as discovering a family that shared its home with a temperamental elephant, and yet never discussed – somehow did not even notice – the beast’s pervasive influence on every facet of their lives (Sclove, 1995:5).

While deep concern around the phenomenon of Technology (big T) is well illustrated as temperamental elephant, our worlds comprise multiple technologies (small t) which are themselves complex beasts. Normal engagement with technologies is often limited to uncritical usage while deep understanding of their multi-faceted, polyvalent (Sclove, 1995) and multistable (Ihde 2002) natures remains elusive. The Blindspot Group have recently attempted to summarise the situation:

Technologies...can assume different roles in various situations and they embody multiple, often competing, values. They are neither ahistorical nor apolitical and articulate powers that are often undemocratically distributed. Technologies are never neutral and they can be overtly present or seemingly invisible in their existence. Deep understandings of technologies are intrinsic to critiques of ecological perception, economy, sustainability and potential post-human conditions. Despite all these circumstances, technologies remain largely understood in only superficial ways and lack critical-ethical interrogation. (The Blindspot Group, 2025)

From what has been said so far, it would be quite unreasonable to expect the technology education community to take on the vast range of issues that constitute the elephant. However, if our community accepts that it has a role to play in the world's sustainability challenges then we might look at ourselves first in relation to technologies, sustainability and education and, second, at how we might work with others with similar ambitions.

The parable of the elephant and the blind people serves to remind us that our personal perspectives are no guarantee that we understand the whole of the technology phenomenon. As the parable goes, a group of blind people (some climbing ladders) gather around an elephant and each one touches a part of the elephant, each now believing that they know what an elephant is. While none can have the whole picture, there is also no guarantee that their collective knowledge is enough to give an accurate understanding of 'elephant'. Equally, amongst technology educators, even our collective perspectives may not amount to a true picture of our elephant.

5 EXPANDING THE BESTIARY

The world of technology education comprises creatures of many kinds. This is of no surprise when we think of the kinds of families that exist in our field. Some examples: are we primary, secondary or tertiary? Are we craftspeople, digitals, foodies, engineers, designers, technologists? Are our tendencies sociological, political, psychological, philosophical? Do we relate to the arts, literacy, mathematics, science, history, anthropology? Are we creative, instrumental, functional, visionary? What kind of technological literacy do we subscribe to – instrumental, participatory, emancipatory, critical, ethical?

With such an exceptional range for one field of education, the opportunities for metaphor are plentiful. We offer some playful but earnest application of animal metaphors for how we might see ourselves in our technology education world. In no particular order:

Technology is perhaps a **chameleon**: changing colours according to situation; able to 'be' in different ways at different times; hard to see in relation to sustainability. Some technology educators may be chameleons themselves or else **leopards**, survivors but unable to change their spots so carrying on the same old way without regard to the environment.

Ants work cooperatively using different competencies to build and maintain their colony. Their nests can spread for thousands of kilometres. Like technology educators, there are many species across the world and while most work to maintain their community, fire ants (like **termites**) are notable for their destructive capabilities, looking after their own environment whilst destroying those of others. Like technology educators, ants have one of the best strength/body weight ratios.

The **owl** has a mixed reputation so far as technology-sustainability relations go. In places it is wise, but it is also a predator and happiest in the twilight – between darkness and light. In some cultures, it is welcomed. In others it is the bringer of supernatural danger or death. It does have binocular vision which is useful for seeing technologies....and **mice**, which it hunts; so mice are quiet, timid and feed on the crumbs from the table – much like technology education.

With special regard to technology-sustainability consciousness many education systems and some educators remain **ostrich**-like. Despite having the largest eye of any land-based creature, that eye is larger than the ostrich's brain. This may explain its lack of interest in the state of the world

around it as well as why it can't fly. It's hard to see where you are going (or might like to go) with your head in the sand. Nor can we maintain criticality if we are **parrots** of the words of others or **mules**, stubbornly refusing to move until we're ready? Better, are we parrots because of our capacities to learn and to use tools or mules for the loads we can bear? Perhaps we're **dolphins** - clever, social, good communicators, smooth, and playful.

Fish offer several metaphors for looking at ourselves. The phenomena that Sclove (1995) and The Blindspot Group (2025) describe are the water that we swim in. When fish ask: "What is water?" it is their version of technology blindness. But we mustn't overlook the ponds we inhabit. Some ponds are very good for sustainability. Unfortunately, many are not; often thanks to technologies. Some have **alligators** – of which we must beware! Technology education and educators might reflect on the size of the pond they inhabit before deciding whether they, or their pond, are big or small.

Or we're tool-using creative problem-solvers such as **primates, crows, and parrots**, (or, recently, a **cow**). Or builder-architects such as **bees, ants, spiders, birds, beavers** all with their own environmental benefits and consequences. Perhaps we're into duplication avoidance like the **cuckoo** who uses other birds' nests; or **magpies**, always stealing or collecting. Our preference might be the metaphor of **fox**, sly, cunning and crafty – who, in Sweden can be found behind the ear.

If endless creativity and problem-solving isn't for us then we could consider the **sloth**, which comes in two forms. The two-toed sloth has two claws on its front limbs (good for getting a grip of things and more – see below) while the three-toed sloth has three claws (for even better gripping perhaps). Both have three claws on the rear feet. There are other advantages too. Sloths are very particular about where they defecate; they have a low-energy, green diet and spend most of their time hanging about in trees and thus having a very low carbon and ecological footprint; they are very good swimmers, so they know about ponds; everything about them is slow-moving which makes them great survivors.

There is one huge beast that lumbers about and is such a size that it can't easily be moved and everyone else has to work around it. It is the **hippopotamus** known as STEM; which actually presents a mixed metaphor as it is also four types of **cat**: two top cats - large and predatory called Maths and Science; another, sometimes a clever problem-solver, called Engineering; and, fourth, Technology - a domestic, alley or pussy cat (a shape-shifting sub-species) which are always present around humans. To further mix the metaphor here, the shape-shifting sub-species of Technology cats can also take the form of the hidden animal that cannot be seen – the elephant. Occasionally, the **giraffe** (known as Art) sticks its long neck in among these creatures, but it usually ends up being devoured.

Our technology education bestiary is well populated with multiple species with varying positions in relation to the technologies, sustainability and education but, it seems to us, there is more to the matter than species-spotting. There is competition; harmony isn't always possible; and there are contradictions. For us, two conundrums arise.

6 TWO CONUNDRUMS

A conundrum is a riddle (often light-hearted) or, otherwise, a hard question – one that is difficult to resolve because of its complexity. We perceive two conundrums at the core of this paper's concerns. First, if one core principle for a sustainable world is that all species should be protected, then should the same be true for all species of technology education? Put otherwise, if some species of technology education are incompatible with sustainability education, then should they be abandoned? Here, the pursuit of the sustainability principle of ecological balance cannot defend all of technology education's species.

Implicit in the conundrum posed above are some serious debates and difficult decisions – for our profession and beyond. Are we willing to engage these debates and challenges? Here lies our second conundrum. Is sustainability technology education's elephant in the room?

With their focus in the nexus of technologies-sustainability-education, The Blindspot Group have this to say about sustainability:

Sustainability is a necessary response to many challenges; some of which are existential. It resists simple categorization but is often viewed positively through hope and strategic optimism towards the future or negatively via pessimism and apathy. It is dynamic and shapeshifting, requiring contextual awareness and sensitivity. The transition to more desirable futures presents technological, political and ethical challenges. Sustainability is ethically defensible yet it remains weakened by the absence of critical technological discourse. (The Blindspot Group, 2025)

If sustainability is technology education's elephant in the room, then such discourse, along with our own internal debates, might help expose the elephant and advance the interests of all planetary species. We suggest that the place for discourse development is in the pond we call the nexus – a place to discuss new approaches, to strengthen our practices, to deepen our knowledge, and to collaborate. The matter of technology education's role in delivering on principles of sustainability is not a challenge for technology educators alone.

7 PUTTING OUR TWO FINGERS TO USE

One use of our two-toed sloth's two claws is to see them as fingers to make the 'V' sign. We identify four Vs for consideration:

Vanity: One way of seeing ourselves is to use the reflections of a mirror or water. However, there are cautionary tales. In Aesop's fable, the dog with a bone in its mouth sees its reflection in the water, perceives another dog with a bigger bone so, trying to grab the other bone, drops its bone and loses both. From the Indian Panchatantra animal fables, the lion falls into the well having been tricked into thinking its own reflection was that of another lion. While reflection is powerful and useful, it can also be a tool of vanity.

Thus, excessive pride is of no value in critical reflection. As big fish in our little pond, we are reminded to maintain objectivity, research, new thinking and, importantly, humility towards

knowledge - both old and new. If we think we have ‘the answer’, or all the answers, we remain unwise. Reflection without vanity is a way of overcoming technology blindness.

Victims: Does technology education see itself as victim or survivor? Are we predators or predated? Are we winners or losers? Have we alligators in our pond? In many ways these are curriculum questions. If, for example we consider Layton’s (1994) work for UNESCO on the (then) globally new and emergent subject of Technology Education he chose the metaphor of the theatre to identify six ‘principal actors in this curriculum drama’ (Layton, 1994:13). Two – economic instrumentalists and professional technologists – remain privileged in that the economy and those perceived necessary to feed it are to be protected. Thirty years on, the other actors (girls and women; sustainable developers; defenders of participatory democracy; and liberal educators - who value the subject for its own intrinsic merit) remain marginalised and continue to struggle for their identity and curriculum survival.

Seeing victims in technology education is a matter both of looking at ourselves and how we respect each other as well as resisting any collective victimhood that is imposed from outside. It is possible that we both create victims and that we are victims; and creating a passive victim mentality of helplessness is no characteristic of sustainability.

Vision: Ways of seeing can take many forms in the animal world. For our part, the Blindspot Declaration is intended to help overcome technology blindness towards sustainability education and vice versa. It is both a way of *seeing* and a way of *imagining*. It offers a vision of different ways of doing things. As it claims: ‘Education that perpetuates technology blindness is no longer defensible’ but it also observes that: ‘An absence of holistic and critical perspectives on the interplay of technologies and sustainability is perpetuated by current educational models.’ (The Blindspot Group, 2025).

Vision is called for to bring a variety of ‘actors’ from multiple disciplines into the nexus. To mix our metaphors again, such actor-animals may help us see otherwise: the wise and binocular owl; the chameleon with two independently mobile eyes with a brain independently processing each input; or, the eight-eyed spider (a weaver of strong but light webs looking to catch the blind).

Volition: If seeing the issues and imagining alternative worlds and ways of doing things are to be realised, and the Blindspot Declaration offers a way to do this, then a necessary ingredient is that of volition: the will to act. At a rather basic level, if things aren’t right, should we act? If yes, how should we act? These are ultimately ethical and political questions. So far as education is concerned, the Blindspot Declaration sees things this way:

Education, formal and informal, is a political act which has the responsibility to better the living world....Matters of complexity, holism, emotions, values and ethics all call for attention when educating about technologies and sustainability. (The Blindspot Group, 2025)

The deep significance of volition in relation to Technology was articulated by Mitcham in 1994 and he reiterated this for engineering education in 2014 (Mitcham, 1994; 2014). He noted that: ‘...the issue of volition remains central to any philosophy of action – and thereby to any comprehensive understanding of technology.’ (Mitcham, 1994:254). This argument remains true for technology education itself (Keirl, 2018).

8 WHICH ANIMAL(S) ARE WE?

Many of our metaphorical creatures in the bestiary could identify with how Mitcham sees technology as object, activity or knowledge but where are we in relation to our will to act, our volition? If no creature we know can be used as a single metaphor for how we could see ourselves in relation to sustainability, perhaps the issue is that the only animal to which we can attribute all four of Mitcham's terms, including volition, is the human. Human action has brought us to the current state of play in the world and, we argue, human action through education must address how things could be otherwise

The great Swedish 'Father of Modern Taxonomy' and a founder of modern ecology, Carl Linnaeus (later Linné) gave us the Latin binomial (two-names) system for creatures large and small. We recall his naming of our own species: *homo sapiens* (wise human). Is it possible to be wise if we remain blind to technologies-sustainability realities?

Acknowledgement

The foundational work of The Blindspot Group was funded by Riksbankens Jubileumsfond, Research initiation, F25-0004

Affirmation

This paper is original work, and the authors take full responsibility for its content.

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Dialogue and Variation as a Didactic Model in Technical Vocational Education

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Abstract

Using didactical models when planning and conducting teaching can be a way of basing teaching on scientific research. However, when it comes to organising teaching and learning in relation to vocational education and technical objects of learning, there is a lack of didactical models. A central part of technical vocational education is teaching and learning how to handle tools related to the vocation students are training for. Previous studies show that teaching about tools in technical vocational education can have different focuses (cf. Asghari et al, 2025) and be based on teachers' experiences and situations arising ad hoc, which can make teaching in this area unequal (Asplund et al., 2022). Therefore, we have been carrying out didactic modelling in three phases - extraction, mangling and exemplifying (Wikman et al., 2020). In this study we focus on how a didactic model emphasising dialogue and variation can create conditions for students' learning of how to use tools in a preferable way in a vocational school workshop. In an intervention study, using learning study as a method, teaching and learning has been documented and evaluated. In this study, video recordings of teaching sessions in car mechanics and building and construction workshop classrooms have been analysed using CAVTA (Conversation Analysis and Variation Theory Approach) as the theoretical and methodological framework (cf. Asplund & Kilbrink, 2020; Kilbrink & Asplund, 2020). Data also consists of interviews with students after the video recorded teaching sessions. Preliminary findings indicate that using a didactic model emphasising dialogue and variation can contribute to students' learning about tools in vocational workshops.

Key Words: Technical Vocational Education, Tools, CAVTA, Interaction, Workshop Teaching

1 INTRODUCTION

The professional science of teachers and teaching is sometimes referred to as didactics (Ingeman & Wikman, 2015; Kansanen, 2009; Wikman et al., 2020) and didactic models can constitute a scientific basis of teaching and contribute to teachers' professional knowledge (cf. Wikman et al., 2020). However, didactic models of how to organise teaching and learning in relation to vocational education and technical objects of learning are lacking (Pahl, 2014). This lack of

research can mean that teachers need to rely on their own experiences, instead of basing teaching on science of teaching and learning different learning content. Consequently, this could make teaching and learning in this context unequal, in the sense that students do not get access to the same learning opportunities (cf. Asplund et al., 2022; Axelsson et al., 2025). Therefore, there is a need to study how didactic models can be developed, tested and implemented in relation to different learning content in technical vocational education and in different groups of students.

One important learning content in relation to technical vocational education is how to handle tools in different ways and different situations (Asghari et al, 2025; Lindberg, 2003), but there is a lack of studies focusing on how tools could be taught and learned in this context in a systematic way. Therefore, the focus in this paper is to study a teaching intervention with a focus on using a didactic model emphasising dialogue and variation (Asplund & Kilbrink, 2025) in relation to teaching and learning in relation to technical vocational education. The teaching content in the study concerns *how to handle tools* in vocational school workshops at the Vehicle and transport programme and at the Building and construction programme. The aim is to contribute knowledge about how a didactic model emphasising dialogue and variation can create conditions for students' learning of how to use tools in a preferable way in a vocational workshop based on the following research questions:

- (i) What aspects of how to handle tools in a preferable way emerge when using dialogue and variation in the teaching interaction?
- (ii) How do students participating in a teaching intervention experience their learning of handling tools?

2 PREVIOUS RESEARCH

Didactic models can be general and two basic didactic models concern the didactic questions *why*, *what*, and *how*, as well as, as in the classical didactic triangle, the relationship between teacher, student and learning content (cf. Gericke et al., 2018; Sjöström, 2023). However, different learning contents and teaching contexts may present different challenges that also require more specific models. Since didactic models cannot cover all contexts, contents or aspects of teaching, there is a need for several didactic models relating to different aims of teaching and teachers (Gericke et al., 2018; Wikman et al., 2020). Wikman et al. (2020) discuss didactical models and modelling in relation to science education, and how these can be used as a scientific basis for teaching and as a support for teachers when planning and analysing teaching and learning. In their study, Wikman et al. (2020) argue that didactic modelling is carried out in three interacting phases and in close cooperation between research and practice. The first phase (*extraction*) concerns studying existing theory as well as practice, the second phase (*mangling*) is about using and developing ideas from the first phase in practice, and the third phase (*exemplifying*) is about highlighting examples of how the didactic model based on the first two phases can be used in relation to different contexts and contents.

In technical vocational education, tools and how to use them are important learning content (Asplund et al., 2022; Lindberg, 2003). Previous research shows that teaching and learning about

tools in technical vocational education can have different focuses (cf. Asghari et al, 2025; Asplund et al., 2022). Asplund et al. (2022) have examined classroom interactions in vocational workshops and conclude that teaching about tools may not always be something that teachers plan for, rather, teaching about tools may take place as a result of suddenly arising problems that the students encounter when conducting a work task, which makes the teaching about tools rather individual and depending on what happens during the sessions. In Asghari et al. (2025) technical vocational workshop teaching in four different vocational programmes have been observed with the focus on how tools emerge as learning content in interaction between teachers and students. The study shows that *what aspects* of the (use of the) tools were foregrounded as learning content could differ. Hence, different categories of how tools were handled as objects of learning in the teaching situations were identified; from finding any tools to solve a task, to understanding of which tool should be used when, and how tools should be used in the right way. One aspect, highlighted in relation to practical objects of learning in technical vocational education, such as the use of tools, is the tacit dimension, which can be complicated to teach using only verbal language (cf. Axelsson et al., 2023; Carlgren et al., 2015; Kilbrink et al., 2022). However, research on didactic models of how to organise teaching and learning in relation to vocational education and technical objects of learning, including the handling of tools, are lacking (cf. Pahl, 2014).

3 THEORY AND METHOD

Since there is a lack of didactic models focusing on teaching practical or technical vocational objects of learning, we have been carrying out didactic modelling in these three phases. During the first phase (the extraction) we scrutinised existing research in the area of technical vocational education (e.g., Pahl, 2014); in the area of the action research method learning study (e.g., Wood & Sithamparam, 2014); and the two learning theories conversation analysis (e.g., Sidnell & Stivers, 2013) and variation theory (e.g., Marton, 2015) as well as how they in combination could contribute to understanding the how- as well as the what- aspect of learning processes (Emanuelsson & Sahlström, 2008). Furthermore, we conducted classroom research in vocational workshops to study how teaching and learning was done in interaction in this context (e.g., Asplund et al., 2022; Kilbrink & Asplund, 2020). In the next step, the mangling phase, we worked in collaboration with teachers in two research projects, using the learning study method for developing teaching in iterative cycles based on a merge between the two learning theories in CAVTA (Conversation Analysis and Variation Theory Approach) as a scientific base for teaching (Asplund & Kilbrink, 2020; Kilbrink et al., 2022), which resulted in ideas about how to base vocational workshop teaching on *dialogue* and *variation* (cf. Asplund & Kilbrink, 2025). In the present study, we use the results from those previous phases to exemplify (phase three, Wikman et al., 2020) how dialogue and variation can be used as a didactic model for teaching and learning practical objects of learning in technical vocational education.

Data in this study derive from an action-oriented study as part of the research project *Approaches to subject-specific teaching for increasing opportunities for learning in vocational education* (supported by the Swedish Institute for Educational Research, Dnr 2022-00035) conducted in collaboration between researchers and teachers in vocational subjects at a Swedish municipal upper secondary vocational education. The study has been ethically approved by the Swedish

Ethical Review Authority (Dnr 2023-00776-01) and all participants are anonymised when presenting data. In this study, GenAI has been used as a supportive tool for translation only.

The method used in the project is learning study, where teaching and learning in relation to specific learning content is collaboratively developed in iterative cycles based on a theory (Marton, 2015; Wood & Sithamparam, 2014). The theory used in this learning study is CAVTA, emphasising learning as something that is done in interaction and always concerning a learning content (object of learning) (e.g., Asplund & Kilbrink, 2020; 2025; Kilbrink, et al. 2022). As a basis for the teaching cycles, didactic tools from CAVTA were used, focusing on dialogue and variation as means for making the learning of the chosen learning content visible in interaction. The focus on dialogue and variation constitutes the didactic model on which the teachers based their teaching in this teaching intervention. In short, the model consists of the following didactic questions:

- (i) What learning content are the students supposed to be able to handle (*the practical object of learning*)?
- (ii) What do the students need to learn to perform/know in order to know the object of learning (*critical aspects*)?
- (iii) What aspects of the object of learning could be expected to cause difficulties for the students (*expected critical aspects*)?
- (iv) What are the actual difficulties in the learning situation (*displayed critical aspects – negotiated in multimodal dialogue in interaction*)?
- (v) How can a learning situation be created where students are able to experience those critical aspects by patterns of variation (e.g., *contrast*, where the students can experience too much – too little, too fast – too slow etc.)?
- (vi) How can dialogue be used in the learning situation to reach a *common understanding* of what the students know and do not yet know in relation to the object of learning?

The teachers planned the teaching focusing on displaying what the students were supposed to learn (*the object of learning*) and systematically varied aspects of the learning content which the students were expected to have difficulties grasping, based on the teachers' previous experiences of teaching that specific content (*expected critical aspects*, see Kilbrink, Axelsson, Asplund, 2022). The variation was based on *contrast* as *pattern of variation* (Marton, 2015; Asplund & Kilbrink, 2025), which in this specific teaching situations related to letting the students compare how it should feel when using the tool (the right way, or the *targeted critical feature*) with how it should not feel – in order to learn, for example, how hard you should pull or how fast you should move a tool.

For this study, the teaching sessions in the learning study cycles were video recorded, and directly after each teaching session, one or two focus students were interviewed about their experiences of teaching and learning that had taken place. For this article, two teaching sessions from the teaching intervention, sessions in which tools were foregrounded as the learning content, were chosen for analysis. The analysis focused on how the didactic model was used by the teachers (one teacher in each session=2 teachers) and how it was experienced by the students (two students

from each session=4 student interviews). These sessions represent two examples of teaching how to handle tools, using dialogue and variation as a didactic model in upper secondary vocational school workshops in the Vehicle and transport programme and in the Building and construction programme. The video data, as well as transcribed interviews, have been analysed with a focus on what aspects (*critical aspects*, cf. Marton, 2015) of how to handle tools as learning content emerge when using dialogue and variation as a didactic model in the teaching interaction. Furthermore, the interviews with the students participating in the video recorded teaching intervention have been analysed with a focus on how the students experienced their learning of how to handle tools in these situations.

4 RESULTS

The results consist of two examples of teaching how to handle tools using dialogue and variation as a didactic model in upper secondary vocational school workshops. The first example derives from the Vehicle and transport programme and the second from the Building and construction programme.

4.1 Example 1: “I thought it was fun to compare”

In the first example, the teaching was about using different tools to tighten a nut properly in a car mechanics workshop at the Vehicle and transport programme. The students were at the end of their first year of upper secondary education, hence they had some experiences of working in the school workshop before. A teacher team consisting of four vocational teachers at the programme planned the teaching together to focus on how hard you should/could tighten the nut when using different tools. The teacher team planned to systematically vary the tools (three different tools were chosen – a spanner, a breaker bar and an impact wrench) as well as vary how hard the students were supposed to tighten the nut (to lose, to hard and as hard as you should to do it right) in order to feel the right way of using the tool(s) in relation to tighten the nut in the preferable way. The pattern of variation was therefore *contrast* in relation to two different aspects of the tools. Hence the students were able to compare different tools and to tighten the nut with varying degrees of force with each tool. At the same time, the teacher, who then conducted the actual teaching, opened up for *dialogue* – and asked the students to express, for example, how it felt when pulling with different tools and to tighten the nut to varying degrees of tightness.

Furthermore, the interviews with the students participating in the video recorded teaching intervention have been analysed with a focus on how they experience their learning in these situations. From the video recorded teaching and the interviews, the following critical aspects regarding the object of learning *using different tools to tighten a nut properly* emerged:

- What tool you use
- The size of the tool/handle length
- How hard you pull/how much power you need to use
- How it feels when you pull hard enough

Below examples from the analysis of two student interviews are presented. S is for student and V is for Vehicle and transport programme.

One of the students expressed:

I thought it was fun to compare; with the impact wrench you hardly need to do anything because it has so much power, and with the breaker bar you barely need to apply force, and on the... what's it called... torque wrench, no, what am I saying, the spanner, you really have to use a lot of force. (S2V)

When the same student was asked how he/she would explain to someone else what is hard about doing these things and what you need to know in order to be able to do it he said:

Well, it's the feeling, I guess. It's kind of... well, it's really bad, I'd say, for me and actually for all my classmates. None of us really have that feeling, right when we first get here. (S2V)

Another student from the same teaching session tells what he/she thought was hard as follows:

Yeah, it's that thing with... what's it called... have I tightened enough or should I tighten more, or have I tightened too much or something like that. (S1V)

One of the experiences, highlighted by one of the students, was that this was a good way of teaching a specific moment, but when it is more about problem-solving, you also need wholeness in teaching.

4.2 Example 2" If you don't experience that feeling, you don't know what it feels like."

The second example is from a wood workshop teaching situation in the Building and construction programme. The teaching was about sawing an OSB board placed on a workbench using a circular saw. Just like in Example 1, the students were at the end of their first year of upper secondary education, and had some experience of working in the school workshop before. The focus of the teaching was to experience different ways of sawing the OSB board and to compare how it felt to do this with different placements of the board on the bench and with different circular saws. Hence, the pattern of variation used in the teaching situation was, as in the first example *contrast*, where the students were encouraged to feel the difference between the different tools and the different positions while sawing. Furthermore, in the teaching situation while performing the task, the students were encouraged to, in *dialogue* with the teacher, express how it felt when using the different saws in relation to placing the board differently when sawing.

From the video recorded teaching and the interviews, the following critical aspects regarding the object of learning *sawing an OSB board placed on a workbench using a circular saw* emerged:

- Which side of the saw the blade is on (right or left side of the motor)

- How deeply you have set the blade on the saw
- How fast you are sawing forward
- How to follow a line (=saw straight)
- How to hold/place the OSB board itself so that it doesn't break
- How it feels when you are sawing with the right speed/in a preferable way

As in the first example above, two interviews with students participating in the video recorded teaching intervention has been analysed with a focus on how they experience their learning in these situations. Examples from the analysis of two student interviews are presented. The students are called S1B and S2B, where B is for Building and construction and I is for interviewer in the transcripts below.

In the first excerpt, the interviewer (I) asks student 1B (S1B) what the student did when he/she was going to saw again:

- S1B: Then I took the other saw, the one with the blade on the left side, because then you can see the blade following the line all the way, and that made it much easier to saw straight. And then, when I had sawed a bit... the whole board a bit, it became more stable, and then I sawed a little more, and then (inaudible) so it stayed still the whole time.
[...]
- I: Did you feel any difference when you saw the second time compared to the first?
- S1B: Yes, it became much easier, it was not at all as slow to saw through then because then there was no weight that made the blade snap.

In this excerpt, the student tells about the experience of how it felt easier the second time, based on what the teacher expected the student to try out. In the next excerpt student 2B (S2B) tells about the benefit of doing in a wrong way (intentionally sawing so that the OSB board broke) in order to know what it felt like when it breaks in an educational purpose:

Yes, but I think that as we did, you have to try making mistakes and feel what it feels like when things go wrong, that it's about to break. Because if you don't experience that feeling you don't know what it feels like and then... yeah. (S2B)

Furthermore, the student tells about what it was like to work with dialogue:

It felt good. I think you learn a lot by yourself when the teacher just asks questions so you can think for yourself and then you come up with your own ideas that make it easier to solve. So, I think it's really good teaching when the teacher doesn't give you the direct answer but you can think a little and come up with your own. (S2B)

Hence, the students saw benefits of learning how to use the tools in the workshop teaching, when teaching was planned using dialogue and variation as a didactic model.

5 DISCUSSION

The results from this study indicate that, when using a didactic model emphasising dialogue and variation in relation to teaching and learning *how to handle tools in a preferable way* in vocational school workshops, students experience that they are given the opportunity to try and experience different ways of working with the tools, in order to find a correct or appropriate way to handle the tools. For example, when learning how to saw an OSB board with a circular saw, students were encouraged to compare how it felt to do this with different placements of the board on the workbench and with different types of circular saws in order to feel (and hear) how it should feel (and sound) when sawing the OSB board in the most preferable way. Moreover, when using (multimodal) dialogue (cf. Abdu et al., 2025), the teacher can get access to the students' displayed understanding of the learning content in the actual performance and adapt the teaching to the student there and then (cf. Asplund & Kilbrink, 2025; Kilbrink et al., 2022). The analysis shows that different aspects of using the tool emerge in the interaction. Those aspects concern both the tools themselves and the context in which they are being used (cf. Asghari et al., 2025). Furthermore, they concern more tacit aspects (cf. Carlgren et al., 2015) concerning how it should feel when using the tool in the right, or preferred ways (the targeted critical feature of how it should feel). Hence, findings indicate that in order for students to learn how to handle tools the right way, one way to go could be to let students get the opportunity to also experience contrast (Marton, 2015); that is how it feels when using tools in wrong ways.

In terms of getting the students to experience the feeling of using tools in the right way, the didactic model based on CAVTA and its use in developing teaching and learning in vocational education (cf. Sjöström, 2023) seems promising. However, more studies are needed focusing on when and how this didactic model can or should be used in relation to different learning contents. One of the student's experiences above indicates that it could be more complex to work like this in relation to teaching that deals with objects of learning concerning problem solving in relation to whole processes (cf. Lo & Chik, 2016), which means that specific learning objects may need to be broken out and focused on in more detail in dialogue and interaction and then linked to larger contexts with the help of other teaching models.

6 AI DISCLOSURE

In this study, GenAI has been used as a supportive tool for translation only.

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Community Involvement as a Resource for Teachers' Professional Practices in Technology Education Projects for Young Learners

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Abstract

Hands-on technology education is regarded as an important aspect in developing wide range of skills among young learners aged 5–8 years. While previous research has emphasized the major role of teachers in supporting learning such skills, less attention has been given to the role of community involvement (CI) as part of teachers' professional practices in technology education (TE). This study examines how involving the local community can support teachers in planning and implementing hands-on TE projects for young learners. The study presents experiences of twelve teachers working in pre-primary education and early primary education and how they describe the role of CI in TE projects. The teachers participated in in-service training on TE and worked with university experts to plan and implement TE projects for young learners. Parents, grandparents, and local services were involved in the projects with different means and in different phases of projects. After the projects, the teachers took part in semi-structured group interviews where they reflected on planning and implementing the projects, participating in in-service training, and the value of CI. The interviews were analyzed using theory-driven content analysis guided by the Multidimensional Adapted Process (MAP) model for teaching. This study focuses specifically on CI as a dimension of professional practices recognized in the MAP model. The findings indicate that teachers valued the participation of parents and other stakeholders, local services, and university experts in the projects. Collaboration with parents, grandparents, museums, libraries, and nearby learning environments were seen as an essential asset for implementing hands-on TE. Collaboration with university experts was beneficial for supporting the integration of technological content. The study suggests that CI has great potential to support TE in early educational settings. Implications for advancing both pre-service and in-service teacher training are discussed.

Key Words: Technology Education Projects, Community Involvement, Teachers' Professional Practices, Young Learners

1 INTRODUCTION

Teachers are increasingly expected to work within rapidly emerging technological and digital learning environments. This ongoing transformation requires growing demands on education for young learners (ages 5–8) to integrate technology effectively. However, teachers in early learning settings often lack competencies in technology education (TE), technology integration, and supporting technological literacy (Casillas Martin et al., 2020; Korkeaniemi et al., 2023). Kewalramani et al. (2025) suggested that young learners' educational settings need more specialized experts on Science, Technology, Engineering, Arts, and Mathematics (STEAM) and TE.

At the same time, the role of parents and other stakeholders is recognized as an important aspect of young learners' development in technological educational settings (Ata-Aktürk & Demircan, 2021; Gonzalez-DeHass et al., 2022). Still, the research on community involvement (CI) has focused on digital learning and investigations in hands-on TE and STEAM context are with lesser focus (Cai & Wong, 2024; Salvatierra & Cabello, 2022). Young learners are recognized to enhance curiosity, creativity, co-operation, and critical thinking in hands-on activities (Perignat & Katz-Buonincontro, 2019; Sundqvist & Nilsson, 2018). Furthermore, young learners are experiencing an important developmental period characterized by curiosity, play, and active exploration (Bers, 2018).

In Finland, TE was introduced nationally in young learners' curriculum (Finnish National Board of Education [FNBE], 2016). Still, in the curriculum, technology is merely integrated in learning of transversal skills, not as an individual content or subject. Thus, Juutinen et al. (2021) evaluated that technological content remains only minimally integrated in Finnish early childhood education and care (ECEC) and preprimary settings. ECEC and pre-primary education provide learning environments that foster curiosity, creativity, and play which together serve as a natural platform for integrating technological content (FNBE, 2016). This study was conducted within the InnoPlay 2018–2022 project, which aimed to address these challenges in young learners' TE (InnoPlay, n.d.). As a key national initiative funded by the Ministry of Education and Culture, InnoPlay strengthened in-service teacher training and promoted technological literacy through hands-on activities. The project employed professional practices – such as CI – that integrated the Finnish subject of craft, design, and technology (CDT) with science, mathematics, and arts through experimentation, play, and creative expression.

This study examines CI as a professional practice to facilitate the integration of hands-on technological content. The study focuses on teachers' experiences of CI when providing TE projects for young learners. The aim of the study is to produce new knowledge of the best practices of CI easing the integration of technology in young learners' educational settings. The study answers to a research question: How do teachers describe the role of CI in TE projects for young learners based on their experiences?

2 LITERATURE REVIEW

Generally, CI refers to communication and collaboration with parents – what Stoll et al. (2006) describe as partnerships that engage parents in the professional community. In this study, CI is defined more broadly to include young learners' parents and grandparents, local services (such as libraries, museums, and nearby outdoor learning environments), and professional community of

university (university teachers and pre-service teachers). Tiippana et al. (2024) investigated teachers applied cross-sectoral collaborative pedagogical practices. Their results indicated three network levels that teachers collaborated with other stakeholders: common city-level, shared school-level, and personal teacher-level. The concept of CI in the current study has similarities with Tiippana et al.'s (2024) view of cross-sectoral collaborative pedagogical practices.

According to Salvatierra and Cabello (2022), parental involvement in young learners' STEAM and TE can promote engagement, enhance the value parents attribute to STEAM, and positively influence learners' outcomes. Research has indicated that practices, such as family involvement, are suggested to enhance young learners' development with technological content but the actual implementation of these practices remain unclear (cf. Abanoz & Kalelioğlu, 2024; Monteiro et al., 2021). Studies indicate that parents influence children's affective, behavioural, and cognitive participation in TE (Cai & Wong, 2024). Parents contribute also to shaping children's interests and self-efficacy which can facilitate their approach and attitudes towards STEAM subjects (Salvatierra & Cabello, 2022). To support this, pedagogical documentation is used to initiate discussions with learners and parents and to plan future learning activities (Yang et al., 2022).

Particularly in TE, teacher's role is to provide a learning environment that boosts learners' engagement. For example, in the teaching of robotics – an activity recognized as important in young learners' technology education (cf. Bers, 2018) – learners tend to become more active, shifting the teacher's role from a leader to a facilitator who supports and scaffolds the learning process (Alimisis, 2018). This shift to facilitator can be extended to involve community. In TE projects described by Rönkkö et al. (2021), parents, grandparents, and older learners were involved in hands-on activities to ensure enough hands-on support for young learners and to highlight cross-age dialogue and collaboration during the projects. Their results indicated that timely scaffolding during the projects was essential (Rönkkö et al., 2021).

In addition to gain factual knowledge of technology, TE increasingly emphasizes transversal skills and knowledge that strengthens technological capability. In this process, hands-on TE is considered essential. Engaging with technological artefacts is considered beneficial for supporting young learners' thinking skills and technological literacy (Sundqvist & Nilsson, 2018). In this process, constructing technological materials serves as what Seymour Papert describes as 'an object-to-think-with' (Papert, 1980, p. 11). According to Ata-Aktürk and Demircan (2021), during the hands-on STEAM, parents help young learners in identifying design problems, brainstorming ideas, and exploring materials.

According to Danielson et al. (2024, p. 48), teachers' responsibility is to support students' learning and development by using resources available in educational settings and beyond these. CI can provide extended learning environments with local services, such as museum and libraries (Sapounidis & Alimisis, 2020; Uppin & Timoštšuk, 2022). Furthermore, approaches that engage out of school partners and learning environment – such as makerspaces – have increasingly been incorporated into TE for young learners (Forbes et al., 2021). Museums for instance are found important opportunities to create meaningful learning activities. They can act as integrated parts of core teaching practice, valued equally to any other instructional activity (Uppin & Timoštšuk, 2022). Teachers' personal factors is recognized as a hindering aspect of CI due initiating partnerships is challenging and causes a heavy workload (Tiippana et al., 2024).

CI includes broader professional collaboration, for example with the university (Kiviranta et al., 2025). This professional learning within a community context emphasizes collective learning

shared meanings, interdependence, and meaningful relationships (Stoll et al., 2006). Havice et al. (2018) argue that in-service training enhances teachers' self-efficacy in teaching technology. University-based in-service training is investigated to be essential for young learners' teachers' competencies in TE (Kewalramani et al., 2025). Pedagogical content knowledge and confidence to integrate technology and STEAM content are found important competencies of teachers (Kewalramani et al., 2025; Korkeaniemi et al., 2025). Research has explored settings involving university experts who offer technical support to help teachers integrate technology more effectively (Nemiro, 2021).

To investigate and develop initial teacher education and teachers' competencies critical for teaching profession, the Multidimensional Adapted Process (MAP) model was developed in national co-operation among seven Finnish universities (Metsäpelto et al., 2021). The MAP model divides teachers' competencies into individual and teaching competencies. Teaching competencies are further divided into three domains: situation specific skills, teaching practices, and professional practices (Metsäpelto et al., 2021). Professional practices cover building relationships with different partners such as parents, and local community members and stakeholders (Stoll et al., 2006). According to Danielson et al. (2024, p. 40), effective teachers plan and prepare teaching by using instructional materials and other resources to support students' intellectual engagement. The current study focuses explicitly on the role of CI as a professional practice that can offer additional resources to ease the implementation of TE projects for young learners.

3 METHODOLOGY

This study employed a phenomenological approach to investigate teachers' experiences of providing TE projects with young learners (Spencer et al., 2020). In a phenomenological approach, the social and cultural situatedness of interaction is recognized important, aligning with the ethos of CI (Cohen et al., 2018, p. 20). A total of 12 teachers of young learners reflected on their experiences in semi-structured interviews of conducting TE projects and participating in in-service training focused on TE. In in-service training, the teachers practiced basic skills of TE. The participants were ECEC teachers ($n = 6$), heads of ECEC centers ($n = 3$), early primary class teachers ($n = 2$), and one principal, who also served as head of a local education and culture department. One ECEC teacher had childcare training but was working as a teacher.

Data were collected at the end of the InnoPlay project through six interviews: four with ECEC personnel (ECEC centers) and two with personnel in early primary education (schools). In total, eight hours of video data were collected. Although, an interview guide was used, space was intentionally left for open and unstructured reflection to capture authentic experiences (Prior, 2020, p. 363). Interview themes included:

- (i) support received from the InnoPlay project,
- (ii) implementation of TE projects with young learners, and
- (iii) in-service training in TE.

Elements of CI were integrated across all themes in line with the InnoPlay project. Interviews were transcribed and analysed using qualitative content analysis (Prior, 2020), applying the MAP model as the coding manual (Metsäpelto et al., 2021). The data is part of the broader research and the MAP model is introduced more in detail in earlier study (Korkeaniemi et al., 2025).

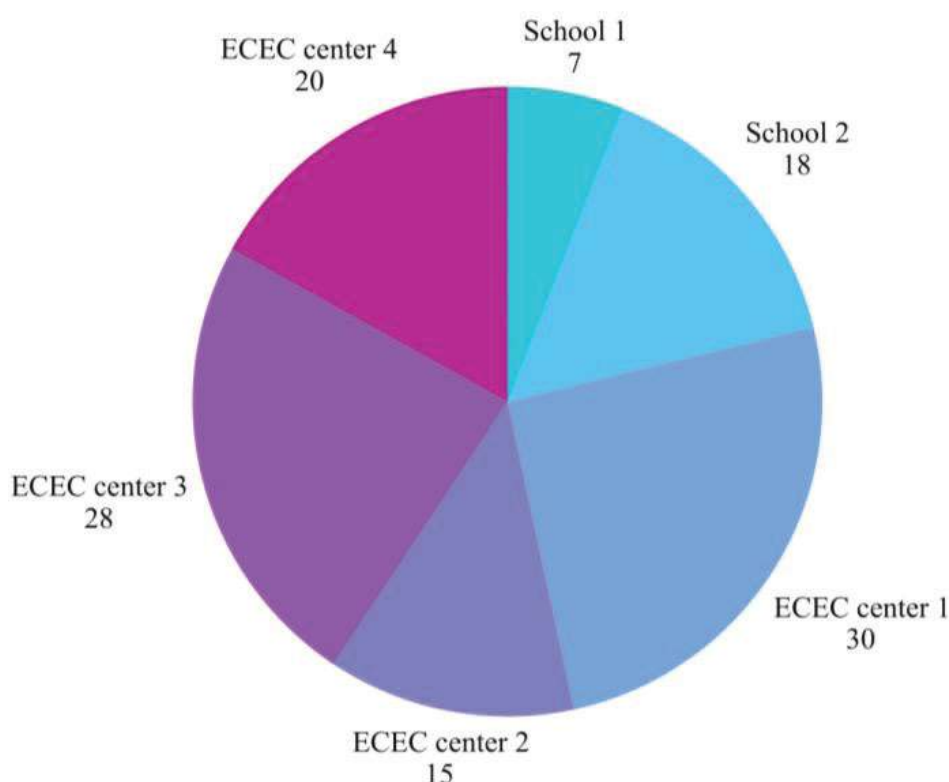
A total of 827 units of analysis representing teachers' reflections were coded using NVivo 12 (Korkeaniemi et al., 2025). Units were categorized into subcategories of teacher competence based on the theoretical framework. CI was implemented in 118 units. To ensure reliability, two researchers conducted the analysis collaboratively, discussing interpretations throughout the coding process. After coding, all subcategories were reviewed, and minor reallocations of units were made to ensure alignment with the coding manual. Generative artificial intelligence was only used as a supportive tool for proofreading individual sentences in this study.

4 RESULTS

Teachers conducted different hands-on CDT and TE projects with young learners, such as movie making projects with educational robotics, making hobbyhorses, and making their own totem animals. CI as professional practice was reflected in all of the interviews as indicated in Figure 1.

Figure 1

*Teachers' reflections of CI as a professional practice when providing TE to young learners.
Total units of analysis $n = 118$*



Teachers reflected in involving community, such as families, local services and other stakeholders, into TE projects. Also, co-operation with the university was reflected. Involving parents to the TE projects was mostly reflected from the point of the pedagogical documentation. For example, projects where young learners made movies 'where shown to the parents and grandparents on a movie night' (Yasmin & Yvonne, School 1; Katherine, School 2) and 'to the local retired people' (Kimberly, ECEC center 1). At the one ECEC center, an exhibition was organized at the center after the project:

Noelle: At the end of the project where we made the totem figures, we invited parents and grandparents.

Nellie: Yes, indeed!

Noelle: We organized an exhibition. There was a good attendance! (ECEC center 2)

For pedagogical documentation shared with parents, teachers used various communication channels, such as social media: 'writing blog and Instagram posts' (Veronica, ECEC center 3) and digital applications: 'Padlet and Wilma [Wilma is a widely used tool for home-school communication in Finnish education]' (Kodi, ECEC center 1).

Activating families in different ways was reflected by the teachers. Teachers encouraged families for example to pay a visit at their 'art exhibition build on the ECEC center's windows' (Veronica, ECEC center 3) and planned to 'build water wheels at the local beck and give a hint to the families to go and see them' (Katherine, School 2). For example, young learners made hobbyhorses that were used in an ECEC center's ceremony. In the hobbyhorse project also young learners' custodians participated in the planning of the products:

Crystal: We used them [the hobbyhorses] at the spring ceremony.

Interviewer: Did the parents participate in the ceremony?

Crystal: Yes, a great amount of them! We could say that almost everyone's parent. And if the parent couldn't make it, then someone else from the inner circle.

Interviewer: That's magnificent!

Crystal: We have this communality and it's incredible! (Crystal, ECEC center 4)

Community was involved also for acquisition of materials. Teachers gave instructions for families to bring different materials from their homes (Crystal, ECEC center 4; Kodi, ECEC center 1). Also, families' special know-how was emphasized. For example, one teacher reflected that when they had parental info, they found out about 'parents' ideas and if anyone has an occupation that could be beneficial for the technology projects' (Nellie, ECEC center 2). One young learners' father 'was working on construction brand so he brought ready sawed pieces of wood' (Veronica, ECEC center 3).

The iterative aspect throughout the teachers' experiences was lack of personnel which was seen problematic for running the TE projects. To ease this, teachers reflected the role of grandparents and local pensioners, as well as the role of pre-service teachers and university teachers, helping during the projects. Teachers reflected that involving local pensioners, some of whom were young learners' grandparents, to projects was positive experience:

'We had these pensioners who were helping their eyes bright! It was fantastic moment!' (Kodi, ECEC center 1)

‘It was nice to see different generations working together. Others [young learners] have grandparents far away, and others may not have them at all. For both generations it was great to be involved. These pensioners have all kinds of different crafts skills, and they can pass them to younger generation, to help them.’ (Kimberly, ECEC center 1)

Local services, such as ‘libraries’ (Crystal, ECEC center 4) and ‘museums’ (Noelle, ECEC center 2) were involved in the projects. Teachers reflected that involving pre-service teachers more in to the projects would be beneficial: ‘it would be great that pre-service teachers come here at ECEC center and do these projects with young learners’ (Kodi, ECEC center 1) and ‘for not just one day but multiply times’ (Nellie, ECEC center 2). Also, university teachers’ involvement and guidance were reflected as important parts of the projects. For example, one teacher reflected her frustration about the technology projects and how university teacher’s support helped her:

‘Well, I was like what I was going to do? I know nothing about this. Then he [university teacher] ‘pushed me of the edge to the deep sea’ and said, ‘Do the movies because you just said that the children want to do movies!’ I was like okay!’ (Katherine, School 2)

Such seeking confirmation and support for the university teachers was recognized also in other teachers’ experiences (Vicky & Veronica, ECEC center 3; Kodi, ECEC center 1). Teachers reflected the in-service training and importance of ‘including the training and projects as part of the normal weekday’ (Katherine, School 2). More training in the field was hoped also from other teachers (Yasmin & Yvonne, School 1; Nellie, ECEC center 2).

5 DISCUSSION

This study focused on teachers’ experiences of providing TE projects for young learners and the role of CI in these projects. Teachers’ descriptions indicated that practices of CI were mainly understood as parental involvement. Although, the findings indicated that the extension to involve also other stakeholders were recognized. Teachers reflected in involving families, grandparents, local services, and university partners in TE projects, primarily through shared events, material contributions, and pedagogical documentation. Teachers emphasized the value of cross-generational support and university guidance, especially when their competencies or sense of capability were limited. Teachers expressed a need for more practice-based in-service training happening on-site in their working places.

The current study suggests extending the view of CI by highlighting the relevance of collaboration with local services and universities across different phases of TE projects. Overall, based on the findings of the current study, CI can be understood as an ongoing process through which the community may be integrated into TE projects across three phases:

- planning and preparing of the projects
- implementation of the projects, and
- evaluation and exhibition of the projects

Different phases and roles of the community in these phases are illustrated in Figure 2. These roles are derived from the aspects that teachers emphasized when describing CI within their TE projects.

Figure 2

Phases and roles of CI in young learners TE projects

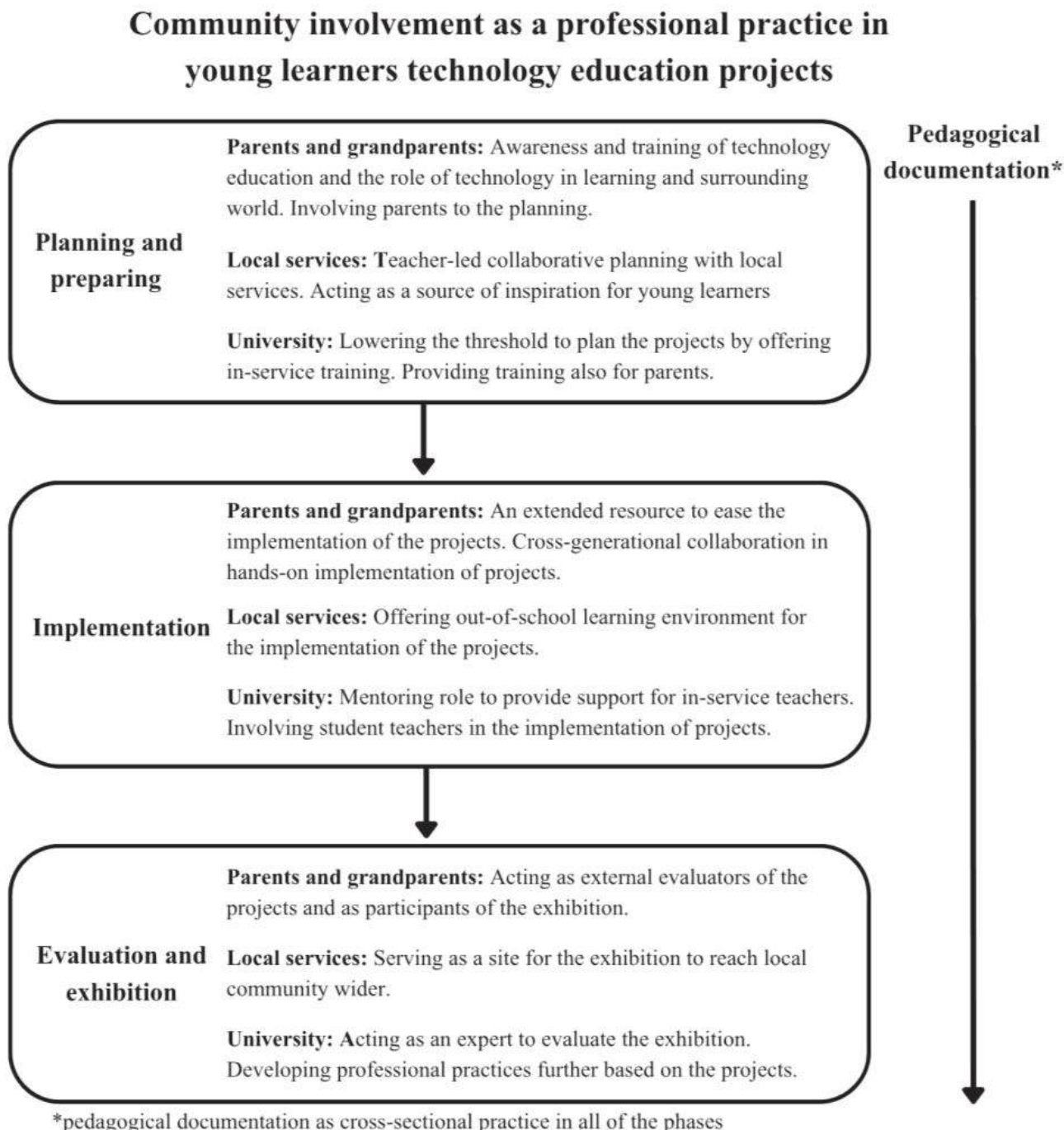


Figure 2 suggests best practices for involving the community in the implementation of TE projects. As teachers described, CI is seen as a collaborative approach that can add value both to the teaching and learning of young learners in TE and to the local community. Nevertheless, significant barriers and obstacles remain in implementing CI practices. First, the teachers' active role and initiative to involve community is essential. Second, the commitment of parents needs to be in focus. Third, the university needs to be in a key role connecting stakeholders of formal and informal learning environments.

Teachers' descriptions of CI indicated that there are plenty of benefits when involving community, such as cross-generational collaboration and making TE projects more implicit to the community. Still, it seems that the teachers' lack skills and means to involve community or CI is emphasized through only personal factors. For example, from the teachers' interviewed only Kodi were able to describe CI beyond involving parents only. This raises the question of how prepared teachers actually are to implement CI in TE projects and how do they conceptualize and understand CI as a professional practice. These aspects were not in focus in the current study but future investigations are needed to have an insight of teacher preparedness. The current study suggest that CI should be emphasized already in pre-service teacher training as an effective professional practice. With this emphasis, future teachers' initiative in CI practices can be supported and become natural part of their professional practices that may also strengthen the commitment of local services and parents. The emphasis of CI targeted especially in TE in pre-service teacher training needs further investigations in the future.

To increase CI, in-service training should highlight the inclusion of parents and other stakeholders. The process should start from the introduction of the TE projects and educating parents to increase awareness of technological content as suggested earlier (Fernández-Samacá et al., 2017; Tippet & Milford, 2017). By raising parents' awareness of the technological content, their interests can be aligned with the activities and implementation of the projects. This allows the nurturing of social aspects, such as positive emotional support from parents and collaborative engagement in hands-on TE projects, which can enhance young learners' participation (Ata-Aktürk & Demircan, 2021). The current study suggests, that aspects, such as awareness of technological content and parents' role in supporting engagement with technology are essential to be recognized in both pre-service and in-service training of teachers.

To ease the integration of technological content, CI can foremost be seen as an extended resource. According to Tippet and Milford (2017), after research-based intervention on hands-on STEM activities, teachers were aware of the resources available for them rather than considering them as a limiting factor. Tiippana et al. (2024) recognized that organizational structures of Finnish schools do not provide sufficient support for teachers to extend their out-of-school collaborations. Thus, university as an institution aiming for pedagogical innovations and development has a role of gatekeeper in this process. University should act as a 'custodian' for regional ECEC centers and schools by offering in-service training and low threshold opportunities to involve community in TE projects as illustrated in Figure 2. With this in-service training teachers' personal factors that hinder the CI – effort and time beyond teaching hours, as well as arrangements and skills of networking – can be supported (cf. Tiippana et al., 2024).

In addition, involvement of local services should be highlighted already in pre-service teacher training. According to Uppin and Timoštšuk (2022), in museum-based out-of-school learning, most teachers did not maintain regular contact with museum educators before the visits. When the museum staff worked with the learners, the teachers felt they had limited influence over the

activities. From CI perspective, this highlights the importance of teacher-led co-operative planning with local services, which is recommended as a good practice for strengthening TE projects. Rönkkö et al. (2021) emphasized that in TE projects involving the community, teachers remain responsible for meeting the projects objectives, which requires careful planning and preparation. Thus, the nature of CI as an ongoing process that needs to be maintained and constantly developed, is essential

To investigate the phenomenon of CI in TE, only a part of the broader dataset was analyzed (cf. Korkeaniemi et al., 2025) in the current study, which limits the generalizability of the findings. Nevertheless, the study highlights the potential of CI as a professional practice that supports TE projects. To have an expanded view of the best practices of CI, more empirical research of implementing CI in TE projects and applying the phases and roles illustrated in Figure 2, are needed. Also, more investigations are needed of the efficiency of teacher training emphasizing CI especially targeted in young learners' TE.

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Inspiring Youth to Programming Through Engagement with Space Technology

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Abstract

This paper describes a study of the effect that participating in the coding challenge Astro Pi has on children's interest and motivation for science and technology, as perceived by their teachers. The European Space Agency (ESA) offers children and young adults the opportunity to run their computer codes on specially designed raspberry pi computers aboard the International Space Station (ISS). This ESA-project, called Astro Pi, allows the participants to learn and practice python programming while also engaging with space and space technology. In addition to developing programming skills, the Astro Pi project studied here also includes elements of art, as the task is to create a piece of pixel art to be displayed for the astronauts at the ISS. As part of an interdisciplinary, authentic learning project general skills such as teamwork, communication and problem solving are practiced. Since both the authentic learning approach and space as a subject have been shown to contribute to increased motivation among pupils, Astro Pi has great potential to increase pupil interest in STEAM. In order to evaluate the effect on pupil interest and motivation of participating in this program a series of interviews was conducted among teachers who had participated in the Astro Pi challenge. Our main findings were that Astro Pi engages most pupils, and teachers especially mentioned the girls' interest. The fact that it is 'real' and about space provides initial motivation to get started, but for most pupils, the task itself becomes motivating. It was also a learning process for the teachers themselves. Challenges they pointed out were that the project required more time than recommended and that especially the younger pupils lacked general computer skills. They also saw the possibility to make a shorter and more structured guide for the pupils to use.

Key Words: Programming, STEAM, Space Technology, Authentic Learning

1 BACKGROUND

Space as a subject (Rymdstyrelsen, 2024; Sjöberg & Schreiner, 2010; Westman et al, 2025) as well as the authentic learning approach (Herrington & Herrington, 2006) have been shown to contribute to increased motivation among pupils. The ROSE-project (Schreiner & Sjöberg, 2019; Sjöberg & Schreiner, 2010; Sjöberg & Schreiner, 2019; Westman et al, 2025) found that among

15-year old pupils, both girls and boys found space fascinating and expressed a desire to learn more about astronomical phenomena. Our own experience from space outreach indicates that this fascination for space is shared by children and youth of all ages, as well as adults. In this study the focus is on 10-year old pupils involved in a space-related programming project.

In authentic learning situations pupils engage in learning tasks that closely mirror the real-world situations, challenges, and practices they will encounter outside the classroom. Instead of abstract or isolated exercises, pupils work with meaningful problems, real data, collaborative processes, and practical tools that have relevance beyond school (Engström & Lennholm, 2025; Herrington & Herrington, 2006).

Since space is a subject that captivates many young people, it often arouses strong intrinsic motivation, i.e. doing something that they find enjoyable in itself (Ryan & Deci, 2020). At the same time, knowing that the work will produce real results that others value can foster extrinsic motivation (Ryan & Deci, 2020). The novelty and context of such activities may also ignite situational interest (Krapp, Hidi & Renninger, 1992; Schrew & Lehman, 2001). Collectively, heightened interest and motivation can foster both behavioural engagement—manifested through participation and effort—and emotional engagement, reflected in pupils’ feelings of interest, enjoyment, and belonging (Fredricks, Blumenfeld & Paris, 2004).

1.1 *Astro Pi*

ESERO (European Space Education Resource Office) is the European Space Agency's (ESA) initiative to increase interest and knowledge in STEM subjects (science, technology, engineering and mathematics) among children and young people, using space as an inspiring context. There are national offices, such as ESERO Sweden¹, in most ESA member states, offering teacher training and school activities for K-12 pupils.

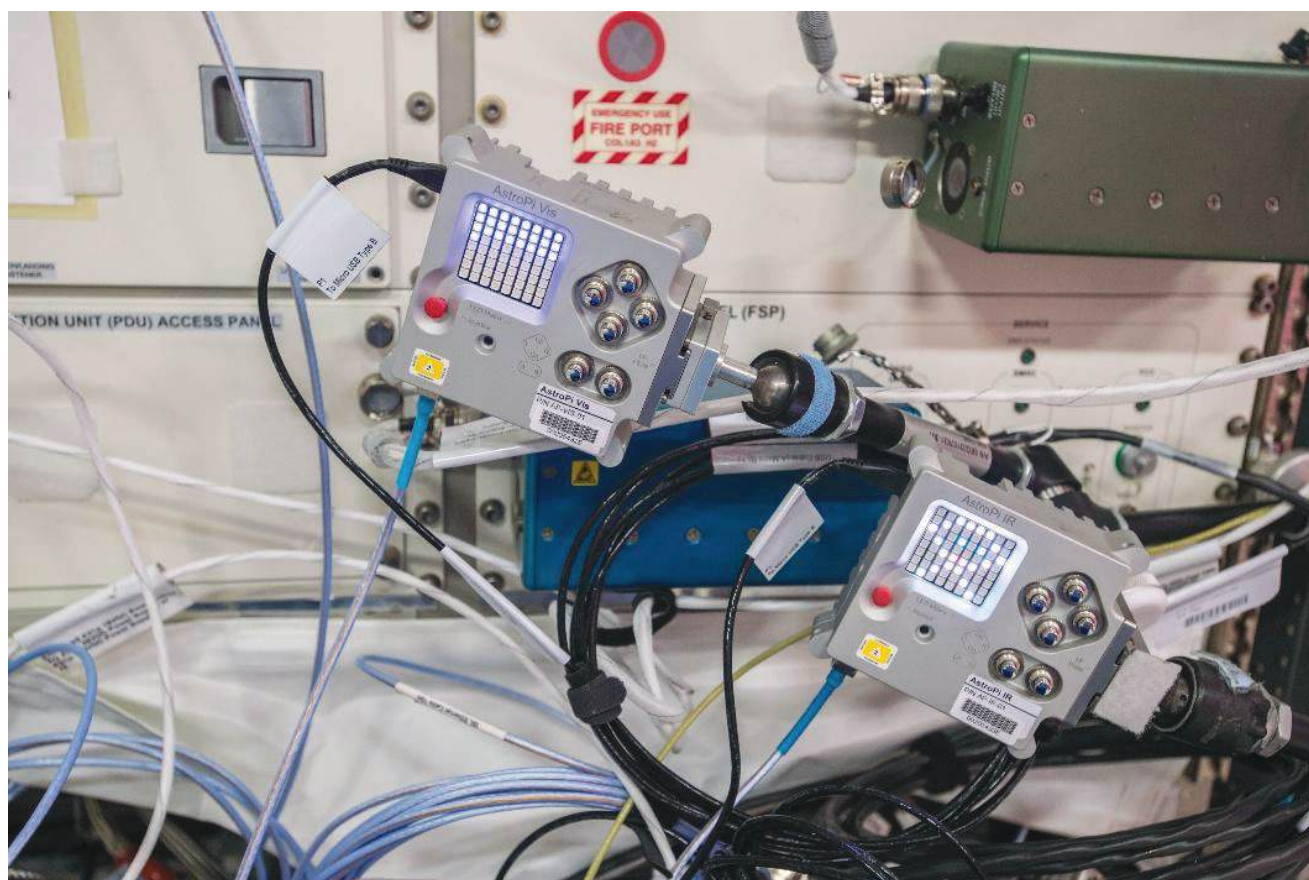
Astro Pi is one of the five school projects run by ESERO². It is an educational project created by ESA in collaboration with the Raspberry Pi Foundation. It gives children and young people up to the age of 19 the opportunity to write computer programs that will be run on the International Space Station (ISS). Participation in the project is free of charge and its aim is to inspire the next generation of scientists, engineers and programmers by enabling them to work with authentic space data and conduct real experiments in a unique environment. Pupils can work with Python programming and sensor data from dedicated Raspberry Pi computers, called Astro Pi, in the classroom or in their free time. Two Astro Pi:s are installed on the ISS (Figure 1). These computers are equipped with various sensors as well as an 8×8 LED matrix that can display text or images, and the hardware is mounted in a specially designed, space-safe enclosure. Astro Pi computers were first installed in the ISS by astronaut Tim Peake in 2015, and have since been used by pupils worldwide to conduct scientific experiments in microgravity.

¹ <https://www.esero.se/>

² <https://astro-pi.org/>

Figure 1

The Astro Pi module on the ISS. Image credit: ESA



One part of the Astro Pi project, Mission Zero³ is aimed at pupils with little or no programming experience and is possible to complete in one lesson. In this study we investigate the effect working on this project has on the interest and motivation of pupils in grade 4-6, as perceived by their teachers. In this task, pupils write a short Python programme to create a simple image or pixel graphic, where the colour sensor on the Astro Pi computer is used to set the colour of the image background depending on the ambient lighting. The image is then displayed on the Astro Pi unit at the space station for the astronauts to view, with the image colour changing depending on e.g. the colour of the astronaut's clothes, thus creating a personalized image. Examples of images created by pupils are shown in Figure 2. This task is completed entirely online via a web emulator, so no special hardware is required. All entries that follow the guidelines are guaranteed to run on the ISS, and participants receive a certificate showing the location of the space station when their programme was executed. Mission Zero is therefore ideal for beginners and primary school pupils. The theme for Mission Zero varies from year to year. For the 2025/26 challenge the requirement is that the image should be inspired by nature, on Earth or beyond.

³ <https://www.esero.se/skolprojekt/astro-pi/>

Figure 2

Examples of images that can be shown on the 8x8 pixel screen on the Astro Pi. Each of these 8 examples represent one representation of nature on Earth or beyond, as interpreted by participating pupils – e.g. a tree in the top right corner, or a penguin in the middle of the bottom row. Image credit: ESA and Raspberry Pi Foundation



In summary, Astro Pi acts as a powerful bridge between school education and space technology. By enabling young programmers to write code that is executed in space, the project fosters a strong commitment to STEM subjects and provides pupils with a tangible experience of how science, technology, and creative problem-solving converge.

1.2 Aim and research questions

The aim of the study is to investigate teachers' perceptions of how pupils' interest and motivation are influenced by space and authentic learning.

The following research questions have been investigated:

How does participating in Astro Pi affect pupils' interest and motivation, as perceived by their teachers?

Which benefits and challenges do teachers see in participating in the project?

2 METHODOLOGY

Interviews were conducted with three teachers who have worked with Astro Pi with their pupils, in grade 4 to 6 in two schools in Sweden. In the following the teachers will be referred to as T1 (Teacher 1), T2 (Teacher 2), and T3 (Teacher 3). The grade and subjects they taught and implemented the project in are summarised in Table 1. All of the teachers had 1 year experience of working with their pupils on Astro Pi.

Qualitative, semi-structured interviews were conducted with the teachers. An interview guide was constructed based on the research questions with initial categories to be discussed. The interviews were recorded, transcribed and analysed. The interviews took about 30 minutes, and the questions asked concerned the teacher's background and previous experience of the project, the pupils' interest and motivation as perceived by the teacher, and the teacher's thoughts about the project and its possibilities and challenges. Based on the teachers' answers additional categories were added in the analysis.

In this paper generative AI has been used for translation and grammar improvement.

Table 1

Summary of the teachers interviewed, which grade they taught and which subjects they implemented the project in

Teacher	Grade	Subjects
Teacher 1 (T1)	Grade 6	technology, mathematics and physics
Teacher 2 (T2)	Grade 5	mathematics
Teacher 3 (T3)	Grade 4	natural science, technology

3 RESULTS

3.1 *How teachers work with Astro Pi in the classroom*

The teachers worked with Astro Pi during several lessons and in different subjects. T1 included Astro Pi as part of mathematics, technology and physics, as programming is part of the Swedish curriculum in mathematics and technology, while space is part of the physics curriculum. T2 only included it in mathematics, while T3 included it in science and technology. The teachers also discussed the possibility to make Astro Pi part of other subjects such as Art and English, as well as an interdisciplinary approach.

T1 used it as an extra task in the classroom which the pupils could do when they had time over. The reason was initially that it took longer than expected. Then the pupils were inspired by each other and wanted to continue working on it to do more advanced codes.

We had it as an extra assignment, sort of, because they really liked it and it took a lot longer than I thought it would. (T1)

Then there were very many who wanted to redo theirs when they got inspiration from each other. [...] you could put them in kind of like a motion, sort of putting several images after each other. Then it was kind of like, yes, “I want to redo mine”, and then they redid theirs [...] I kind of wanted to let it happen. (T1)

T3 chose to initially do the programming as a joint task, with the teacher showing all steps on the projector and the pupils repeating the exact same steps on their computers. T3 found that this step was essential, as many of the pupils had little or no previous experience of using computers, and therefore needed to practice basic tasks like cut and paste.

Yes, basically they don't know how to turn on a computer when they get to grade four, so the conditions there are not good. (T3)

All three teachers noted that one lesson was not sufficient. In all cases the project took several weeks, and was included in various ways in the lessons.

We used it over a longer period, but not as intensively [...] perhaps over a five-week period. But not every lesson. (T1)

We didn't work for one 40-minute lesson, but rather for about 1.5 weeks. (T2)

Yes, but it took almost a couple of weeks [...] because we did a lot of it together. (T3)

3.2 *The pupils' perception of working with Astro Pi, as seen by the teachers*

The teachers noted that the pupils appeared to enjoy working with Astro Pi, as many pupils did more advanced work than they needed to. The pupils kept asking if they would be working with Astro Pi, and several also wanted to continue working on their projects at home.

[the pupils said] “oh, please, can we work with pi today? Can we work with astro pi today?” (T2)

When they ask “can I continue working at home?” Yes absolutely, do that. (T2)

Well, they were looking forward to these opportunities, they did. So it was fun. (T3)

The pupils' behavioural and emotional engagement could also be seen from the way the pupils interacted with each other during their work with Astro Pi, and the fact that most pupils wanted to continue working and solve problems instead of giving up. This engagement indicates both intrinsic motivation and a situational interest formed by the activity.

It was through their interaction with each other that one could see that this was something fun and interesting and something new. (T1)

But, I think it becomes very obvious through the interest in sitting and working, the commitment. If you don't think it is fun, you don't do it. And I also noticed that the ones who really were committed, they tried to solve the problems themselves. (T2)

T1 noticed that one pupil who had never been interested in anything in school, suddenly wanted to keep working and asked for more advanced examples to work on at home.

And then there was one boy who stuck out because he had never really. He was never interested in anything really in school at all, neither reading, math, sports, nothing was kind of his thing, but this was something he really got into. So his father contacted me and asked if there were more similar examples that he could work on at home. That was really fun.” (T1)

Two of the teachers pointed out that the girls especially enjoyed working with the project.

Many of them had their eyes opened to that [that wasn't so hard], especially the girls. (T1)

There was a girl who made a dinosaur egg that hatched and became larger and then it became a big dinosaur and then there was someone who made a flower that kind of grew so they made up their own as well. Not only the codes that were kind of in that program, so that was really fun. (T1)

So that the ones that were most skilful, that was the girls. (T2)

Even though most pupils were motivated, there were some who became frustrated and gave up. The teachers noted that these pupils could still contribute by sitting together with other pupils and taking part in their work.

For many, it was really difficult, because it was this particular text programming. Many pupils have difficulty with [patience]; it has to be done immediately. (T3)

[Some pupils] have this drive to say, 'No, it's not right. No, I'll try again.' While others give up. 'No, I'm not going to do anything more today. I give up'. (T3)

I had pupils who from lesson to lesson had no idea why they were there or what they were supposed to do. So this also meant that some pupils submitted while others did not. (T2)

T1 commented that many of the pupils realized that programming was not as hard as they had thought. T2 mentioned the pupils' understanding of programming and what you can do with a code. The task made it very clear, not so abstract, for the pupils.

I think that many had their eyes opened to the fact that it wasn't so hard. (T1)

A very good way to kind of get an understanding of how programming works, that is, what they actually have to do. (T2)

3.3 *Authenticity and space to inspire and motivate*

T1 pointed out that the pupils liked the idea that the project involved space as a subject and was connected to something real, and that their work had a recipient. Those facts captured their interest but it was the process of programming that drove their work and kept their interest alive. This indicates that the external motivation offered by the task and the connection to space was initially important but once they got started it turned into internal motivation that helped them continue working.

Yes, I think that space is exciting for many children. [...] But also that it was something that was connected to something real, that it was a space station that would get this code. There was a recipient, an authentic recipient and that was something that I think many found exciting to begin with. It aroused their interest so to speak, but it was the coding itself and the process itself to see what and how one could do different things. (T1)

T3 noted that the fact that the code would be sent to the space station was inspiring for the pupils. It was also seen to be important to get feedback in the form of a certificate, which confirmed that it was “for real”. T3 introduced the project by referring to and talking about the Swedish astronaut Marcus Wandt and his journey to the ISS that had taken place earlier that year. This made the pupils interested and gave them an initial external motivation as they understood the context in which their codes would be run.

Just this that they knew that it was going to be sent up to space, that was something that I thought they became kind of motivated by. I thought so, so I think that was important for them and then also just to get this response, to get this certificate back. (T3)

In the classroom of T2 the pupils didn’t really believe that their codes would be sent to and run on the ISS. They thought the teacher was joking. Not all of T2’s pupils finished and submitted their code. But at the end of the term when the certificates were sent out, those pupils not submitting their code were very disappointed. The comfort from the teacher was that they would get to do the project again next year.

When they realized that “Oh, but mine then?” No, but you didn’t finish, do you remember that? You didn’t complete yours. “Yeah, right” like this. But I said I think we will do it again. Yes, but “yes yes, we want to do that”. (T2)

Here we can see how the lack of external motivation, through the pupils’ disbelief, contributed to an absence of situational interest and internal motivation, leading to not completing the projects.

3.4 *Teachers' experiences – opportunities and challenges*

The teachers enjoyed the Astro Pi tasks and also learned a lot for themselves working with it, so that it became a sort of teacher training as well.

So, because I had a lot of fun with that too. I also made my own pictures with bats flapping their wings and blinking their eyes and gaping so it's like that. It was really fun. (T2)

The teachers also saw a number of challenges. The major challenge for the teachers doing the project for the first time, was their lack of experience in coding. It took a lot of time for them to prepare for the lessons. It also made it difficult for them to help the pupils during the lessons.

The teachers had a number of strategies in order to deal with these challenges. For example, the teachers saw the potential in collaborating with other teachers to share experiences and lesson plans. Also, they let the pupils help each other

T1 also pointed out the importance in accepting that you are not in full control and allowing the pupils to be the experts.

I think you have to let go of quite a lot as a teacher in that you have full control over it. (T1)

T3, who had the youngest group of pupils, noted that the lack of programming experience was a challenge for the pupils, and that this affected the way the teaching situations had to be designed. Even though they had some experience of block coding it was a big step to do text programming. The process of debugging and finding errors required patience which was harder for the younger pupils.

I think they should actually have some programming experience. (T3)

[The instructions say] that you should be able to [do the project] at earlier ages too, but I am not sure. I probably wouldn't, fourth grade was on the limit there, or so I thought anyway, and this thing about having computer skills... (T3)

4 DISCUSSION

All three teachers found Astro Pi engaging for most pupils. They noted behavioural engagement through pupils taking on tasks beyond requirements, collaborating with peers, and asking to continue working. The case of the previously disengaged boy who requested extra tasks at home illustrates Astro Pi's potential to give an external motivation that sparks interest and motivates learning. T1 and T2 also observed that the project particularly motivated girls, suggesting it supports diversity and inclusion in STEM.

The connection to space was shown to be important both as an initial external motivator for the pupils and as a confirmation that the project was based in reality. All teachers introduced the project by talking about space and the ISS, and that the code should be sent to ISS where it would be run by the astronauts. The pupils of T2 didn't really believe the teacher, resulting in disappointment when those that had not submitted their code didn't get a certificate. This became an extra external motivation for participating in the project again.

According to Herrington & Herrington (2006) collaboration is an essential part of authentic learning scenarios. The teachers in this study all emphasized the fact that working with Astro Pi allowed the pupils to collaborate on their projects and that after a while they started to spontaneously help each other and work together. This is likely to have enhanced the authenticity of the learning experience and contributed to the inspirational aspect of the project.

The teachers saw some different challenges as they had pupils of different ages and computer skills. All of them needed several lessons to complete the task for the pupils to really get a chance to work with and develop their codes. They all described that it was a learning process also for themselves and that they saw the potential in working together with other teachers to support each other and discuss different coding strategies and challenges. They also expressed that as a teacher you had to let go of the control, daring not to be the expert, as also pointed out by Engström & Lennholm, 2025. T1 and T2 discussed the value of working together with other teachers, to support each other and complement each other's skills.

Although this was a small study with only three teachers, the experience of the interviewed teachers shows that authentic projects with a connection to space, like Astro Pi, have a great potential for increasing both learning and interest among middle school pupils. To better understand the capabilities of Astro Pi and similar projects for stimulating pupils' interest, more interviews with teachers at different stages should be carried out, as well as observations and interviews with pupils.

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Redefining Technology in Rural STEM: School Leaders' Perspectives on AI

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Abstract

The rapid integration of Artificial Intelligence (AI) into primary and secondary education necessitates a re-evaluation of Technology Education, specifically how the Technology component within STEM is conceptualized and led in schools. While AI offers transformative potential, its integration in rural contexts faces unique boundaries ranging from infrastructure deficits to pedagogical gaps. In rural Pingtung County, Taiwan, this integration faces unique challenges, including infrastructure deficits and pedagogical gaps.

This study shifts focus from classroom practitioners to the strategic gatekeepers of curriculum innovation, school principals. It investigates how rural school leaders perceive AI not merely as a tool but as a core knowledge area within modern Technology Education and assesses their readiness to lead this transformation. This study employs a convergent mixed-methods design involving six school principals. Qualitative data from focus group interviews were analyzed using deductive thematic analysis supported by AI-assisted coding, while quantitative data from the Intelligent TPACK survey provided a triangulation profile.

The findings reveal that rural principals conceptualize Technology in STEM through three key dimensions: evaluative literacy, AI-enabled praxis, and ethical stewardship. Rather than emphasizing technical proficiency, leaders prioritized the ability to verify AI outputs using disciplinary knowledge. Furthermore, AI was viewed as a boundary spanner capable of mitigating rural resource deficits by acting as a virtual colleague for isolated teachers.

However, ethical concerns regarding the digital parenting void and the preservation of human-centric social-emotional learning dominated the leadership discourse. The study contributes to the field by defining a leadership-centric model of Intelligent TPACK, suggesting that for rural principals, effective technology leadership is less about operational fluency and more about critical evaluation and ethical responsibility.

Key Words: Technology Education, AI in STEM, Intelligent-TPACK, Rural School Leadership, Mixed-Methods

1 INTRODUCTION

The rapid integration of Artificial Intelligence (AI) into primary and secondary education (ages 6-18) STEM education represents a paradigm shift, positioning AI as a fundamental literacy for the 21st-century workforce (Ng et al., 2023). Consequently, international bodies advocate including competencies ranging from algorithmic logic to ethical reasoning in national curricula (Miao & Shiohira, 2022; UNESCO, 2024). While AI offers transformative potential enabling personalized learning and automated feedback (Xu & Ouyang, 2022), these advancements demand a corresponding evolution in the professional knowledge of educators and, crucially, school leaders.

Despite global momentum, AI-enhanced STEM education remains uneven as rural schools face unique ecological constraints, including geographical isolation and infrastructure deficits (Khan et al., 2019). While urban centers rapidly pilot AI initiatives, rural contexts risk marginalization unless integration adapts to specific socio-cultural realities. Since rural teachers' adoption of technology is contingent on environmental factors (Wu et al., 2022), uniform approaches often fail to address rural needs (Kim & Wargo, 2025; López Costa, 2025), particularly in contexts where infrastructure limitations, uneven resource distribution, and teacher capacity constraints shape technology adoption.

Research on AI in STEM has predominantly focused on classroom practitioners and Technological Pedagogical Content Knowledge (TPACK; Chai, 2019), with comparatively less attention given to the role of school leadership in AI integration (Kim & Wargo, 2025; López Costa, 2025). In rural settings where principals serve as primary instructional leaders, understanding their perceptions of AI as a subject matter is essential for sustainable reform. Assessing leadership readiness requires a modernized framework. While the foundational TPACK framework (Mishra & Koehler, 2006) remains relevant as a model for understanding how teachers integrate technological, pedagogical, and content knowledge in instructional practice, it was originally developed in the context of traditional digital tools. The unique generative affordances of AI, however, demand an expanded lens. Celik (2023) proposed the Intelligent TPACK framework, arguing that effective integration requires specific knowledge regarding the ethical, pedagogical, and technical dimensions of intelligent systems.

Addressing the research gap on rural leadership in high-tech environments, this study shifts the analytical focus from classroom practice to leadership cognition by exploring how rural school principals conceptualize AI integration in STEM through the lens of Intelligent TPACK. By investigating perspectives on the technical, pedagogical, and ethical dimensions of AI, this study aims to identify specific leadership competencies required to foster equitable, sustainable STEM education in under-resourced rural contexts.

2 LITERATURE REVIEW

2.1 *AI Integration in STEM Education: Paradigms and Tools*

The intersection of AI and STEM education has evolved from experimental applications to a central component of modern pedagogy. The current literature increasingly suggests that AI serves a dual role in STEM education: as a pedagogical tool to enhance learning efficiency and as a subject matter essential to fostering AI literacy (Ng et al., 2023; Su et al., 2024; Zawacki-Richter et al., 2024). In terms of application, a systematic review by Xu and Ouyang (2022) identified key categories of AI technologies in education, including intelligent tutoring systems (ITS), educational robotics, and learning prediction models. These tools facilitate the shift from traditional, lecture-based instruction to student-centered models by enabling personalized feedback and adaptive learning pathways (Hwang et al., 2020). Furthermore, integrating AI into STEM curricula, often referred to as AI-STEM, supports the development of computational thinking and complex problem-solving skills, aligning with the interdisciplinary nature of engineering design and scientific inquiry (Chai, 2019). However, scholars caution that the mere presence of AI tools does not guarantee pedagogical transformation; successful integration requires a fundamental restructuring of how STEM content is delivered and assessed.

2.2 *Evolving Competencies: From TPACK to Intelligent-TPACK*

To navigate the complexities of AI, the theoretical frameworks governing teacher knowledge need to be evolved. The TPACK framework (Mishra & Koehler, 2006) has long served as the standard for understanding how educators blend technology, pedagogy, and content (Figure 1). However, the unique affordances of AI, such as its autonomy, data-driven logic, and generative capabilities, pose challenges that generic TPACK cannot fully address.

Addressing this theoretical necessity, Celik (2023) proposed the Intelligent-TPACK framework (Figure 1). The framework delineates five distinct domains: (1) Intelligent-TK (knowledge of AI tools and their capabilities); (2) Intelligent-TPK (knowledge of how AI supports pedagogical strategies); (3) Intelligent-TCK (knowledge of how AI represents and transforms subject matter); (4) Intelligent-TPACK (the synthesis of these knowledge bases for curriculum design); and (5) AI Ethics (knowledge of ethical issues such as privacy, bias, and accountability). This expanded model posits that educators require specific knowledge regarding the intelligence of educational technologies. The framework was validated using Structural Equation Modelling, which indicated that technological knowledge (TK) may be insufficient for effective AI integration. Instead, the analysis suggests that the intersection of AI-specific pedagogical knowledge (Intelligent-TPK) and ethical evaluation, encompassing transparency, fairness, and accountability, significantly influences successful adoption. This aligns with the UNESCO (2024) AI competency framework (Figure 3), which emphasizes a Human-centred mindset and Ethics of AI as foundational layers before technical mastery. In the context of STEM, Intelligent-TPACK implies that educators must not only know how to operate AI tools (Intelligent-TK) but also understand how AI transforms disciplinary content (Intelligent-TCK), for instance, by recognizing the limitations of AI-generated data in scientific experiments and the ethical implications of algorithmic decision-making.

Figure 1

TPACK framework (Mishra & Koehler, 2006)

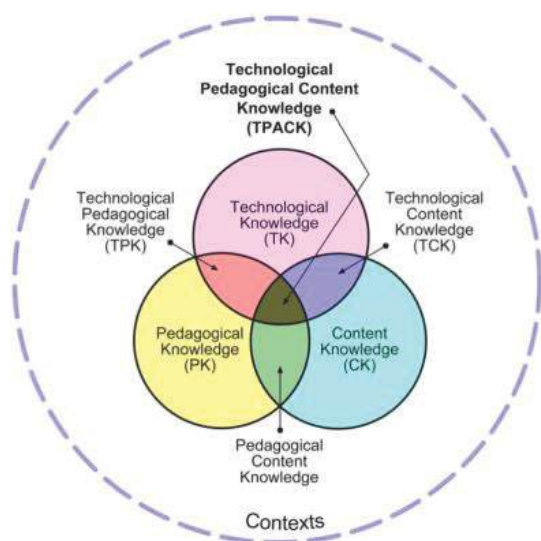


Figure 2

Intelligent-TPACK Framework (Celik, 2023)

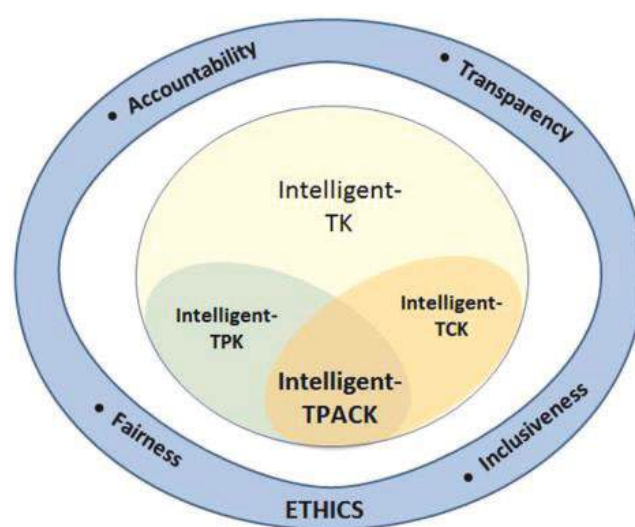


Figure 3

AI competency framework (UNESCO, 2024)

Aspects	Progression		
	Acquire	Deepen	Create
1. Human-centred mindset	Human agency	Human accountability	Social responsibility
2. Ethics of AI	Ethical principles	Safe and responsible use	Co-creating ethical rules
3. AI foundations and applications	Basic AI techniques and applications	Application skills	Creating with AI
4. AI pedagogy	AI-assisted teaching	AI-pedagogy integration	AI-enhanced pedagogical transformation
5. AI for professional development	AI enabling lifelong professional learning	AI to enhance organizational learning	AI to support professional transformation

2.3 School Leadership and the Rural Context

While teacher competencies are well documented, the role of school leadership in fostering them, particularly in under-resourced environments, remains underexplored. Research indicates that the

adoption of innovations in rural schools is heavily contingent upon environmental factors and administrative support (Wu et al., 2022). Rural schools often face a double bind: needing to modernize curricula while managing severe constraints on infrastructure and specialized staffing (Khan et al., 2019).

In these contexts, the school principal acts as the primary change agent. The literature suggests that a leader's technological vision directly influences teachers' behavioural intention to adopt engineering-focused and AI-enhanced curricula (Yu et al., 2021). However, most existing studies on AI in education focus on classroom implementation rather than on leaders' strategic cognition. There is a paucity of research examining how rural principals possess or perceive the components of Intelligent-TPACK. Do they view AI ethics as a leadership responsibility? How do they leverage Intelligent-TPK to mentor staff in schools where they might be the only instructional leader? Addressing this gap is crucial, as the successful infusion of the Technology component in rural STEM depends not just on available hardware but on the leader's capacity to conceptualize AI as a sustainable, ethical, and pedagogical asset.

3 METHODOLOGY

3.1 Problem Statement and Research Questions

Despite the global advocacy for AI in STEM, a significant gap remains in understanding how rural school leadership adapts to this technological paradigm shift. Most existing studies focus on classroom implementation or urban contexts, leaving the strategic cognition of rural leaders underexplored. Specifically, there appears to be a paucity of research examining how rural principals possess or perceive the components of Intelligent-TPACK, considering that they often serve as the sole instructional leaders in resource-constrained environments.

Addressing this gap is crucial, as the successful infusion of the Technology component in rural STEM depends not just on available hardware but on the capacity of the leader to conceptualize AI as a sustainable, ethical, and pedagogical asset. To explore this issue, this study is guided by the following research questions: (1) How do rural school principals conceptualize the necessary competencies for integrating AI into STEM education? (2) In what ways do these leaders leverage AI to navigate specific rural boundaries and resource deficits? (3) To what extent do rural principals view ethical stewardship as a core component of their technology leadership?

3.2 Research Design

This study employs a convergent mixed-methods design (Creswell & Clark, 2017) to investigate how rural school principals conceptualize and lead the integration of AI within STEM education. The research is grounded in an interpretive paradigm, aiming to understand the subjective meaning-making processes of school leaders as they redefine the *Technology* (T) component of STEM. Qualitative data from focus group interviews serve as the primary source of inquiry, while quantitative data from the Intelligent-TPACK survey (Celik, 2023) provide a descriptive profile to triangulate and corroborate the qualitative findings.

3.3 Participants

The study was conducted in Pingtung County, a region in southern Taiwan characterized by significant rural-urban disparities. Purposive sampling was used to recruit six school principals (four from elementary schools and two from junior high schools) serving in rural districts. These participants were selected based on their active involvement in promoting STEM or cross-disciplinary curriculum reform. The participants possess diverse disciplinary backgrounds, including Science, Mathematics, Special Education, Social Studies, and Mandarin, ensuring a multifaceted perspective on technology leadership. All schools face common rural challenges, including faculty aging, high staff turnover, and limited access to external educational resources.

Table 1

Participants' demographic information and Intelligent-TPACK survey results

Code	Gender	Schooling level	Years of Teaching Experience	Backgrounds	AI-TK	AI-TPK	AI-TCK	AI-TPACK	AI-Ethic
P-A	M	Primary	32	Science	5.60	5.43	5.50	5.14	5.25
P-K	M	Primary	22	Social Studies	6.80	6.29	5.75	5.57	5.00
P-Li	F	Primary	32	Mandarin, Math	5.00	4.57	5.25	5.00	3.75
P-Le	F	Primary	29	Social Studies, Mandarin	5.20	4.00	5.00	2.71	4.00
P-H	F	Middle	23	Special Education, Mandarin	7.00	6.86	6.00	5.57	5.25
P-C	F	Middle	27	Science	5.20	4.43	5.00	4.71	4.50

3.4 Data Collection

Data collection proceeded in two phases:

3.4.1 Online Focus Group Interview

A semi-structured focus group interview was conducted via Google Meet, lasting approximately 120 minutes. The session was video-recorded and transcribed verbatim. The interview protocol was designed to elicit in-depth discussions guided by four core questions: (1) What is the perceived impact of AI on STEM teaching in rural areas? (2) What core competencies are required for rural teachers to integrate AI into STEM education? (3) How can rural teachers enhance their

capabilities for AI-integrated STEM teaching? (4) How should teacher education be designed to cultivate pre-service teachers' readiness for future AI-STEM initiatives?

3.4.2 *Intelligent-TPACK Survey*

Following the interview, participants were asked to complete the Intelligent-TPACK survey, adapted from Celik (2023). The instrument was translated into Mandarin and underwent an expert review process to verify its content validity and readability. The survey utilizes a 7-point Likert scale to measure self-efficacy across five domains: Intelligent-TK (AI Knowledge), Intelligent-TPK (AI Pedagogical Knowledge), Intelligent-TCK (AI Content Knowledge), Intelligent-TPACK (AI Integration Knowledge), and AI Ethics.

3.5 *Data Analysis*

A deductive thematic analysis was applied to the interview transcripts, using the five domains of the Intelligent-TPACK framework as a priori codes. To enhance analytical efficiency and reduce bias, a *Human-in-the-Loop* AI-assisted workflow was implemented using Google NotebookLM. The analysis followed a hybrid coding strategy:

- (i) **AI-Assisted Coding and Quantitizing:** The verbatim transcripts were processed by NotebookLM to extract relevant excerpts corresponding to each TPACK domain. A data quantitizing technique (Sandelowski, 2000) was employed to calculate the frequency of mentions for each domain per principal, providing a preliminary heatmap of leadership priorities.
- (ii) **Thematic Synthesis:** The AI tool was prompted to identify recurring patterns and shared perspectives within each domain. For instance, data segments originally coded under Intelligent TCK regarding the verification of AI errors crystallized into the theme of Evaluative Literacy. Similarly, perspectives categorized under AI Ethics regarding family structures converged into the theme of Ethical Stewardship. This process ensured that the findings remained grounded in the theoretical framework while capturing the specific nuances of the rural context.
- (iii) **Human Interpretation and Verification:** Crucially, the researcher manually cross-examined all AI-generated codes and synthesized themes against the original transcripts. The researcher served as the final arbiters of interpretation, ensuring that the findings accurately reflected the nuanced context of rural education and were not artifacts of algorithmic hallucination.

Finally, the qualitative themes were integrated with the quantitative survey profiles to identify convergences (e.g., high ethical concerns) and divergences (e.g., gaps between operational knowledge and pedagogical vision). Interview excerpts are coded using the format [construct–participant–excerpt number].

4 RESULTS

The deductive thematic analysis of the focus group interviews, triangulated with the Intelligent-TPACK profile data, revealed that rural school principals conceptualize the *Technology* (T) in STEM not merely as a toolset, but as a complex interplay of evaluation, praxis, and ethics. Based on the coding framework described above (See Section 3.5), specific patterns within the Intelligent-TPACK domains were synthesized into three overarching themes: (1) The shift from operational skills to evaluative literacy; (2) AI as a boundary spanner addressing rural resource constraints (i.e., enabling teachers to access instructional support, collaborative input, and curricular resources beyond their immediate school context); and (3) Ethical stewardship amidst the digital parenting void.

4.1 *From Operation to Evaluative Literacy: The Primacy of Subject Knowledge*

The first theme highlights a redefinition of technological literacy. Rather than emphasizing technical proficiency (e.g., coding or prompt engineering), the principals unanimously identified *Evaluative Literacy*, the ability to verify and judge AI outputs based on deep subject matter expertise, as the critical competency for the AI era.

In the interviews, participants frequently described AI as “powerful but unreliable,” reflecting a shared perception across multiple participants. P-Li (with a background in Mandarin and Mathematics) shared an example using a *Prime Number Relay* game. She recounted using an AI tool to generate a sequence of prime numbers for a lesson; however, the AI produced a sequence of repetitive and incorrect numbers. She suggested that without her foundational domain knowledge, such errors might have gone unnoticed, which could potentially mislead students [AI-TK-P-Li_4]. Similarly, P-K (with a background in Social Studies) shared an instance in which an AI tool fabricated a historical account of *Einstein’s visit to the Republic of China* [AI-TK-P-K_2]. He used this as a pedagogical moment to demonstrate that the T in STEM requires a strong anchor in the S (Science) and M (Mathematics). P-Le reinforced this, arguing that Pedagogical Content Knowledge (PCK) is a prerequisite for AI use; without it, teachers cannot correct the biases or oversimplifications inherent in AI-generated materials [AI-TCK-P-Le_2].

This qualitative emphasis on subject-based verification aligns with the participants’ Intelligent-TPACK profiles. Generally, the principals reported moderate-to-high self-efficacy in the Intelligent-TCK (AI Content Knowledge) dimension. This suggests that their confidence in leading AI integration stems not from their technical skills (TK), which were often self-reported as their weakest area, but from their established disciplinary expertise.

4.2 *AI as a Boundary Spanner: Overcoming Rural Isolation through Praxis*

The second theme addresses the specific context of rural education, where the T acts as a bridge across resource limitations. In the interviews, principals did not describe AI merely as a teaching aid. Instead, they frequently referred to it as a form of virtual co-prep support that may help mitigate the professional isolation of rural teachers, many of whom are the sole subject specialists in their school.

P-Li and P-H described how AI tools enable rural teachers to transcend the boundaries of a single-person department. By simulating a colleague for lesson planning and brainstorming, AI may allow teachers to maintain curriculum quality despite staff shortages. One illustrative example was provided by P-Li, who described using NotebookLM to analyze curriculum guidelines and generate literacy-oriented assessment items. She noted that designing similar materials previously required several days of professional development training [AI-TPACK-P-Li_1]. Another example came from P-A (science background), who emphasized that AI-supported processes remain embedded within hands-on STEM learning. In a school project involving Black Soldier Fly cultivation, AI was used to assist with data interpretation and inquiry preparation, while the experimental activities themselves remained grounded in physical investigation [AI-TPACK-P-A_1].

When these qualitative insights are considered alongside the survey data, an interesting pattern emerges. The Intelligent-TPACK integration scores varied across participants, and several principals described feeling uncertain about their personal technical proficiency. Some participants characterized their information or AI-related skills as relatively limited or shallow [AI-TK-P-Le_1; AI-TK-P-H_1; AI-TK-P-C_1; AI-TK-P-Li_1]. However, their narratives also indicated a capacity for strategic integration. Rather than attempting to master all technical tools themselves, the principals described adopting distributed leadership strategies. Several participants reported establishing small *seed teams* of two or three young teachers or information technology specialists to support the technical implementation of AI-related practices [AI-TPACK-P-Li_3; AI-TPACK-P-K_1; AI-TPACK-P-H_2].

Through this structure, principals focused primarily on guiding curricular direction and policy alignment, while the technical experimentation was carried out by these teams [AI-TPACK-P-K_1; AI-TPACK-P-Li_3]. Taken together, these accounts suggest that in rural contexts, successful AI integration may depend less on a leader's individual technical proficiency and more on their capacity to organize and mobilize available human resources.

4.3 *Ethical Stewardship in a Digital Parenting Void*

The final theme reveals that for rural leaders, the Technology component carries a heavy burden of social responsibility. In the interviews, principals frequently framed AI integration as an ethical stewardship issue, particularly in relation to what several participants described as a growing digital parenting void in their communities.

A recurring concern involved the impact of AI and mobile devices on students from grandparent-led or socioeconomically disadvantaged households. P-K and P-C expressed concern that, without consistent parental supervision, AI and digital devices may easily become sources of distraction rather than meaningful learning tools [AI-Ethics-P-K_2; AI-Ethics-P-C_1].

For instance, one principal described situations in which mobile phones increasingly replace parental companionship, particularly in households where grandparents serve as the primary caregivers [AI-Ethics-P-K_2]. In these contexts, digital devices may function more as passive entertainment than as educational resources. Several principals, therefore, suggested that schools

need to take a more active role in guiding students toward responsible and reflective uses of AI technologies.

Participants also discussed the boundaries between AI-supported information access and human-centered educational roles. P-Li distinguished between the informational capabilities of AI and the relational role of teachers, emphasizing that social-emotional learning (SEL) remains an area where human interaction continues to be essential [AI-Ethics-P-Li_2]. Similarly, P-C emphasized that students should not treat AI-generated responses as answer keys. Instead, AI outputs should be approached as materials that require interpretation, verification, and personal reflection [AI-Ethics-P-C_2].

These qualitative accounts provide additional contextual explanation for the AI Ethics dimension measured in the survey. While participants' self-reported ethics scores varied (see Table 1), ethical considerations were frequently mentioned during the focus group discussion. Taken together, these narratives indicate that in this rural context, school leaders frequently associate AI integration with responsibilities related to value guidance, student well-being, and responsible technology use.

4.4 *Variation in Perspectives by Educational Level*

Differences in emphasis could be observed in how principals discussed the operationalization of AI in STEM education across school levels. Secondary school principals tended to describe AI integration in relation to structural curriculum arrangements and academic rigor. In several cases, they referred to a gradual institutionalization process in which AI-related initiatives that initially emerged through clubs or extracurricular activities were later incorporated into formal, flexible curricula or school-based courses [AI-TPACK-P-Li_2; AI-TPACK-P-H_1; AI-TPACK-P-C_1]. Such discussions often emphasized the need to maintain academic standards when integrating AI into credit-bearing curricula. In this context, ethical concerns were frequently framed in terms of academic integrity and the reliability of information, particularly regarding the possibility that students might rely on AI-generated responses without sufficient cognitive engagement.

In contrast, primary school principals more frequently discussed AI integration in relation to pedagogical engagement and holistic student development. Several principals described how AI-supported media transformations, such as converting texts into podcasts or animated stories, could help stimulate students' curiosity and participation in classroom learning. Ethical considerations at this level were often situated in relational contexts, including the digital parenting void and teachers' roles in supporting students' social-emotional learning. In addition, two principals described AI as functioning as a virtual co-preparation partner, particularly in small rural schools where teachers often work as the sole subject specialist [AI-TPK-P-Le_2; AI-TPK-P-H_1].

Taken together, these accounts suggest that principals at different educational levels may emphasize different operational roles for AI in STEM education. While secondary school leaders more frequently associated AI with curriculum structuring and academic governance, primary school leaders often described AI as a supportive tool that helps teachers facilitate learning in resource-constrained environments.

5 DISCUSSION

This study aimed to examine how rural school leaders perceive and interpret the role of AI within STEM education in their school contexts. By exploring how these principals conceptualize Technology in STEM through the lens of Intelligent TPACK, the findings suggest a shift in how technology education is understood in rural settings. For the leaders, the Technology component appears to extend beyond operational proficiency toward critical evaluation, ethical stewardship, and strategic resource management.

5.1 *Redefining Intelligent TPACK for Leadership*

The results appear to corroborate and extend the Intelligent TPACK framework (Celik, 2023). While Celik emphasizes the necessity of combining ethical, pedagogical, and technical knowledge for teachers, this study suggests that, for leaders, the hierarchy of these domains may differ. The qualitative emphasis on verification based on subject knowledge aligns with the participants' Intelligent TPACK profiles. Generally, the principals reported moderate to high efficacy in the Intelligent TCK dimension. This indicates that their confidence in leading AI integration may stem less from their technical skills (TK), which were often reported as a weaker area, and more from their established disciplinary expertise. Consequently, effective technology leadership may not require mastery of coding or algorithms. Instead, it seems to demand a high degree of Evaluative Literacy, defined as the capacity to assess the pedagogical validity and factual accuracy of AI outputs. As evidenced by principals' reliance on disciplinary knowledge to detect AI hallucinations, Human Intelligence, specifically Pedagogical Content Knowledge, appears to serve as the necessary auditor of AI.

5.2 *AI as an Equity Engine*

In the specific context of rural education, AI appears to function as a boundary-spanning resource. While the literature often highlights the structural deficits in rural schools, including limited staffing and restricted access to professional collaboration (Khan et al., 2019), the principals in this study frequently described AI as a generative support mechanism that helps mitigate these constraints.

Several participants characterized AI as a virtual collaborative partner that assists teachers in single-teacher departments. For example, one principal described using AI-supported tools to analyze curriculum documents and generate literacy-oriented assessments, a process that previously required extended professional development training [AI-TPACK-P-Li_1]. Other principals noted that AI could simulate collegial dialogue during lesson planning, enabling rural teachers to brainstorm interdisciplinary STEM activities despite the absence of subject-area colleagues [AI-TPK-P-Le_2; AI-TPK-P-H_1].

These accounts suggest that principals do not perceive AI merely as a technological innovation or a modernization mandate. Instead, AI is conceptualized as a structural support mechanism that partially compensates for rural professional isolation. By assisting with the generation of lesson ideas, literacy-based assessments, and interdisciplinary instructional materials, AI may enable

rural schools to sustain rigorous STEM learning opportunities despite the institutional constraint of limited human resources.

From a leadership perspective, this reframes AI integration not only as a technological initiative but also as a potential equity strategy. Rather than widening the urban-rural technological divide, AI may operate as a compensatory mechanism that helps rural schools maintain curricular quality and instructional diversity.

5.3 *The Ethical Imperative*

The emergence of Ethical Stewardship as a dominant theme underscores the critical role of principals as gatekeepers. Rural leaders' concern about the Digital Parenting Void highlights a societal dimension often absent from purely technical implementation frameworks. Principals view their role as protecting the human-centric aspects of education, specifically Social Emotional Learning, from automation. This suggests that in under-resourced communities, the Technology in STEM is inextricably linked to its social consequences, validating the emphasis on a human-centered mindset as the foundation of AI literacy in global frameworks.

5.4 *Educational Level Nuances*

Finally, the divergence between primary and secondary principals suggests that AI integration may follow different developmental trajectories across educational levels. Primary leaders tended to emphasize AI as a tool for engagement and pedagogical scaffolding, highlighting its role in supporting exploratory and multi-sensory learning experiences. This emphasis is consistent with broader pedagogical traditions in elementary education, which often prioritize student engagement, holistic development, and scaffolded learning environments. A recent systematic review of 258 studies on AI in elementary STEM education similarly found that many AI applications are designed to support adaptive learning, intelligent tutoring, and personalized feedback to enhance students' participation and conceptual understanding (Memari & Ruggles, 2025).

In contrast, secondary leaders more frequently discussed AI in relation to curriculum structuring, academic integrity, and the governance of credit-bearing courses, reflecting the stronger emphasis on disciplinary rigor, curriculum coherence, and formal assessment structures that typically characterize secondary schooling. This emphasis is consistent with recent research indicating that AI education at the secondary level increasingly focuses on higher-order competencies, including the application, evaluation, and creation of AI systems, often situated within design-based and problem-solving learning contexts (Su et al., 2024).

This orientation toward structure, accountability, and governance also echoes emerging discussions in higher education, where AI integration is increasingly associated with institutional policy, ethical considerations, and system-level implementation challenges (Zawacki-Richter et al., 2024). Rather than being treated merely as instructional tools, AI technologies in these contexts are positioned as elements that reshape assessment practices, academic integrity norms, and the broader organization of teaching and learning. These patterns suggest that leadership

approaches to AI integration may vary not only with technological considerations but also with the pedagogical and institutional priorities associated with different educational stages.

In addition, studies on AI integration in rural education highlight that school leaders must often navigate practical constraints such as limited digital infrastructure, uneven access to technological resources, and teachers' varying levels of AI-related expertise (Kim & Wargo, 2025; López Costa, 2025). These conditions may shape how AI is operationalized at different educational levels. For example, primary school leaders may focus on using AI to support engagement and instructional scaffolding in classroom learning, whereas secondary leaders may place greater emphasis on curriculum governance and academic integrity when integrating AI into formal course structures.

From this perspective, the different leadership emphases observed in this study may correspond not only to the institutional responsibilities associated with each educational stage, but also to the contextual challenges rural school leaders encounter when implementing AI-supported STEM initiatives. However, relatively few studies have examined how school leaders interpret AI integration differently across educational stages in rural contexts, underscoring the need to explore leadership perspectives as an underexplored dimension of AI-STEM research.

6 CONCLUSION

This study contributes to the ongoing discussions in Technology Education by proposing a leadership-centered perspective on the evolving role of Technology component in STEM. In this view, rural principals tend to conceptualize AI integration not merely as hardware adoption, but as a practice grounded in critical evaluation and ethical responsibility.

While these findings are shaped by the small-scale qualitative design and the rapid evolving nature of AI technologies, they offer initial insights that may inform future research, policy considerations, and professional practice. For instance, the findings suggest that professional development may benefit from placing greater emphasis on evaluative literacy alongside technical skills. Similarly, teacher education programs may consider strengthening pedagogical content knowledge to support educators in critically interpreting AI-generated outputs.

Future research could build on these insights by examining the longer-term implications of AI integration, including its potential role as a collaborative partner in relation to teacher retention and student learning outcomes in rural contexts.

Overall, these findings suggest that addressing the digital divide in rural STEM education may involve not only expanding access to technology, but also supporting leaders in navigating the ethical and pedagogical dimensions of AI integration.

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Towards a Framework of Knowing in Technical Vocational Education and Training (VET)

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Abstract

Technical vocational education and training (VET) is shaped by tensions between policy-driven, measurable notions of competence and the situated, relational, and materially embedded forms of expertise that define vocational practice. To address this tension, the study employs knowing as an analytic lens to examine how vocational knowledge is enacted, recognised, and valued within the visual cultures of Swedish VET. Four analytical dimensions—content, embodiment, valuation, and temporality—guide the exploration of how knowing becomes visible in 144 marketing images representing four VET programmes. *Through a collaboratively conducted analysis of the visual material*, the research team examined recurring representational patterns during a two-day analytic session in the Norrköping Decision Arena. The analysis identifies contrasting vocational ontologies. In Building and Construction, knowing is associated with durable materials, large-scale processes, externalised plans, and collaborative work extending across longer temporal horizons. In Hairdressing and Styling, knowing appears through fine-grained embodied gestures, aesthetic judgement, and dialogic interaction with clients, characterised by immediate outcomes and short, repeatable cycles. Similarly, distinct ontologies were identified within Industrial Technology and Natural Resource Use, indicating broader patterns in how vocational knowing is visually structured across VET. The analytical framework has enabled a more nuanced reading of the visual material, clarifying how various forms of expertise are made visible, legitimised, or backgrounded through specific representational choices. This contributes to a more refined understanding of how vocational knowing is visually constructed and communicated across different educational contexts. While the visual data necessarily restrict the analysis to what images render observable, the framework supports a deeper examination of how vocational knowing is organised, negotiated, and valued across programmes with distinct material and epistemic conditions.

Key Words: Technical Vocational Education and Training (VET), Visual Culture, Vocational Knowing

1 INTRODUCTION

Debates around competence shortages have intensified as demands for competitiveness intersect with the green and digital transitions, together creating challenges that cannot be addressed by technology and innovation alone. At the same time, dominant policy approaches tend to operationalise competence as a measurable and transferable entity, thereby concealing the historical and political negotiations through which particular forms of knowledge, skill, and competences are recognised as valuable (Hultén et al., 2022; Smit et al., 2020). As a consequence, competence-based, experiential, and community-generated practices risk being undervalued or rendered invisible, in favour of academically codified knowledge that is measurable, assessable, and easily articulated (Nuur et al., 2020).

Although frequently used interchangeably, terms such as knowledge, skills and competences refer to different aspects of vocational learning (e.g., Baartman et al., 2018; Korp et al., 2025): knowledge is commonly associated with abstract and generalisable understanding, while competence and skills denotes the ability to act effectively in specific situations. Within technical vocational education and training, the boundary between what is treated as knowledge and what is framed as competence is often unclear, shifting across policy, curriculum, and workplace contexts. When these distinctions remain blurred, it becomes difficult to account for how vocational expertise is developed, recognised, and sustained across educational and work-based settings, raising questions about how competence in technical vocational education and training can be identified, recognised, and supported in emerging educational and labour-market contexts.

1.1 *Research objectives*

To address the conceptual gap outlined above, this article proposes a framework where *knowing* is used as an analytical lens for examining the relationship between theory and practice in technical vocational education and training (see, Lindberg, 2003). Hence, rather than treating knowing as something learners possess, it is approached here as a relational and continuous process that emerges through interaction with artefacts, bodies, environments, social relations, and temporal conditions. To make this process analytically accessible, knowing is examined through four interconnected dimensions:

- Content, as referring to what is known or enacted in practice.
- Embodiment, as referring to how knowing takes form through bodily, material, and representational expressions.
- Valuation, as referring to how particular ways of knowing are recognised, legitimised, or marginalised.
- Temporality, as referring to how knowing unfolds, stabilises, and changes over time.

Guided by this approach, this article explores how knowing is shaped and manifested within visual representations of technical VET-practice found in, for instance, marketing materials (see, Larsson et al., 2024).

2 THEORETICAL FRAMEWORK

To analyse how the dimensions of knowing are expressed in vocational education and training (VET) practice, this article draws on perspectives from visual culture studies that conceptualise images as both shaped by, and shaping, prevailing norms, beliefs, and lived experiences within societies (Mirzoeff, 2009; Mitchell, 2005; Rose, 2023). From this perspective, visual cultures are not merely reflective of social realities but actively participate in human meaning-making processes through which phenomena are understood, categorised, and valued (Mitchell, 2005). Images are thus approached not as neutral illustrations of vocational activity, but as socially and materially embedded representations that also contribute to the constitution of professional practice.

Although discourses are immaterial, they exert material effects that become observable through their manifestations, including visual representations of educational and vocational practices. Images organise attention, frame relations between bodies and tools, and articulate assumptions about progression, expertise, and professionalism, and can therefore be understood as sites where discursive norms are materialised (Fälton, 2021) and, as such, provide a crucial entry point for examining how knowing is enacted and negotiated across educational and work-based settings in VET. In technical VET, such norms may concern what constitutes proper technical work, which forms of competence are rendered visible, and whose knowing is recognised as authoritative (Larsson et al., 2024; Larsson et al., 2025).

3 DATA AND ANALYTICAL PROCEDURE

The study's empirical material comprises 144 marketing images representing four Swedish Vocational Education and Training (VET) programmes: the Building and Construction (BC), the Hairdresser and Stylist (HS), the Industrial Technology (IT), and the Natural Resource Use (NR) programmes. Images were collected via an image search on Google (December 17th, 2025), using the respective programme name as a search string. In relation to the study's theoretical framework, rather than viewing these images as mere documents of education practice, they are understood here as integral to how vocational knowing is structured, communicated, and legitimised and treated as empirical sites where the ongoing production of vocational knowing becomes visible (Fälton, 2021; Larsson et al., 2024).

The analysis spanned over two consecutive days in the Norrköping Decision Arena; a venue that enables users to compare pictorial content in a non-hierarchic environment and thus suitable to use when more extensive data sets are to be analysed and discussed. Initially, the analysts' focus was on identifying so-called representational commonalities – i.e., recurring themes, objects, and interaction patterns that could provide insights into how knowledge, competence, and knowing are portrayed in the images (Larsson et al., 2024). These preliminary mappings of the four VET programmes served as a foundation for the subsequent day's detailed analysis of the BC and HS. The discussions were audio recorded (approx. 200 minutes in total) and later transcribed.

Consequently, the study's analytical procedure can be seen as a Directed Content Analysis (DCA) (see, Hsieh & Shannon, 2005) of the visual cultures of BC, HS, IT, and NR in relation to the four

dimensions of knowing, where the researcher's interpretive conversations serve as auxiliary data that both shape and are shaped by the study's visual culture (see, Larsson et al., 2024).

4 RESULTS AND ANALYSIS

The following section presents the principal findings of the study. It begins with a concise overview of the defining features of the visual cultures of Building and Construction (BC) and Hairdressing and Stylist (HC) programmes, drawing on insights from the researchers' interpretive discussions. This is then followed by a detailed analysis of the empirical material in relation to the study's conceptual frame (content, embodiment, valuation, and temporality).

4.1 *The visual culture of BC*

The analysis of the visual culture of the BC programme reveals a discourse in which tools, materials, and the human body together manifest a knowing in process. Several images depict situations in which tools function as “extension[s] of the user's hands” (Researcher 1), enhancing the body's capabilities (e.g., a crowbar, power drill, or hammer). In such instances, eye-hand coordination is at the centre of attention. Some construction tools, such as compound saws, are too heavy to use one-handed and must be mounted on stands. Still, the images emphasise the importance of eye-hand coordination, showing students carefully following lines and angles. This demonstrates the precision required in construction tasks, highlighting how skilled movements and the ability to maintain accuracy are central to mastering the trade's practical elements. The images illustrate a focused engagement, with the alignment of tools to specific guides or measurements as a recurring theme, reinforcing the importance of developing coordinated motor skills within the BC program.

Furthermore, the images portray a collective practice; Researcher 3 describes “It also looks like they are helping each other to build [...] It feels like some tasks you wouldn't be able to do yourself. Someone has to hold, and someone has to nail”. The apparent collaboration underscores that knowing is integrated in the coordination of work and interaction among students. Also, the pictures project “[T]he impact of a major process. Part of building a house or part of laying a roof or part of making a complete paving” (Researcher 3) and represents a stable, standardised and long-term type of knowing that is tied to plans, patterns and traditions. Standard and tradition are also visible in, for instance, protective clothing and high-visibility clothing: “These [builders] should be visible. They should not go to the construction site dressed in black” (Researcher 2).

Knowledge within BC appears as fundamental and society-bearing: “Construction is a fundamental activity for the whole of society. You can't do without good buildings. We would perish without being able to sleep under a roof” (Researcher 1). Thus, the pictorials mediate a discourse in which knowledge has both individual and collective value. Meanwhile, the pictures lack tangible elements of theoretical knowledge, even though they are represented, for instance, in blueprints and in situations where teachers point to different items.

Overall, the transcript shows that the value of knowledge in BC is multifaceted: it is practical, collective, traditional, and socially significant, and it is conveyed through action, cooperation, and established structures.

4.2 *The visual culture of HC*

The analysis of the visual culture of the Hairdressing and Stylist programme reveals a discourse in which hands-on skills, aesthetic sensibility, and client interaction together manifest a knowing-in-process. Several images portray situations where tools such as scissors, combs, and brushes are handled with precision and dexterity, often in combination, highlighting the importance of fine motor skills and detailed craftsmanship: "You have a comb and then you have a pair of scissors so that you have small tools that you even sort of handle in combination with each other" (Researcher 3). This emphasises the simultaneous use of multiple tools and the need for nuanced coordination on the students' part.

In these representations, the process of dividing, shaping, and styling hair is foregrounded. Furthermore, attention to detail and the ability to adapt techniques to individual needs are central to success. The images illustrate how the act of creating a hairstyle is not only technical but also interpretative, involving the reading of client wishes and the translation of these into concrete results. This involves a seemingly dialogic process between the hairdresser/stylist and the client, where it is "the customer who decides what is beautiful. It may not be rules and norms that do that" (Researcher 1).

Furthermore, the visual representations point to a practice that is both individual and relational. While much of the work is performed one-on-one, the interaction with the client or model is integral to the process, requiring social and communicative competence as well as technical skills. The environment is characterised by order and structure, with tools organised and processes broken down into clear steps. Yet, there is also space for creativity and personal expression: "Design is at the heart of [practice]" (Researcher 2).

The images also reflect a professional identity, signalled through attire and the use of specialised equipment, and a focus on hygiene and safety, for example, through the use of gloves and aprons when handling chemicals. However, elements of theoretical knowledge are less visible in the images, even though it is implicitly present in understanding materials, techniques, and the effects of various products.

Overall, the portrayals of the value of knowledge in the Hairdressing and Stylist programme is multifaceted: it is practical, creative, individualised, and relational, and it is conveyed through both skilled action, client interaction, and the ability to translate aesthetic and technical understanding into tangible results.

4.3 *BC and HC viewed through the lens of knowing*

4.3.1 *Content*

In terms of content, the images present two contrasting material ecologies and domains of action. In the construction images, the recurring presence of timber, stone, heavy machinery, measuring tools, and architectural structures foregrounds a world organised around structural, and processed materials (e.g., stone, metal, and timber) and large-scale processes. These materials imply forms of understanding linked to stability, resistance, geometry, and structural integrity. By contrast, the Hairdresser and Stylist images represent work with human-centred materials (e.g., hair, skin, faces) as well as dyes, chemicals, and lightweight hand tools. The close-up gestures, delicate sectioning, and micro-adjustments characteristic of these images suggest a content dimension rooted in tactile sensitivity, material responsiveness, and individualised attention. Thus, the visual representations themselves inscribe two distinct forms of vocational substance: one based on structural transformation of matter, the other on aesthetic and corporeal transformation of persons.

4.3.2 *Embodiment*

The embodiment dimension becomes visible in the contrast between codified and embodied modes of representation. Construction images often include evidence of externalised knowledge forms (e.g., blueprints, grids, angles, linear guides) positioned alongside the workers. Bodies in these images appear engaged in measurable, spatially coordinated tasks, linking the abstract logic of plans to the physical execution of cuts, joints, and assemblies. In the hairdressing images, by contrast, the form of knowing is represented almost entirely through the body: the alignment of the stylist's hands, the orientation of the comb, the tilt of a head, or the interaction mediated through a mirror. There is no visible codified plan. Instead, knowing appears as a choreography of gestures and proximities. The images thus stage two contrasting epistemic modalities: one in which knowledge is both outside and ahead of action, and one in which knowledge is enacted in an immediate, reciprocal relation with the material and the client.

4.3.3 *Valuation*

The valuation dimension is inscribed through visual cues that signal professional legitimacy and merit. Construction images foreground safety equipment, reflective clothing, and collaborative bodily formations, marking the work as institutionally regulated and socially recognised. The emphasis on teamwork and the visibility of heavy tools further aligns the practice with culturally valued notions of strength, precision, and trade expertise. Meanwhile, the stylist images emphasise aesthetic refinement, interpersonal engagement, and careful bodily presentation. The near-uniform dark clothing, the clean studio environment, and the focus on faces and styles confer a different, and often more gendered form of professional worth, one tied to service, client experience, and creative labour. These visual framings implicitly reproduce societal hierarchies of value, with tangible products, machinery, and standardised equipment on one side, and personalised service, affective labour, and aesthetic outcomes on the other.

4.3.4 *Temporality*

Finally, the temporality dimension is embedded in the images' depiction of rhythm, duration, and scale. Construction scenes show moments situated within long-term processes (e.g., laying foundations, assembling frameworks, installing components), each representing a fragment of an extended linear sequence. The unfinished structures surrounding the workers make visible the trade's cumulative, staged temporality. By contrast, the stylist images capture short, cyclical, and repeatable processes such as cutting, colouring, and blow-drying. These activities occur in tightly bounded temporal units, each culminating in an immediate aesthetic result. Even when the outcome is not yet shown, the framing of the images signals a temporality of rapid iteration rather than long-range assembly. The photos, therefore, encode two temporal logics: a slow-building, accumulative temporality in construction, and a rhythmic, short-horizon temporality in hairstyling.

4.3.5 *In summary*

Taken together, the image sets can be read as visual enactments of contrasting vocational ontologies (Table 1). Construction is represented as planned, externally guided, collaborative, and materially enduring, while hairdressing and styling is embodied, affectively mediated, individually tailored, and temporally cyclic. Yet the images also hint at shared dimensions of professional knowing: attention to geometry, disciplined bodily coordination, and the shaping of materials—whether stone or hair—with skill and intention. Through their representational choices, the images map the relational terrain in which knowledge, competence, and knowing take form in different yet comparable ways across vocational contexts.

Table 1

Comparative overview of the dimensions of knowing in the BC and HS programmes.

Dimension	Building and Construction	Hairdresser and Stylist
Content	Work with durable, processed materials (wood, stone, machinery/tools); structural transformation; large-scale processes.	Work with living material (hair, skin), chemicals, and fine tools; individualised aesthetic transformation.
Embodiment	Codified knowledge forms visible (blueprints, measurements); actions guided by external plans; spatial coordination.	Embodied interactive knowing (hand choreography, mirror use, tool coordination); no external plans visible.
Valuation	Safety gear, reflective clothing, teamwork, and heavy tools signal institutional legitimacy and technical value.	Aesthetic labour, client interaction, polished presentation; theoretical knowledge is less visible in images.

Temporality	Segments of long, accumulative processes; unfinished structures show extended temporal arcs.	Short, cyclic, repeatable processes with immediate outcomes; iterative, client-specific temporal logic.

5 METHODOLOGICAL AND ANALYTICAL DISCUSSION

The main objective with this study has been to explore how knowing is shaped and manifested within visual representations of technical VET-practice found in, for instance, marketing materials. In response to this, we have employed a collaborative Directed Content Analysis (DCA) (Hsieh & Shannon, 2005) informed by the analytical dimensions of knowing: content, embodiment, valuation, and temporality. The proposed framework offers two key methodological advantages:

First, it provides a coherent structure for examining how vocational knowing is enacted and represented without reducing VET practice to predefined, dichotomy-oriented categories, such as “knowledge” or “competence”. Instead, it facilitates nuanced comparisons between various VET programmes, ensuring close attention to the unique ways in which vocational knowing emerges within the distinct visual cultures and specific educational contexts in which it is situated.

Second, the framework promotes collaborative analysis by encouraging analysts to draw upon diverse research backgrounds and educational experiences, thereby enhancing both teamwork and reflexivity. Nevertheless, this collaborative approach requires careful attention to the ways in which the analytical context is discursively constructed. In the study, this was addressed by ensuring each researcher received equal speaking time, with the order of speakers systematically rotated throughout discussions. Also, time was allocated to jointly explore different approaches to exploring the study’s data set.

At the same time, the framework has inherent limitations stemming from its analytical orientation. The four dimensions are analytically distinct but empirically intertwined, so their boundaries may overlap in analysis. Moreover, because the study focuses on visual materials, it is necessarily limited to forms of knowing that become visible within images and visual representations. Forms of knowing that remain tacit, taken for granted, or excluded from dominant visual cultures cannot be fully captured through this approach. The analysis's interpretive and discussion-based character further suggests that the findings reflect situated readings of the material rather than definitive accounts of vocational knowing.

Together, these strengths and limitations highlight the importance of transparency in the development and articulation of interpretations. The framework provides a structured way of analysing the complexity of vocational knowing as it is enacted and visualised in technical VET, while also acknowledging that such analyses are partial and contingent on what becomes visible within the available empirical material.

6 AI DISCLOSURE

Generative Artificial Intelligence (GenAI) has been provided during the transcription of the audio recordings (Microsoft Word) and to support the extraction of illustrative examples from the data, the generation of Table 1, and the structuring of the text (Co-pilot). Furthermore, AI has been employed to assist in writing and proofreading of the text (Co-pilot, ChatGPT 5.0 & 5.2, and Grammarly). At no point during the process have data or copyrighted material been uploaded to a third party.

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Design, Control and Experimental Validation of a Wireless Power Transfer Charger: A Pedagogical Approach

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Abstract

This paper presents the systematic design and control of a wireless power transfer (WPT) charger, from early modeling to experimental validation. The study begins with a detailed analytical modeling of the resonant WPT system to analyze its electrical behavior and identify key parameters influencing efficiency and stability. Based on this analysis, the power stage—including the coils, compensation network, and inverter—is designed in accordance with the SAE J2954 standard to ensure compatibility with emerging electric vehicle charging requirements. Several control strategies are then developed and compared using MATLAB/Simulink, focusing on maintaining battery charging current and voltage regulation under variations in coupling and misalignments. The most effective control approach is implemented on a microcontroller and experimentally tested on a 500 W laboratory prototype. Measurements confirm stable operation, efficiency above 80 %, and robust performance against misalignment. The work provides a pedagogical yet realistic example of the complete design process for modern WPT systems, illustrating how modeling, control design, and hardware validation can be integrated to bridge theory and practical engineering education.

Key Words: Wireless Power Transfer, SAE J2954, Resonant Converter, Control Design, Experimental Validation, Engineering Education

1 INTRODUCTION

The gradual depletion of fossil fuels and the growing impact of climate change are forcing a shift away from conventional vehicles powered by internal combustion engines. These vehicles remain heavily dependent on petroleum and are major contributors to greenhouse gas emissions. As a result, electric vehicles have emerged as a practical solution for more sustainable transportation, offering the advantage of zero local emissions (Huo et al. 2015). Over the past decade, strong

interest from automotive manufacturers has driven rapid growth in the electric mobility market, with millions of EVs now in circulation, particularly in Europe, the United States, and China. This expansion has been supported by a wider range of available models and significant improvements in driving range (Machura, De Santis, and Li 2020).

Despite this progress, the widespread adoption of EVs still faces several challenges. Limited charging infrastructure, long charging times, high initial costs, and policy-related issues remain major obstacles. Among these, the lack of public charging stations is considered the most critical barrier, especially in countries with high EV penetration, where the number of chargers does not yet meet demand (Brenna et al. 2020). These limitations form the motivation for the work presented in this paper, which focuses on improving EV charging solutions through the development of a wireless power transfer charger.

At present, conductive charging systems dominate the market due to their high efficiency, but they come with practical drawbacks such as cable handling, wear, maintenance, and safety concerns under adverse weather conditions (Lassioui et al. 2018). Wireless charging offers an attractive alternative by eliminating physical connectors, improving user convenience, and reducing maintenance requirements. WPT systems can be classified as stationary, static, or dynamic, with the latter still largely confined to research due to technical challenges (Bertoluzzo et al. 2020).

Although the WPT market is growing, several issues limit its use in EV applications. Large air gaps, coil misalignment, safety concerns related to electromagnetic fields, system complexity, and high costs all affect performance and acceptance (Trends and developments in electric vehicle markets – Global EV Outlook 2021 – Analysis n.d.). In addition, controlling a WPT charger is inherently complex because it involves multiple power conversion stages with nonlinear and constrained dynamics. Depending on the system architecture, control can be implemented on the ground side, the vehicle side, or on both sides simultaneously, each approach presenting its own advantages and challenges (Baros et al. 2020; A. Lassioui et al. 2024; Miller, Onar, and Chinthavali 2015).

This paper presents the design and implementation of a wireless power transfer (WPT) charger developed mainly for educational purposes. The system is described step by step so that engineering students can easily follow the design approach. Emphasis is placed on practical aspects such as component selection, control strategy, and experimental testing. Rather than focusing only on performance, the work aims to serve as a learning support. The proposed charger can therefore be used as a laboratory platform in engineering schools. Overall, it is intended to help students better connect theoretical concepts with real applications.

This work is not only focused on the development of a wireless power transfer (WPT) charger, but also on its use as a pedagogical platform for engineering education. The proposed system is grounded in established educational frameworks, particularly design-based learning, experiential learning, and systems thinking. From a design-based learning perspective, students are actively engaged in the complete engineering process, from analytical modeling to experimental validation. This approach promotes iterative problem-solving and critical thinking. In parallel,

the system aligns with experiential learning principles, where students construct knowledge through direct interaction with physical systems, bridging the gap between theory and practice. Furthermore, the WPT charger inherently represents a complex multidisciplinary system, involving electromagnetics, power electronics, control systems, and embedded implementation. This makes it particularly suitable for fostering systems thinking, enabling students to understand interactions between subsystems and constraints in real-world engineering design.

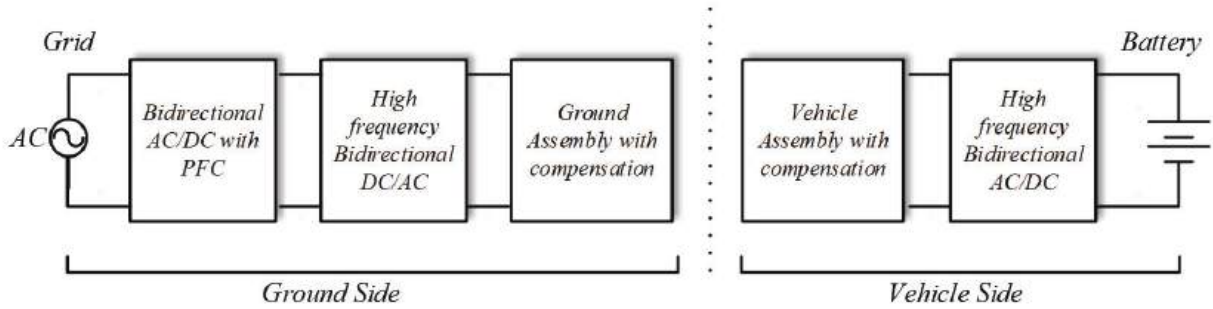
2 DESIGN OF THE WPT CHARGER

2.1 Overall bloc diagram of the UWPT charger

The figure 1 presents the overall architecture of the proposed bidirectional wireless power transfer UWPT charger. Each block plays a specific role in the energy conversion process. In grid-to-vehicle (G2V) mode, the charger is connected to the grid through a bidirectional AC/DC converter equipped with power factor correction. This stage regulates the DC-link voltage and ensures unity power factor operation. On the ground side, a bidirectional high-frequency inverter generates a square-wave voltage using a phase-shift control strategy at an operating frequency of 85 kHz. This voltage supplies the ground coil and its compensation capacitors, creating an alternating magnetic field. Due to the magnetic coupling between the coils, a voltage is induced on the vehicle-side coil, which is then rectified and filtered to provide a DC voltage suitable for charging the EV battery.

Figure 1

Overall topology of a WPT charger (Issam Bentalhik et al. 2022)



2.2 Technical specification of the UWPT charger

This work focuses on the design of a unidirectional wireless power transfer (UWPT) charger based on the 3.7 kVA power class defined in the SAE J2954 standard. This power level is selected mainly to clearly illustrate the design methodology, which can later be extended to higher power classes if needed. In order to ensure safe operation of the charger, it is very important to ensure grid side requirement including power factor quality, voltage magnitude and frequency. According to the specified power, the grid could be single or three phase system. For a 3.7kW, a 230V, 50Hz, 16A grid could be used. The battery of the electric vehicle differs from one

constructor to another. A 48V battery pack is used in our case. As for the power transfer efficiency, the SAEJ2954 allows a minimum value of 85% when the coils are aligned and 80% otherwise. The system adopts the Z1 class, corresponding to a vehicle-ground clearance between 100 and 150 mm. In addition, it is designed to tolerate lateral misalignments in the range of 7 to 10 cm, as specified in the standard. Finally, the operating frequency is set to 85 kHz in line with conventional unidirectional WPT systems. The Table 1 summarizes the aforementioned technical specifications of the UWPT charger.

Figure 2

Equivalent circuit of a WPT charger

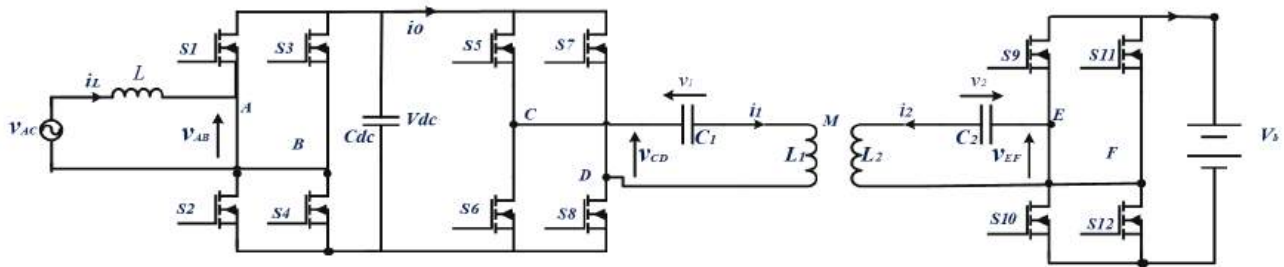


Table 1

Technical specification of a WPT charger according to SAEJ2954 standard

General specifications according to the SAEJ2954 standard	
Maximum power transfer	3.7 kVA
Minimum targeted efficiency	80%
WPT frequency	85 kHz
Z-class	Z1 (100-150 mm)
Misalignment tolerance	$\Delta x = 7 \text{ cm}$, $\Delta y = 10 \text{ cm}$,
AC input voltage range	85 - 275 VRMS
Nominal input AC voltage	230 VRMS
Nominal AC input current	16 ARMS
Electric vehicle battery voltage range	48VDC

2.3 AC/DC PFC design

The AC/DC is the interface between the charger and the main grid. It ensures power factor correction and regulates the DC voltage to the desired value usually 400V. Its topology consists of a totem-pole where one leg is operating at the PWM switching frequency f_{sw} while the other leg are operating according to the sign of the grid voltage thus switching at a lower frequency. This operating mode helps reduce the switching power losses. As for the DC-link capacitor, the latter is used to reduce the 100Hz ripple frequency occurring at the DC voltage (I. Bentalhik et al. 2022; Lassioui et al. n.d.).

2.4 Power switches choice

The choice of power switches is mainly driven by the need for bidirectional current flow and reliable operation at a relatively high switching frequency of 85 kHz, while keeping losses as low as possible. These requirements narrow the options to two advanced technologies: silicon carbide (SiC) MOSFETs and gallium nitride (GaN) HEMTs. Both technologies are well suited for high-frequency and high-power applications, but they differ in practical limitations. GaN devices offer very high electron mobility, which makes them attractive for high-frequency operation, especially in low-power systems. However, their relatively low thermal conductivity complicates heat management and limits their use to power levels of only a few kilowatts. SiC MOSFETs, on the other hand, provide much better thermal performance, allowing them to operate safely at higher power levels. They also maintain good efficiency at high switching frequencies, which helps increase power density by reducing the size of magnetic and filtering components. For these reasons, SiC MOSFETs are better suited for applications that require both high power and high-frequency operation (Ding et al. 2016; Hazra et al. 2016)

2.5 Ground side and vehicle side coils design

Coil design plays a critical role in the WPT charger performances. Poor designs may lead to lower efficiency. In general the coils, are designed taking into account several parameters such as the maximum current, the bifurcation phenomena and the available space beneath the vehicle chassis. The following figures show some coils geometries used in WPT chargers (Bouanou, Fadil, and Lassioui 2020; Kim et al. 2016).

The coil design process starts with the selection of suitable conductors. Because wireless power transfer operates at high frequency, skin and proximity effects become significant, which is why Litz wire is commonly used. This type of wire is made of many thin, twisted strands and is specifically designed to reduce high-frequency losses. The choice of Litz wire mainly depends on the operating frequency, since higher frequencies require thinner strands and a larger number of them to carry the same current.

For an operating frequency of 85 kHz, AWG 38 falls within the recommended range. Based on available commercial options, a type-2 Litz wire with a high number of strands was selected, as it offers sufficient current-carrying capability and an adequate cross-section to safely handle the maximum coil current.

Several coils geometries have been used in the literature. It is worth noting that circular and rectangular are the most used as they allow higher efficiency, more tolerance to misalignments and simpler design. As a result, circular coils are generally preferred for stationary charging applications, whereas rectangular coils are better suited for dynamic charging. Since the charger considered here is intended for stationary use and modern vehicles can be accurately positioned using parking assistance systems, circular coils were chosen (Luo and Wei 2016).

Finally, the calculation of coil inductance typically begins by defining a target quality factor on the vehicle side. Higher quality factors improve performance but require larger inductance values, which introduces practical design trade-offs. The main parameters of the coils and a typical simulation example are illustrated in the following figure.

Figure 3

Coils parameters

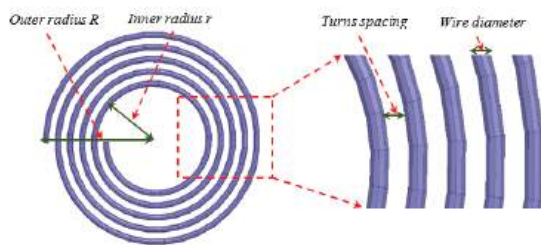
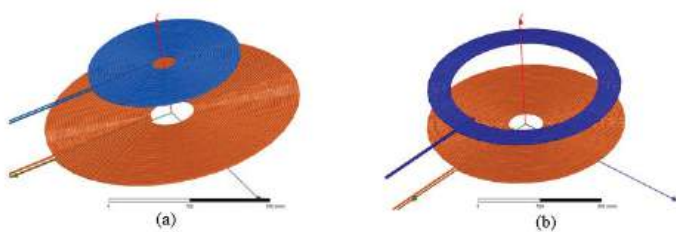


Figure 4

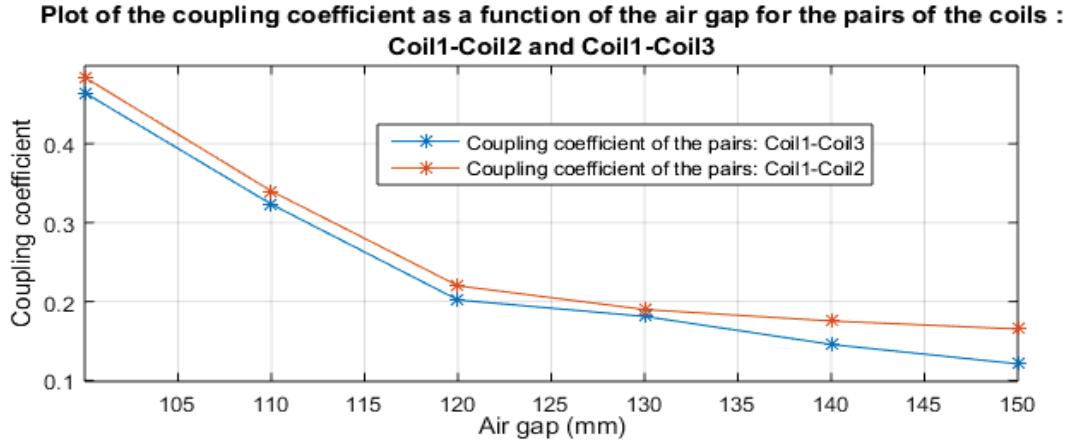
Simulation examples of two coupled coils (Issam Bentalhik et al. 2022)



The coupling coefficient between the coils is a function of the distance between them. Thus for large distances, the coupling coefficient drops drastically which lowers the power transfer efficiency as shown in the following figure.

Figure 5

Plot of the coupling parameter as function of the distance (Issam Bentalhik et al. 2022)



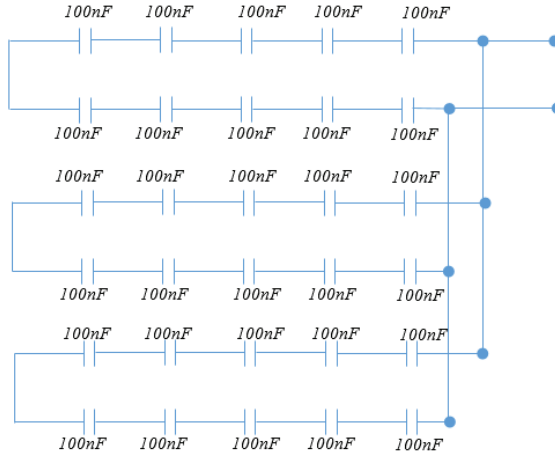
2.6 Reactive power compensation capacitors design

The compensation stage is used to eliminate the reactive impedance of the WPT system, which helps reduce circulating reactive energy and improve overall efficiency. In this work, a series-series compensation topology is adopted, as it is widely used in the literature and has the advantage that the required capacitance values do not depend on the load or the mutual inductance between the coils.

The design of the compensation capacitor bank requires particular attention. The capacitors must first ensure resonance with the coils and, at the same time, be able to withstand the high voltages present in the system. A structured design approach is therefore necessary. When identical capacitors are used, the total compensation capacitance depends on the number of parallel branches and the number of series-connected capacitors in each branch (Mohamed et al. 2017). To satisfy the voltage constraints, the number of capacitors connected in series is determined based on the maximum voltage rating of a single capacitor. This ensures safe operation of the compensation block under high-voltage conditions. That being said, an example of compensation bloc is illustrated in the following figure.

Figure 6

Multiple capacitors made in series to withstand the high voltage



2.7 Control and communication boards

In the developed WPT charger, the control and communication tasks are shared between a TMS320F28335 DSP and a Raspberry Pi 4. This choice was made to benefit from the specific advantages of each platform. The TMS320F28335 is mainly used for real-time control tasks, since it offers fast computation, accurate PWM generation, and efficient ADC modules. These features are particularly important for controlling the power converters, regulating currents and voltages, managing the phase-shift control of the high-frequency inverter, and implementing protection functions. Relying on the DSP for these operations helps ensure stable operation, especially given the high switching frequency of the system. The Raspberry Pi 4 is used for supervision and communication purposes. It provides a convenient environment for monitoring system variables, recording data, and managing operating modes such as G2V and V2G. In addition, its built-in communication interfaces make it easy to exchange data with external systems or user interfaces when needed. By separating fast control tasks from higher-level supervision, the system becomes easier to manage and more flexible. The DSP remains focused on deterministic control, while the Raspberry Pi handles tasks that are less time-critical. This organization also leaves room for future improvements without requiring major changes to the core control structure (Abdellah Lassioui et al. 2024).

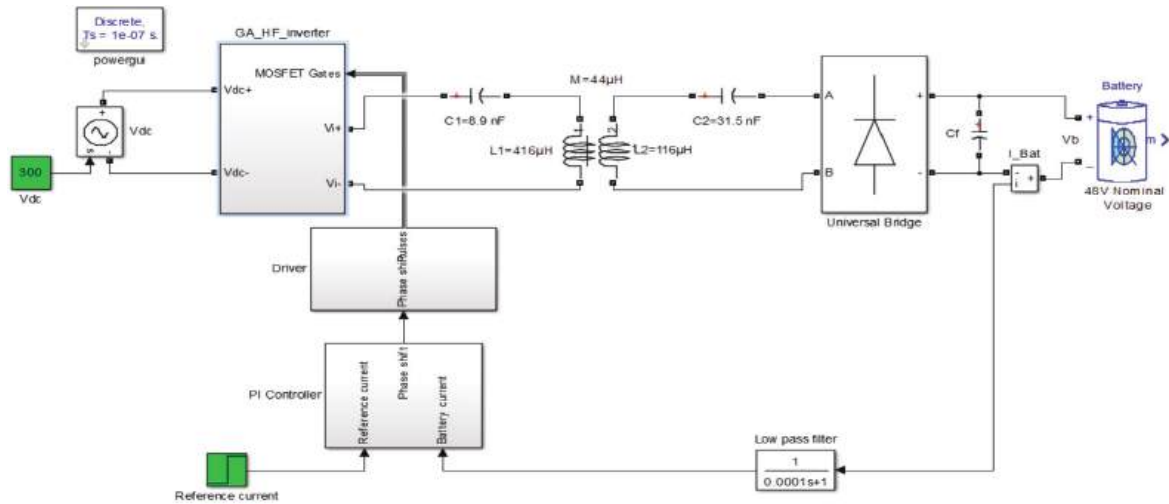
2.8 Modelling and simulation using MATLAB/Simulink software

It is worth noting that a simulation software must be used to confirm the design calculations before passing to the hardware realization. In our case, MATLAB/Simulink software was used. It offers a lot of toolbox used for power converters analysis and modelling and control. It allows the entire modelling of the WPT charger from the grid to the battery. All the component of the charger could be personalized according to the calculated values. Also it makes it possible to test the

behaviour of the controller to detect possible issues at early stages and avoid damaging electronic component of the charger. In addition it allows to test several control strategies and approaches and compare them in order to assess the performances of each controller. The complete Simulink model of the system is presented in the following figure.

Figure 7

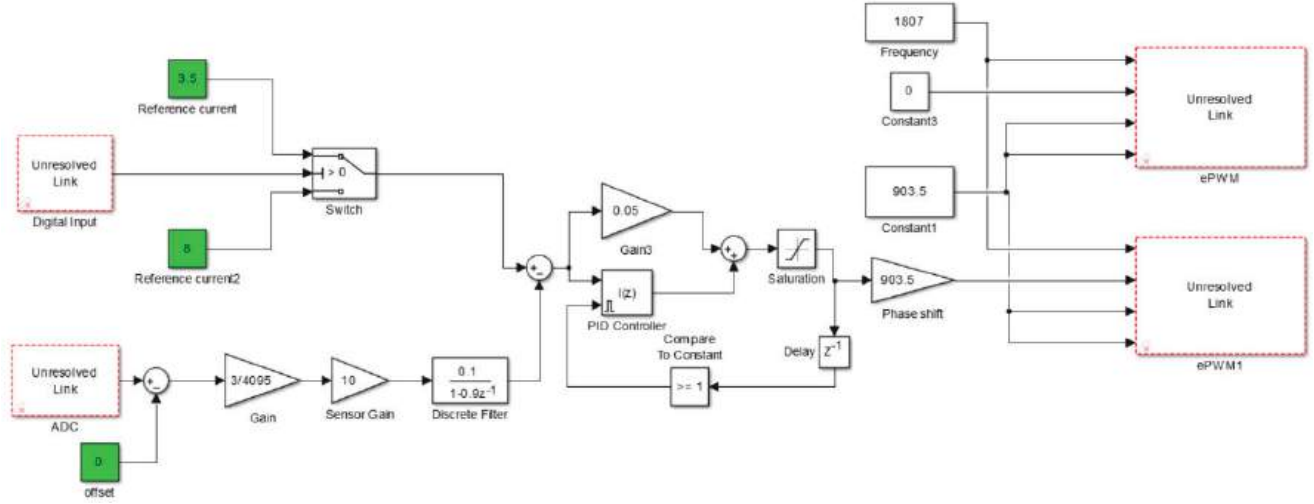
Simulation of a WPT charger using MATLAB/simulink



Also the external mode of Simulink is used in order to allow the interaction between the charger and the controller. It is a real time approach allowing online tuning of the controller parameters in order to ensure stable operation of the charger. It is worth noting that the controller has been downloaded on the C2000 F28335 MCU and it runs directly on the hardware but with the possibility of changing the parameters in real time. This results in rapid control prototyping and avoids wasting time. In addition, charging parameters such as current and voltage of the battery are monitored in real time. Other parameters of the charger are also monitored to ensure safe operation of the charger

Figure 8

WPT controller implemented in Simulink using external mode to allow online tuning and visualization

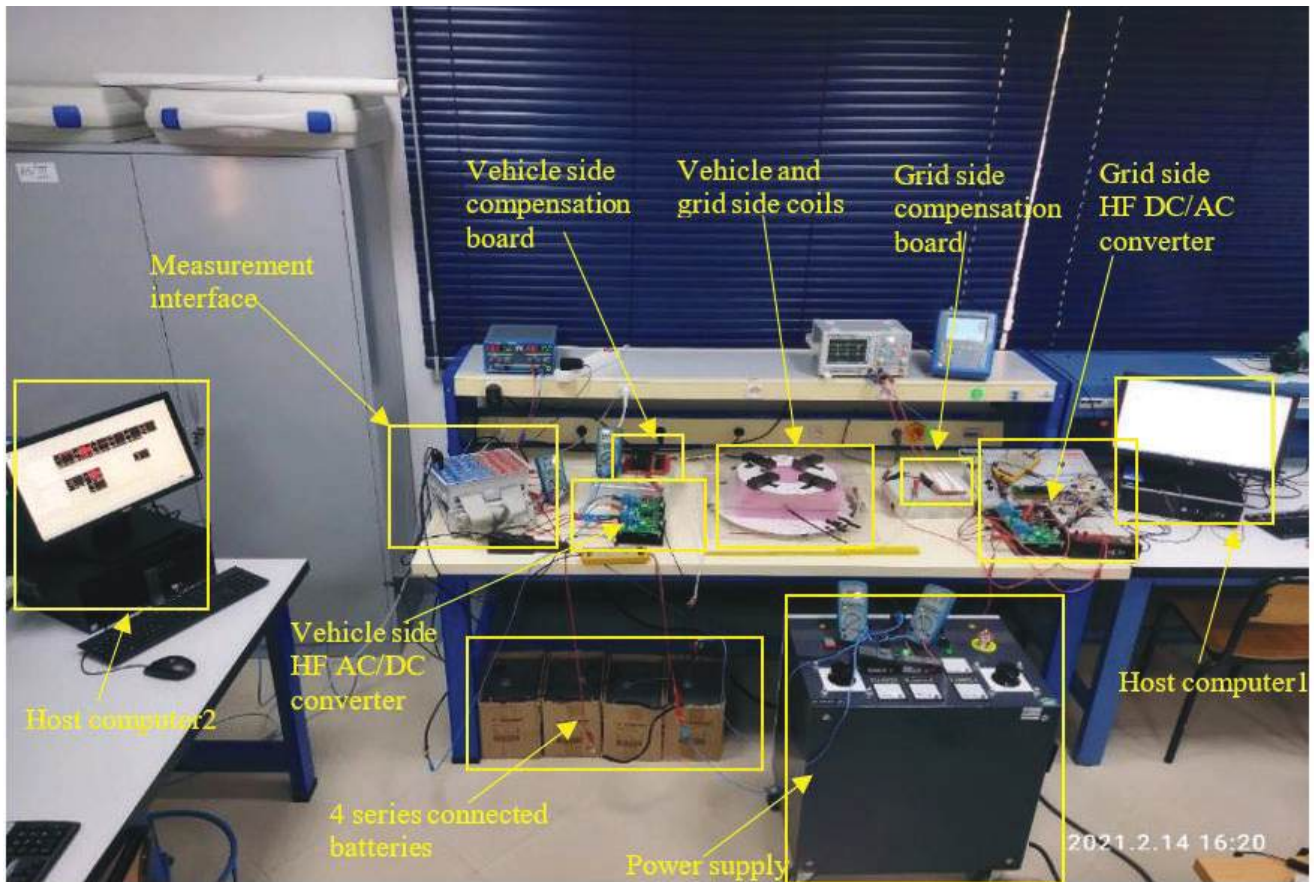


3 LABORATORY SETUP AT THE NATIONAL SCHOOL OF APPLIED SCIENCES KÉNITRA-MOROCCO

The developed laboratory setup is shown in the figure below. It is designed based on an open hardware and software approach to allow students to perform several tests including changing the soft or the hard parts. The prototypes includes all the components that could be encountered in a real WPT charger such as power converters, coils, reactive compensation, control and communication boards, measurements boards and so on. The students could perform several testing scenarios including: misalignments testing and efficiency assessment, controller design and performances evaluation, CC-CV charging and battery monitoring. It should be noted that all the real experiments could be initially tested on a digital twin model to predict the behavior of the charger before passing to the real testing. Also the students could test other coils geometries and shapes in order to assess their performances. In this way, the prototype serves both as a learning tool for students and as a flexible test bench for experimental research. The complete experimental setup is shown in the following figure.

Figure 9

Experimental setup (Issam Bentalhik et al. 2022)



4 EDUCATIONAL USE AND OBSERVED LEARNING OUTCOMES

The developed WPT platform has been utilized in an engineering educational context to support hands-on learning activities. Students were engaged in tasks such as:

- Measuring system efficiency under varying load conditions
- Investigating the impact of coil misalignment on power transfer
- Analyzing the relationship between resonance tuning and system performance
- Comparing theoretical predictions with experimental results

These activities enabled students to directly observe the influence of key parameters and to validate analytical models through experimentation.

From an instructional perspective, the platform facilitated improved student understanding of abstract concepts such as resonance and electromagnetic coupling. Students demonstrated

increased ability to interpret experimental data, identify discrepancies with theoretical models, and propose design improvements.

Although a formal quantitative assessment was not conducted, qualitative observations indicate that the platform enhances student engagement, promotes active learning, and strengthens the connection between theoretical knowledge and practical implementation.

The proposed WPT system can be also integrated into engineering curricula as part of laboratory sessions, project-based courses, or capstone projects. Its multidisciplinary nature makes it particularly suitable for courses in power electronics, renewable energy systems, and embedded control.

From a pedagogical standpoint, engaging students in the design and experimentation of such a system is important because it exposes them to real-world engineering challenges, including system integration, parameter sensitivity, and performance optimization. Unlike purely simulation-based approaches, the physical implementation allows students to confront practical constraints such as losses, misalignment, and measurement uncertainties.

5 PEDAGOGICAL APPLICATIONS AND LABORATORY EXERCISES

To facilitate adoption by educators, several example laboratory activities can be implemented using the proposed platform:

- **Resonance Tuning Experiment:** students adjust the compensation network to achieve resonance and observe its impact on power transfer efficiency.
- **Misalignment Analysis:** Learners investigate how lateral and angular misalignment between coils affects system performance.
- **Efficiency Optimization Task:** Students evaluate efficiency under different load conditions and propose design improvements.
- **Model vs Experiment Comparison:** Students compare analytical predictions with experimental results, identifying sources of discrepancy.

Instructors can adapt these activities depending on course level and available time. The platform can also be used for project-based learning, where students are tasked with modifying or improving specific subsystems (e.g., coil design, control strategy). These exercises aim to develop not only technical knowledge but also transversal skills such as problem-solving, teamwork, and critical analysis.

6 CONCLUSION

This paper presented a wireless power transfer charger developed not only as a functional system but also as a pedagogical platform for engineering education. By integrating analytical modeling,

control design, hardware implementation, and experimental validation, the proposed approach enables students to engage in a complete engineering workflow.

Beyond technical performance, the system supports active and experiential learning, allowing students to explore key phenomena such as resonance, coupling, and efficiency through direct experimentation. The proposed platform thus contributes to bridging the gap between theoretical instruction and practical application.

Future work will focus on conducting formal educational assessments to quantitatively evaluate learning outcomes and further refine the integration of the platform into engineering curricula.

7 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Pedagogy of the Self: Reflective Becoming in Technology Teacher Education

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Abstract

Reflective practice is widely positioned as central to Initial Teacher Education, yet novice reflection often begins as descriptive, compliance-shaped, and closely tied to assessment demands. Rather than treating this as a deficit, this paper asks how reflection in Technology Teacher Education might be supported to deepen over time into a more interpretive, ethical, and professionally generative practice. Drawing on a historical archive of reflective journals written during a ten-week school placement in Technology education subjects, the study adopts a critical autoethnographic approach to examine the process of reflective becoming. A two-cycle coding process identified recurring tensions around teacher identity, gender, discipline, workshop safety, assessment, inclusion, and subject pedagogy. Findings are organised through three scenes emerging from the archive: becoming the Technology teacher, ethical recognition in the workshop classroom, and a gradual movement from reflection as record toward reflection as inquiry. Framed within Irish Initial Teacher Education and informed by Céim's emphasis on identity, reflective practice, and ongoing professional formation, the paper argues that historical novice journals can function as a valuable pedagogical resource for rehumanising reflection. In response, the paper proposes the HEARTS framework, Human Connection, Ethical Recognition, Assessment for Professional Becoming, Reflective Intentionality, Trust through Modelled Vulnerability, and Subject Informed Judgement, as a conceptual model for reflective becoming in Technology ITE. The paper concludes that reflection in Technology Teacher Education is most usefully understood not as a polished demonstration of competence, but as part of the uneven and relational work of becoming a teacher.

Key Words: Autoethnography, Reflection, Vulnerability, Technology, ITE

1 INTRODUCTION

When I read aloud an extract from a reflective journal written during my 2015 school placement, the response from current student teachers was immediate. What appeared to resonate was not polished expertise, but the unfinishedness of becoming: the uncertainty of entering the workshop as the person responsible, the pressure to appear in control, and the effort to reconcile subject confidence with the human demands of teaching. Across ten weeks of placement in technology

subjects, these journals captured a version of myself that was technically eager, increasingly reflective, and still learning how to inhabit the role of teacher. In my first week I wrote that I was “calm and determined to show everyone and myself that this is the profession I belong in”, while later reflections captured the discomfort of having to “remove my teacher skin and readopt my student skin” at the end of placement. Together, these entries positioned teaching not as a settled state, but as a process of becoming.

Reflective practice is widely positioned as central to Initial Teacher Education (ITE), yet it can become narrowed into a procedural or assessment-led exercise rather than a critical exploration of professional judgement (Verene, 2013; Cloete, 2017). Recently, I had noticed reflections that were polished in form but often limited in pedagogical depth, describing events without fully engaging with uncertainty, ethical tension, or the reasoning behind professional decisions (McGarr and McCormack, 2014). This is not simply a deficit in novice teachers. Descriptive or compliance-shaped reflection is often a plausible starting point in early professional formation. As Mäeots et al. (2016) suggest, without careful scaffolding, reflection can remain at technical or situational levels rather than deepening into moral, relational, and pedagogical inquiry.

This issue is especially significant in Technology Education, where teaching brings technical competence, classroom authority, ethical judgement, and learner identity into close relation (Loughran, 2002; Cloete, 2017). Drawing on a coded and themed archive of reflections from ten weeks of school placement, this paper examines how historical novice journals can illuminate reflective becoming in Technology Teacher Education. Framed within Irish ITE and informed by Céim’s understanding of identity as both concept and process, the paper argues that revisiting the novice self can refocus reflection by making uncertainty, ethical recognition, and professional judgement more visible (Teaching Council, 2020). In doing so, it proposes the HEARTS framework as a way of conceptualising reflective becoming in Technology ITE, while remaining attentive to the risk that reflection, and even vulnerability itself, can become performative if reduced once again to compliance (Duarte, 2007; Baumer, 2015).

2 REFLECTIVE BECOMING IN IRISH ITE AND TECHNOLOGY EDUCATION

Within Irish Initial Teacher Education, reflection is central to how student teachers come to understand themselves, their practice, and their developing place within the profession. Céim: Standards for Initial Teacher Education positions identity as both concept and process, grounded in the view that teachers are always “becoming and being” teachers. In this sense, ITE is not a completed endpoint but an early stage in a longer professional journey. Céim further emphasises professional identity and agency, creativity and reflective practice, Taisce, professional conversations, and a realistic relationship between learning opportunities and assessment criteria (Teaching Council, 2020). Reflection, therefore, is not simply a written record of experience, but a means of supporting inquiry, dialogue, judgement, and further professional learning.

This framing is especially significant in Technology Education, where technical competence, classroom authority, ethical judgement, and learner identity are brought into close relation (Loughran, 2002; Cloete, 2017). Teaching in workshop and design-based environments requires movement between demonstration and dialogue, safety and trust, structure and creativity, and

subject expertise and relational care. The placement reflections used in this study make these tensions clear through recurring concerns with gender imbalance, teacher clarity, questioning, classroom discipline, workshop safety, pupil confidence, assessment, and mixed-ability teaching. These were lived pedagogical dilemmas through which a novice teacher was learning to balance authority with fairness, subject confidence with humility, and technical instruction with human responsiveness.

For this reason, the paper uses the term reflective becoming to describe the developmental movement visible within the journal archive. The phrase offers a more accurate account than simply criticising novice reflection as insufficiently deep. Early reflection is often partial, descriptive, and shaped by the demands of placement and assessment. The more useful pedagogical question is how ITE can support movement from those early forms toward reflection that is more interpretive, ethically alert, and professionally generative. That question is explored here through a critical autoethnographic revisiting of novice placement journals and is later synthesised through the HEARTS framework: Human Connection, Ethical Recognition, Assessment for Professional Becoming, Reflective Intentionality, Trust through Modelled Vulnerability, and Subject Informed Judgement. Together, these dimensions provide a conceptual model for reflective becoming in Technology ITE.

3 METHODOLOGY

This study adopts a qualitative critical autoethnographic approach to examine how historical novice reflections can illuminate the process of reflective becoming in Technology Teacher Education. Critical autoethnography is used here not as autobiography for its own sake, but as a way of revisiting personal experience as a site through which broader pedagogical, professional, and cultural questions can be examined (Ellis and Bochner, 2000; Egitim and Watson, 2024). In this study, a historical archive of placement reflections is re-read to surface the tensions, assumptions, and ethical judgements involved in becoming a technology teacher.

The principal dataset comprises the author's reflective journal archive from a ten-week school placement completed in 2015. The weekly entries, written across technology subjects, documented classroom experiences, pedagogical decisions, emotional responses, and emerging professional concerns. Recurring issues included gender participation, discipline, workshop safety, questioning, planning, assessment, pupil confidence, differentiation, and subject-specific teaching decisions. Originally produced as part of placement-based professional learning, the journals are revisited here as historical documents that offer insight into the early formation of teacher identity and judgement.

Analysis proceeded through a two-cycle coding process. First-cycle descriptive coding identified recurring incidents and pedagogical concerns such as gender, safety, discipline, questioning, clarity, assessment, motivation, inclusion, and confidence. Second-cycle analysis grouped these into broader interpretive themes, including novice-expert dissonance, ethical recognition, and reflection as inquiry. These themes shaped the findings and later informed the development of the HEARTS framework. In this sense, the framework emerged from the coded archive rather than preceding it.

A note of ethical positioning is necessary. Although extracts from the journals were later shared with current student teachers to prompt professional discussion, these contemporary responses are not treated as a formal secondary dataset. As they were not gathered through a separately consented research instrument, they are referred to only cautiously and illustratively. The evidential centre of the paper therefore remains the historical journal archive. Equally, the 2015 journals are not presented as somehow pure or free from performativity. Their value lies in their proximity to the lived immediacy of becoming, before later professional smoothing and retrospective coherence had taken hold.

Table 1

Thematic Analysis of 10-Week Reflective Data Aligned with HEART Framework and CéIM Standards

Wk.	Code / Critical Incident	HEART	Supporting CéIM Statement
1	“Cocktails of nervous and excited energy”. Gender divide in Metalwork.	Human / Ethical	Standard 2.1.1: Professional Identity & Agency for holistic development of all.
2	Blue report card incident; “I just wanna be average”.	Ethical	Standard 2.1.5: Upholding core values of care and respect in discipline.
3	Board-work critique; Inclusive school ethos plaque.	Reflective	Standard 2.2.27: Reflective Practice & Inquiry.
4	“Medals and Missions” feedback; Pitching to the “middle range”.	Assessment	Standard 2.2.13: Using feedback strategies to support progress.
5	“Masterchef” revision class; Journals and “yellow sheets”.	Human / Trust	Standard 2.3.10: Recognising pupils as active agents in their own learning.
6	Assessment for vs. of learning; Habitus and social class.	Assessment / Ethical	Inclusive Education: Responding to diverse socio-economic backgrounds.
7	Lathe intimidation / Gender roles; Diverse subject range.	Ethical / Human	Standard 2.2.12: Applying knowledge of pupil identities to planning.
8	Encouraging the student “staring into space”: Benefits of sketching.	Assessment / Reflective	Standard 2.2.11: Motivating and acknowledging effort and success.
9	Report card student as “role model”; Snappy teacher responses.	Trust	Standard 2.2.15: Collaborative professionalism and agentic trust.
10	Removing “teacher skin”: Obsessive planning as a confidence tool.	Reflective / Trust	Standard 2.1.2: Adaptive Expertise and Capability to identify when routines fail and seek new info.

4 FINDINGS

Analysis of the coded journal archive identified recurring tensions around authority, inclusion, technical confidence, discipline, assessment, and care across the ten-week placement. Three recurring scenes were evident: novice-expert dissonance, ethical recognition in the workshop classroom, and a movement from reflection as record toward reflection as inquiry. These are presented as patterns across the archive rather than as fixed stages.

4.1 *Novice-expert dissonance*

The early journal entries show a novice teacher entering placement with determination, subject enthusiasm, and a strong awareness of professional visibility. In Week 1, I wrote that I was “calm and determined to show everyone and myself that this is the profession I belong in”, capturing both confidence and the pressure to establish myself in the role. Across the early weeks, recurring attention was given to clarity, questioning, preparation, and maintaining an orderly but respectful learning environment.

This tension appeared across both practical and theory-based teaching. In Metalwork and Engineering, the entries focused on demonstrations, workshop procedures, safety, and pupils’ need for clear step-by-step guidance. In Technical Graphics, similar concerns appeared through pacing, explanation, questioning, and the presentation of visual material. After tutor feedback in Week 3, I noted that a well-written lesson plan did not necessarily translate into a clear lesson for pupils, particularly where board-work and staged explanation could have been improved.

By the final weeks, the entries show greater classroom ownership, though still shaped by reflection on organisation and control. In Week 10, I described having to “remove my teacher skin and readopt my student skin” at the end of placement, while also reflecting on how planning and preparation had supported my confidence. Across the archive, the journals repeatedly register the gap between subject confidence and the pedagogical demands of inhabiting the teacher role.

4.2 *Ethical recognition in the workshop classroom*

A second recurring pattern concerned moments in which practical classroom issues were accompanied by questions of fairness, participation, expectation, and dignity. One focus was gender in Metalwork and Engineering. In Week 1, I noted the low number of female pupils in practical classes and questioned why these subjects remained so male-dominated, particularly when the girls present appeared just as capable as the boys. This concern resurfaced in Week 7 during a lathe demonstration, when one girl immediately said, “Sir, I won’t be able to do it” because “it’ll be too hard”. The reflection captured both the incident itself and my attention to confidence and willingness in that setting

Questions of discipline also appeared in ethically charged ways. In Week 2, after a pupil used a metal rule inappropriately during practical work, I reflected not only on the sanction given but on whether I was dealing with the pupil in a “correct and professional manner” and how disciplinary consequences might affect the pupil-teacher relationship. Similar concerns appeared later in Week 5, where I contrasted positive classroom relationships in some groups with more difficult

interactions in a 5th year Engineering class. Across these entries, the issue was not only behaviour management, but how authority was exercised in a safety-critical environment

This pattern extended to how pupils were perceived across subjects. In Week 9, I reflected on a pupil who was repeatedly described elsewhere as lazy, disinterested, or rude, but who performed strongly in my class, particularly during practical work and revision activities. The entry focused on the contrast between those descriptions and my own classroom experience of the pupil. Across the archive, questions of participation, confidence, behaviour, and capability were repeatedly read through the teacher's response to pupils in the workshop classroom.

4.3 *From reflection as record toward reflection as inquiry*

A third recurring scene involved a shift in how classroom events were reflected upon. Earlier entries often documented what had happened in class and whether a lesson had gone well. Later entries more frequently asked why particular strategies worked, how pupils were responding, and what alternative approaches might be more effective.

This shift is visible in reflections on differentiation and questioning. In Week 4, I questioned whether some lessons were being pitched too heavily toward the middle range of ability and whether weaker pupils were therefore experiencing only surface learning. I then recorded changes in how questions were structured and directed to pupils at different levels of understanding. In Week 6, after a Technical Graphics exam, I described asking pupils to identify what had gone well, what they found difficult, and what grade they believed they deserved. The entry linked this to assessment for learning, diagnosis, and pupils' awareness of their own understanding.

Similar patterns appeared in reflections on revision and task design. In Week 5, I described using a "Masterchef" style revision task in which groups presented parts of a topic back to their peers. The reflection focused on pupil engagement, what the activity revealed about understanding, and the extent to which pupils could take responsibility for their own learning. In Week 8, reflections on Technical Graphics moved toward questioning whether drafting was always the most appropriate approach for learning, with more attention given to sketching, visualisation, and alternative strategies in the subject. Across the archive, later entries were more likely to include explicit questions about method, understanding, and subject-specific teaching decisions.

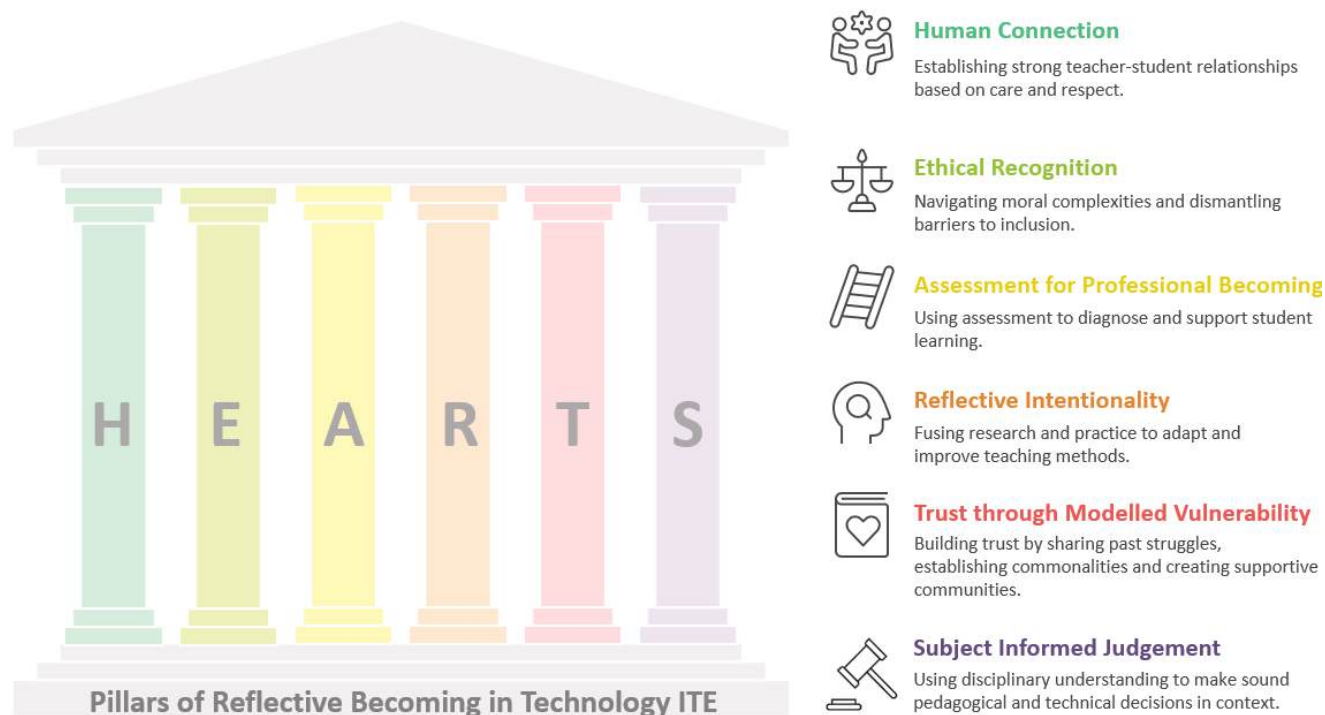
5 DISCUSSION: THE HEARTS CONCEPTUAL FRAMEWORK

The findings of this study suggest that the value of the historical journal archive lies not in presenting an exemplary model of reflection, but in making visible the uneven process of reflective becoming in Technology Teacher Education. Read in this way, the journals do not show a novice teacher failing to meet an ideal standard of critical reflection. Rather, they show a beginning teacher working through the ordinary but significant tensions of early practice: wanting to appear competent, learning how to exercise authority, navigating safety and relationships in workshop settings, and gradually moving from describing events toward questioning pedagogical decisions. This is an important distinction. If novice reflections are often partial, descriptive, or shaped by assessment expectations, that should not be treated as surprising. It is a plausible feature

of early professional formation. The more meaningful question for ITE is how teacher education can help reflection deepen over time into a more interpretive, ethically alert, and professionally generative practice (Mäeots et al., 2016; McGarr and McCormack, 2014).

Figure 1

The HEARTS framework: a conceptual model for reflective becoming in Technology ITE



What the archive particularly exposes is a form of novice-expert dissonance. The journals repeatedly register a gap between subject confidence and the pedagogical reality of inhabiting the teacher role. This was visible in the desire to appear clear, controlled, and technically capable, even while still learning how to read a room, scaffold effectively, and respond to pupils as learners rather than simply recipients of subject knowledge. In this sense, the novice archive is valuable because it captures what later expertise can obscure. As Loughran (2002) argues, reflective practice is not simply about reviewing action, but about searching for meaning in learning about teaching. Rereading the reflective journals from 2015 revealed the intense emotional instability inherent in the transition from presumed technical expert to neophyte pedagogue (Neyman, 2011). As Trevallion (2018) notes, individuals entering Technology Education often possess a professional identity rooted in technical competence and a master-and-apprentice model of instruction. However, the journals reveal that this technical confidence is quickly destabilised by the pedagogical realities of the classroom. Reviewing the journals from the standpoint of teacher educator also supports Egitim and Watson's (2024) argument that revisiting the self can expose assumptions that routinised practice may otherwise leave unexamined. The journals therefore illuminate not only what happened during placement, but what early professional formation felt like from within.

Framed in relation to Irish ITE, this developmental reading aligns strongly with Céim, which positions identity as both concept and process and understands teachers as always “becoming and being” teachers (Teaching Council, 2020). Céim also places professional identity and agency, creativity and reflective practice, Taisce, and professional conversations as central to student teachers’ learning and development. Through that lens, the journal archive can be read not as a record of completed competence, but as evidence of early professional formation shaped through reflection, inquiry, and experience. The HEARTS framework is offered here as a conceptual synthesis of that process in Technology ITE: Human Connection, Ethical Recognition, Assessment for Professional Becoming, Reflective Intentionality, Trust through Modelled Vulnerability, and Subject Informed Judgement.

Human Connection and Ethical Recognition were especially visible in the way classroom incidents carried relational and moral weight beyond their immediate practical form. The findings showed that participation, gender confidence, pupil behaviour, and belonging were not peripheral to teaching technology subjects, but deeply entangled with them. In workshop classrooms, capability is not encountered only through making or drawing, but through how students are positioned, noticed, challenged, and affirmed. This supports Neyman’s (2011) view that teaching identity is formed through the reciprocal relationship between the personal and the professional. In this respect, becoming a Technology teacher involves learning to read pedagogical situations not only technically, but ethically. This matters because Technology Education makes the interaction between practical competence, authority, safety, and inclusion especially visible in day-to-day teaching.

Assessment for Professional Becoming and Reflective Intentionality were evident in the gradual shift from recording classroom events toward questioning strategy, differentiation, and subject pedagogy. These findings suggest that reflection became more useful when it was tied to professional judgement rather than simply retrospective description. This is important in light of Céim’s emphasis on a realistic relationship between learning opportunities and assessment criteria, and on reflective and portfolio-based learning as developmental rather than merely performative (Teaching Council, 2020). From this perspective, the issue is not whether reflection is assessed, but whether assessment helps student teachers think more deeply about practice or simply learn to produce acceptable reflective texts. The HEARTS framework therefore positions assessment as something that should scaffold professional growth rather than merely measure reflective compliance. This also aligns with Larrivee’s (2008) distinction between descriptive reflection and more critically aware forms of reflective practice.

Trust through Modelled Vulnerability emerged as the clearest pedagogical implication of revisiting the journals. Re-reading these entries has reshaped how I now think about teaching reflection on the ITE programme. While contemporary student responses are not treated here as a formally analysed dataset, reading aloud excerpts from my own novice reflections appeared, anecdotally, to shift the tone of reflective conversations with current student teachers. What seemed to matter was not simply the content of the stories, but the openness of hearing uncertainty, awkwardness, ethical tension, and incompleteness voiced by a lecturer who now occupies a position of relative authority. This has made me more conscious that reflection may need to feel discussable before it can become meaningful. In my current practice, I now place greater value on openness, professional honesty, and the naming of tensions, rather than treating

reflection primarily as a polished written performance. At the same time, this paper does not propose vulnerability as a new performative ideal. If uncertainty or disclosure become markers of “good” reflection, student teachers may simply learn to perform authenticity. The pedagogical value of modelling vulnerability lies not in rewarding confession, but in making professional reasoning and uncertainty more visible and therefore more discussable (Duarte, 2007; Baumer, 2015).

Finally, Subject Informed Judgement keeps the framework anchored in the disciplinary character of Technology Education. The findings showed that reflection was repeatedly tied to subject-specific decisions about demonstration, drafting, sketching, questioning, practical revision, workshop safety, and visual explanation. This is significant because it suggests that reflective becoming in Technology ITE is not separate from disciplinary learning but bound up with it. Student teachers are not only learning to reflect on teaching in general. They are learning to make pedagogical judgements within the distinct technical, material, and social demands of their subject. The HEARTS framework therefore offers a way of understanding reflective becoming in Technology Teacher Education as a process in which human, ethical, developmental, and disciplinary dimensions are formed together rather than in isolation.

6 CONCLUSION

This paper has argued that reflective practice in Technology Teacher Education is better understood as a process of reflective becoming than as a finished demonstration of professional competence. Revisiting a historical archive of novice placement journals made visible the uneven and developing nature of early reflection, showing how questions of authority, inclusion, assessment, subject teaching, and ethical judgement were already present within the lived experience of becoming a teacher. Rather than treating descriptive or compliance-shaped reflection as a simple deficit, the paper has suggested that such reflection is often a plausible starting point in Initial Teacher Education, and that the more important pedagogical question is how it may be supported to deepen over time.

Framed within Irish ITE, this argument aligns with Céim’s understanding of identity as both concept and process, and with its emphasis on reflective practice, professional conversations, Taisce, and the continuing development of the teacher across the broader professional continuum. In response to this, the HEARTS framework was proposed as a conceptual model for reflective becoming in Technology ITE.

The paper does not claim that vulnerability offers a simple solution to the challenges of reflective practice, nor that it should become a new performative marker of reflective success. Instead, it suggests that revisiting and, where appropriate, pedagogically sharing the unfinished novice self may help make reflection more honest, relational, and professionally meaningful. In Technology Education, where teaching continually moves across technical, ethical, and human domains, this matters. Reflection is not only about recording practice after the fact, but about learning how to inhabit the professional self with greater awareness, care, and judgement.

7 AI DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the author.

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Preliminary Effects of STEAM Programs on Students' Career Variables in the Republic of Korea's K-12 Classrooms: Meta-analysis and Systematic Literature Review

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Abstract

In South Korea, STEAM education policy has been implemented since 2011. STEAM education has also been implemented with the aim of promoting students' interest in pursuing careers in STEM fields; however, existing studies on the impact of STEAM programs on career-related outcomes remain limited. The purpose of this study is to identify trends in STEAM education research related to students' career-related benefits and to examine its effectiveness. A systematic literature review was employed to describe key trends in STEAM education related to career-related benefits. A multilevel meta-analysis was also conducted using R for Statistical Computing (Version 4.5.2) to achieve the research goal. This study included only theses and dissertations published between 2011 and 2025. A total of 27 studies were selected, all focusing on STEAM programs that examined career-related variables. From these studies, 35 effect sizes were extracted for analysis. STEAM education showed a moderate positive effect on students' career-related outcomes (Hedges' $g = 0.45$), with most programs being science-centered and primarily focusing on short-term outcomes such as career awareness and interest.

Keywords: STEAM, Career-related, Meta-analysis, Literature, Students

1 INTRODUCTION

Today's social problems are complex, and it is hard to solve them with only simple or separate knowledge. In the future, society will require people to have integrative thinking that combines different kinds of knowledge (OECD, 2019). Because of these changes, integrative education has been implemented around the world, although it is used under different names such as STEM (Science, Technology, Engineering, Mathematics) education in the US or STEAM education in South Korea.

Academic research on integrative STEM education has also been conducted worldwide. Sanders (2001) defined integrated STEM education as an effort to integrate the basic ideas used in science, technology, engineering, and mathematics, which are closely interrelated. This approach, with its profound historical, philosophical, and pedagogical perspectives, has been consistently studied and implemented in school settings. Therefore, the school subjects can be taught in an integrated way called Integrative STEM education (Kim et al, 2012). The reason the United States began to emphasize STEM education was because students' mathematics and science achievement was not sufficient, and fewer students wanted to enter STEM fields. STEM education was promoted to increase students' interest and motivation, help them develop STEM literacy, encourage more students to go into science and engineering fields, and ultimately strengthen the nation's science and technology competitiveness (Sim, Lee & Kim, 2015). Integrative STEM Education is teaching and learning that connects two or more STEM subjects, and it started in the United States and is now happening all over the world.

Influenced by STEM education in the United States, South Korea introduced STEAM education as a Korean-style convergence approach in 2011. STEM education in the US is primarily grounded in integrative approach, as it focuses on the connection of multiple disciplines. However, when it extended to emphasize creativity and real-world problems solving, it also aligns with the principles of convergence education. The goal of STEAM education in South Korea is to cultivate creative and convergent individuals who can solve real-world problems by integrating knowledge across disciplines, while simultaneously enhancing students' interest, motivation, and career awareness in science and technology/engineering fields. STEAM education incorporates the Arts. The "Arts" component does not merely refer to the inclusion of art subjects, but rather functions as means to promote creativity, emotional engagement, and human-centered design, thereby facilitating the integration of disciplinary knowledge into meaningful and contextually relevant problem-solving (MEST, 2010).

Educational researchers and practitioners in South Korea have developed STEAM programs and have examined the general effects of STEAM education, such as academic achievement and learning-related outcomes (Sim, Lee & Kim, 2015). Korean Ministry of Education took the lead in developing STEAM programs and encouraged their implementation in school curricular in the early days of STEAM education policy. The development and expansion of STEAM education in South Korea have been relatively active, with generally positive outcomes. Prior studies have preliminary reported improvements in students' cognitive development, problem-solving abilities, and creativity, which are considered essential components in STEM-related fields (Lee, Ham, & Kwon, 2020). However, findings on the influence of STEAM education on career-related variables-including career interest, career attitudes, and students' intentions to pursue STEAM careers remain inconsistent and insufficient. Therefore, this study conducts a meta-analysis to synthesize existing research and determine the overall impact of STEAM education on students' career-related variables.

2 RESEARCH QUESTIONS

This study aims to systematically analyze the literature on STEAM education related to students' career development to identify research trends and to synthesize the results of multiple studies through meta-analysis to determine the overall effect size.

- What are the research trends in STEAM education on students' career development in South Korea, as identified through a systematic literature review?
- How are career-related variables addressed in STEAM education research in Korea? (e.g., career awareness, career interest, career self-efficacy)
- What is the overall effect size of STEAM education programs on students' career-related variables?

This study presents research trends in STEAM education related to students' career benefits, providing implications for future research. Furthermore, it explored the sub-construct of career benefits measured when addressing students' career benefits. Finally, by assessing students' career benefits, calculation of the effect size can be utilized to estimate the effectiveness of STEAM education programs developed in South Korea. This study could offer valuable implications for educational practice and policy.

3 LITERATURE REVIEW

With the development of technology and the social changes that follow, problem-solving skills, critical thinking, and creativity are becoming more important in future society (OECD, 2019). To meet these needs, Korea's curriculum has continued to expand convergence education to develop creatively convergent talents. Convergence-education policies have also been carried out systematically at the national level, since Korea's curriculum is based on a national curriculum and is implemented in the same direction across the country (Kang, 2019).

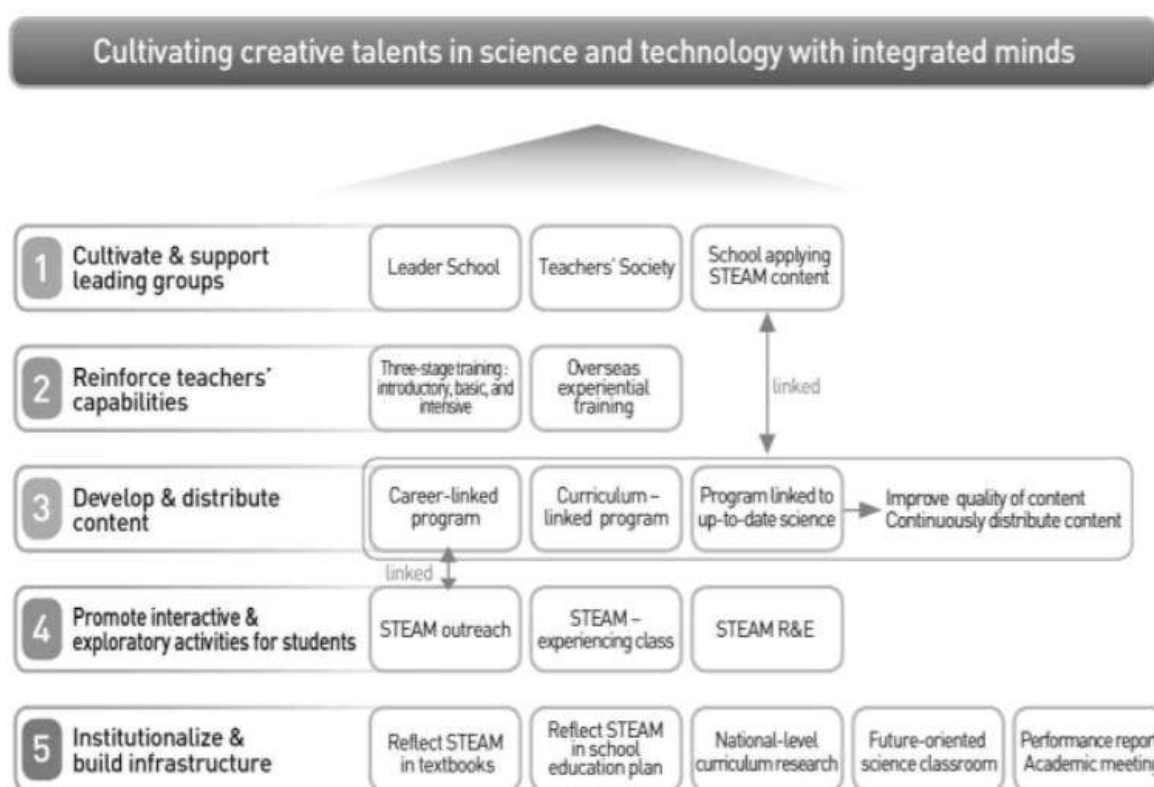
In South Korea, convergence education – referred to as STEAM (Science, Technology, Engineering, Arts, and Mathematics) education - was first promoted as a national policy in 2011 (MEST, 2010). The Ministry aimed to develop students who have both scientific and technological literacy and artistic sensitivity by connecting math and science with technology, engineering, and the arts. STEAM education was introduced to increase students' interest and understanding of science and technology, and to help them develop integrated thinking and problem-solving skills in real-life contexts (Kim et al., 2012; Sim, Lee & Kim, 2015). Figure 1 provides an overview of STEAM education policy.

Changes were applied to the national curriculum. The 2015 Revised Curriculum, implemented in 2017, included integrative thinking and real-life problem-solving skills as key educational goals and presented the cultivation of creative and convergent human resources as its vision. The most significant change was that, instead of dividing high school tracks into humanities and sciences, the curriculum made subject boundaries more flexible to promote interdisciplinary understanding (MOE, 2015).

The Mid- to Long-term Plan for Convergence Education (2018–2022) was designated as a national policy task in line with the full revision of the Act on the Promotion of Science, Mathematics, and Information Education (revised on October 14, 2017). As a result, the second Comprehensive Plan for Convergence Education: 2020–2024 introduced practical measures to ensure the establishment and expansion of convergence education in school settings, including the development and distribution of convergence-education programs and the provision of professional development for teachers (MOE, 2020).

Figure 1

The Structure of STEAM Education Policy in South Korea



Source: Hong (2018)

The Third Comprehensive Plan for Convergence Education: 2025–2029 aims to enhance and strengthen convergence education suitable for the digital era. Under this plan, STEAM education is implemented with a primary focus on science, mathematics, and software (SW) & Artificial Intelligence (AI) (MOE, 2024).

To realize this goal, the 2022 Revised Curriculum introduced new convergence subjects grounded in inter-subject linkage and integration and promoted project-based learning to expand student-led experiences in convergent problem solving (MOE, 2021).

Korea's convergence education policy aims to cultivate creative problem-solving skills as its core goal. To ensure that convergence education is effectively implemented in schools, Korean education policy has continued to promote the development of instructional programs that

integrate knowledge, values, and attitudes, alongside curriculum revisions. In addition, to strengthen student-led problem-solving experiences, teaching and learning methods have been shifting toward project-based learning approaches, supported by corresponding teacher professional development.

4 METHODS

This study focuses on prior studies that investigated the effect of STEAM education on students' career-related benefits. To accomplish the goal of this study, systematic literature review and meta-analysis were employed. Meta-analysis is a systematic strategy to synthesize the research findings of prior empirical studies to obtain a systematic comprehension of the future development of the field (Johnson & Christensen, 2008).

4.1 Data Collection

Theses and dissertations that implemented the integrative STEAM education program measuring students' career-related variable(s) and published between 2011 and 2025 in South Korea were used as data for a meta-analysis to calculate the effect size. The data were collected by using diverse search keywords (see Table 1) at the Korean academic database such as the National Assembly Digital Library (<https://www.nanet.go.kr/english/main.do>), Korea Citation Index (<https://www.kci.go.kr/kciportal/main.kci>), DBpia(<https://www.dbpia.co.kr/>), and RISS (<https://www.riss.kr/index.do>). The inclusion criteria are presented in Table 2, and the exclusion criteria are summarized in Table 3. Through several steps of a screening process, this study finally selected twenty-seven papers for meta-analysis (see Figure 2).

Table 1

Searching Keywords

Term related to STEAM	Term related to the career variable	Term related to the educational context
“STEM” OR	Career W/5 (aspiration* OR	“education” OR
“STEAM” OR	interest* OR esteem OR	“program” OR
“Integrated” OR	motivation OR efficacy)	“development” NOT
“Convergence” OR		(college or Undergraduate)
“Integrated STEM” OR		
“Conversion Program” OR		
“Multidisciplinary STEM”		

Table 2*Inclusion criteria*

Inclusion criteria	Rationale
The study used STEAM education as an intervention.	This criterion ensures that only studies examining the effects of STEAM or integrated STEM education are included, allowing for a focused analysis of their impact on students' career-related outcomes.
The study used experimental and quasi-experimental designs.	Experimental and quasi-experimental designs enable stronger causal inferences regarding the effects of STEAM education compared to descriptive or correlational studies.
The study used K-12 students as participants.	This criterion ensures that the analysis focuses on school-aged learners and excludes higher education or adult populations, which differ in developmental and educational contexts.
The studies were conducted in South Korean K-12 educational settings.	Restricting the context to South Korea ensures consistency in curriculum, educational policy, and cultural context across studies.
The study included a comparison group or a pretest–posttest design.	The inclusion of a control/comparison condition or pretest–posttest design allows for the estimation of effect sizes and strengthens internal validity.
The study provided sufficient statistical information to calculate effect sizes.	Studies were included if they reported sufficient statistical information to calculate effect sizes (e.g., means, standard deviations, sample sizes, t , F or r values).
The study was published in Korean or English.	This criterion ensures feasibility and accuracy of data extraction while covering the primary languages used in South Korean educational research.
The study was published as a thesis or dissertation.	This research was conducted as a preliminary study; only theses and dissertation were included.
The study was published from 2011 to 2025.	STEAM education began to be actively researched in South Korea after 2010; thus, studies published after 2011 were considered to reflect the contemporary implementation of STEAM education.

4.2 Data Collection and Analysis

Data collection procedure was conducted by the identification, screening, and final inclusion (See Figure 2). A total of 157 studies were initially identified and imported for screening. During the identification stage, studies were excluded if they did not focus on K-12 education, were review

articles, or were duplicated records. During the screening stage, studies that did not implement STEAM education programs or did not examine career-related outcomes were excluded. In addition, a quality screening process was conducted to ensure methodological rigor. Specifically, studies were included only if they employed appropriate research design and used clearly described and statistically valid analytical methods. As a result, 27 studies were included in the final systematic literature reviews and meta-analysis.

Figure 2

Data Collection procedures

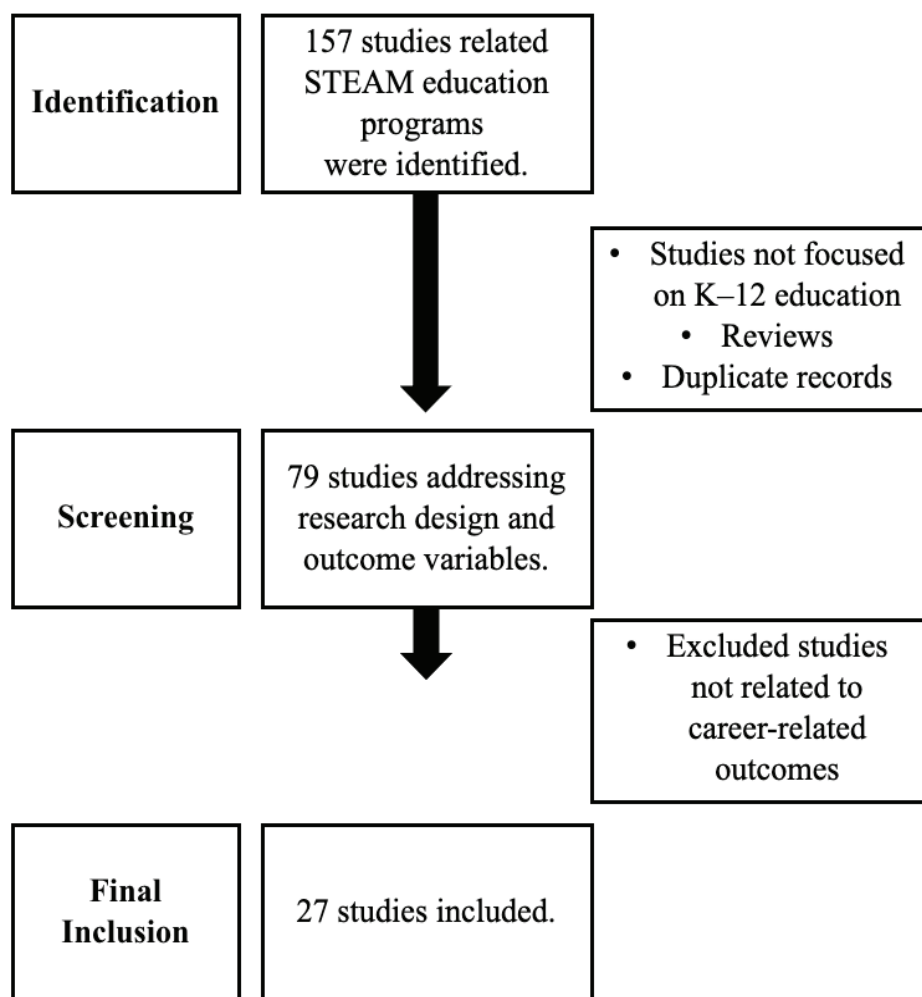


Table 3*Exclusion criteria*

Exclusion criteria	Rationale
The study exclusively used qualitative research methods without quantitative data.	This meta-analysis focuses on quantitative synthesis; therefore, studies without measurable outcomes cannot be used to calculate effect sizes.
The study did not implement STEAM or integrated STEM education as an intervention.	Studies without STEAM interventions fall outside the scope of this review, which aims to examine the effects of such programs on career-related outcomes.
The study focused solely on academic achievement or general learning attitudes.	This review specifically examines career-related outcomes; studies not measuring career variables are not directly relevant to the research objectives.
The study involved participants other than K–12 students (e.g., college students, preservice teachers, or adults).	Excluding non–K–12 populations ensures consistency in developmental stage and educational context across included studies.
The study was conducted outside the South Korean educational context.	Limiting studies to South Korea ensures comparability in curriculum structure, educational policy, and cultural context.
The study lacked a comparison group or pretest–posttest design.	Without a comparison condition or pretest–posttest structure, it is not possible to estimate the effects of STEAM education reliably.
The study did not provide sufficient statistical information to calculate effect sizes.	Effect size estimation requires adequate statistical data (e.g., means, standard deviations, and sample sizes).
The study was a meta-analysis, systematic review, theoretical paper, or policy report.	This review synthesizes original empirical studies only; secondary analyses and conceptual papers are excluded.
The study was not published in Korean or English.	Language restrictions ensure accurate interpretation and data extraction within the scope of this review.

The study was published before 2011.

STEAM education began to be actively implemented and researched in South Korea after 2010; earlier studies do not reflect contemporary practices.

This study conducted a systematic literature review and meta-analysis, extracting 35 effect sizes from 27 papers. For this systematic literature review, a coding table was developed to systematically categorize study characteristics and career-related variables, as shown in Table 4. Then, the effect sizes of career-related variables were analyzed to determine the effects of STEAM programs on students' career-related variables. In some cases, multiple effect sizes were reported within a single article, so a multilevel meta-analysis was performed to account for the interdependence of effect sizes (Van den Noortgate et al., 2013; Cheung, 2014). This approach controlled for the issue of non-independence among effect sizes produced within the same study and aimed to more accurately estimate the effects of STEAM programs on students' career-related variables.

Two researchers independently screened the titles and abstracts of the retrieved studies through two rounds to determine their eligibility. As a result, a total of 27 studies were selected for the final analysis. To ensure the reliability of study selection and data coding, the two researchers conducted the analyses independently and then assessed inter-rater reliability using Cohen's Kappa (K) (Cohen, 1960). Cohen's Kappa is a statistic used to measure inter-rater reliability (IRR) by accounting for the probability of agreement occurring by chance (Landis, Koch, 1977). The kappa value ranges from -1 to $+1$, where 1 indicates perfect agreement between raters and 0 indicates agreement due entirely to chance. According to Landis and Koch, Kappa values can be interpreted as follows: ≤ 0 = poor, $0.01-0.20$ = slight, $0.21-0.40$ = fair, $0.41-0.60$ = moderate, $0.61-0.80$ = substantial, and $0.81-1.00$ = almost perfect agreement.

In this study, the IRR was substantial ($K = 0.75$). Discrepancies between the researchers were resolved through cross-checking and discussion to reach consensus.

Table 4

Analytical framework for systematic literature review

Category	Analysis Contents	Category	Analysis Contents
School level	○ Elementary School ○ Middle School ○ High School	Duration	○ 4-6 sessions ○ 7-10 sessions ○ 11-15 sessions ○ ≥ 15 sessions
Focused-subject developed	○ Science-focused ○ Technology-focused ○ Engineering-focused	Career Variable	○ Career Awareness ○ Career Interest ○ Career Attitude

STEAM program	○ Arts-focused	○ Self-Efficacy
	○ Mathematics-focused	○ Career Development
Contexts	○ Regular curriculum	○ Free semester program
	○ Gifted education	○ After-school program

5 FINDINGS

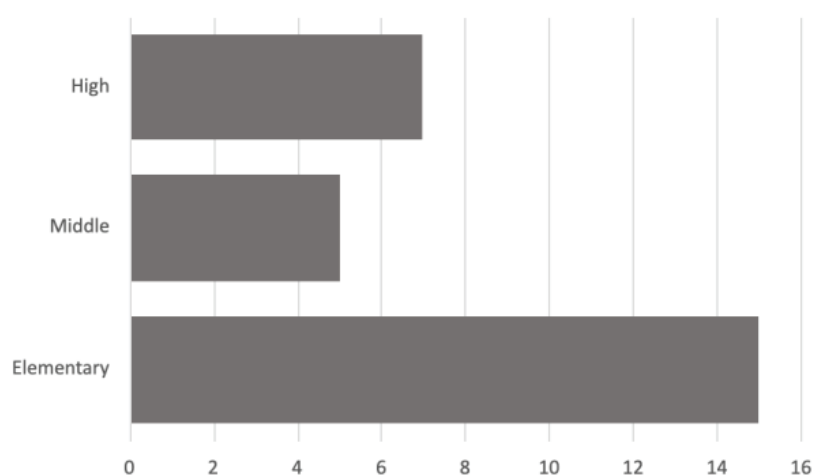
5.1 *Systematic Literature Review*

5.1.1 *School level*

Out of the 27 studies, 15 focused on elementary school, 5 on middle school, and 7 on high school level conducted. Overall, most studies were conducted at the elementary school level.

Figure 3

Distribution of studies by school level (Total N = 27)

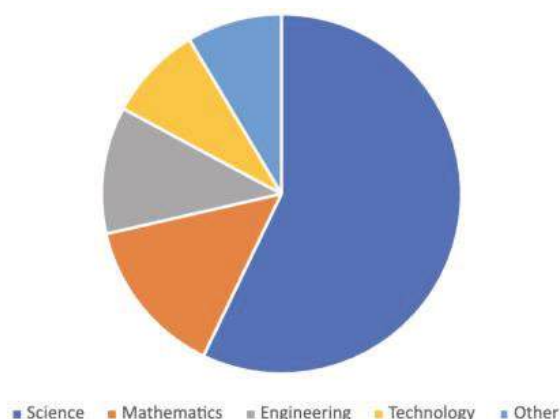


5.1.2 *Distribution of Core Disciplines in STEAM Program Design*

The results regarding the subject areas on which STEAM programs were primarily developed are as follows: they were most frequently developed with a focus on science, accounting for 16 of the 27 studies. Fewer studies focused on mathematics (N = 2), while engineering, technology, and other subjects each accounted for 3 studies. The category “other” refers to programs developed in non-STEAM subjects, such as social studies and Korean language subjects.

Figure 4

Distribution of core disciplines in STEAM program design (Total N = 27)

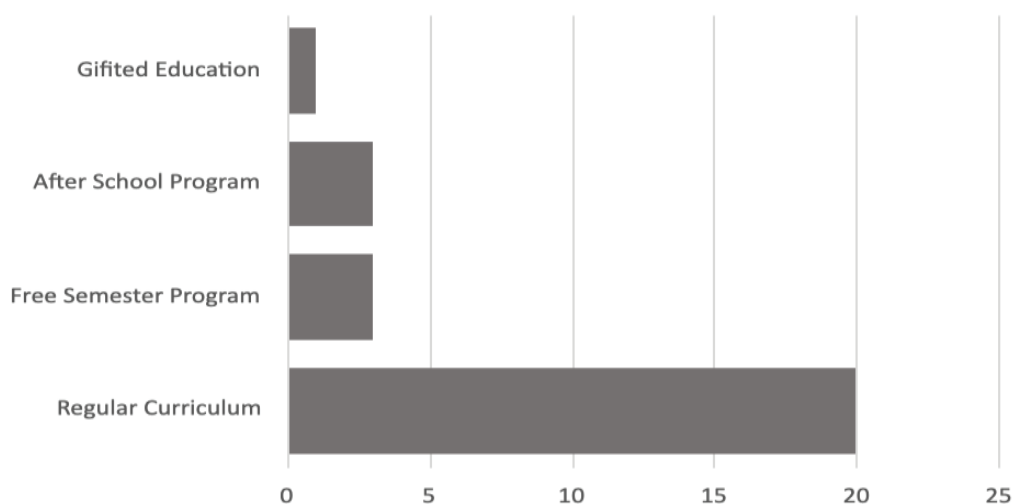


5.1.3 Implementation context of STEAM programs

Most STEAM programs were implemented as part of the regular curriculum, accounting for 20 of the 27 studies. Fewer programs were conducted during the free semester (N = 3) or as after-school programs (N = 3), while only one study focused on gifted education.

Figure 5

Distribution of STEAM programs by implementation contexts (Total N = 27)



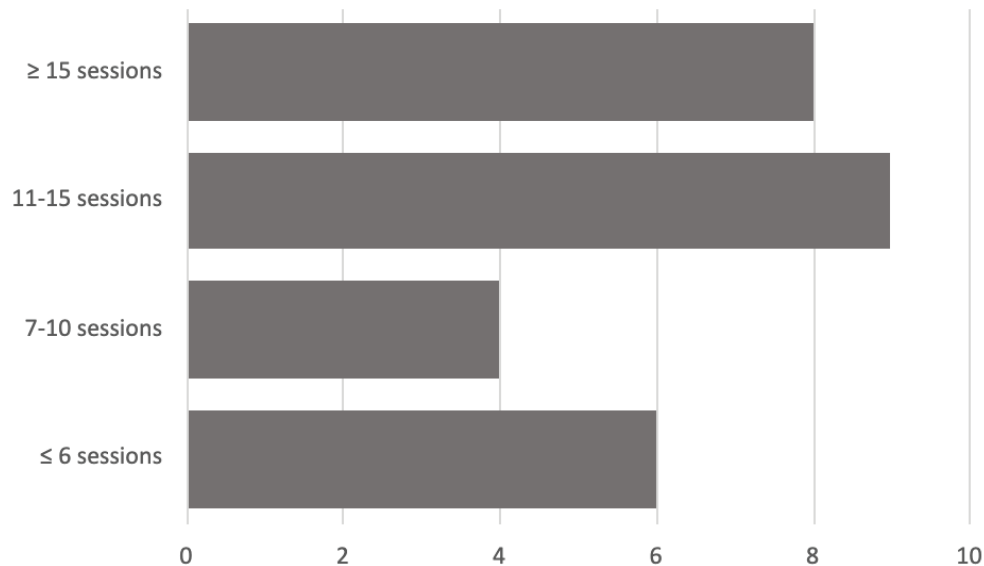
5.1.4 Program Durations

The duration of STEAM programs varied across the included studies, ranging from a minimum of three sessions to a maximum of 80 sessions. Programs consisting of 11–15 sessions were the

most common ($N = 9$), followed by programs with 15 or more sessions ($N = 8$). Shorter programs with six sessions or fewer accounted for 6 studies, while 7–10 sessions were reported in 4 studies. Overall, most STEAM programs were implemented over more than 10 sessions.

Figure 6

Distribution of STEAM programs by number of sessions (Total $N = 27$)

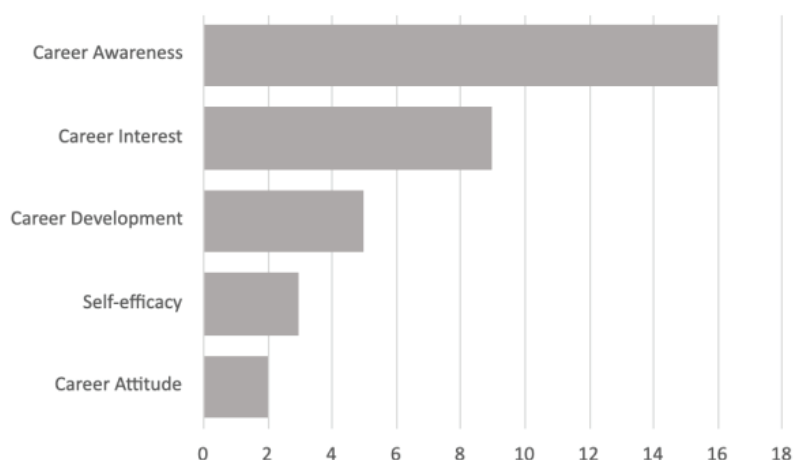


5.1.5 Career Variables

A total of 35 effect sizes were extracted from the 27 studies, and a systematic literature review was conducted to examine which career-related variables were measured by these effect sizes. Career awareness was the most frequently examined outcome, accounting for 16 effect sizes. This was followed by career interest ($N = 9$) and career development ($N = 5$). Fewer effect sizes focused on self-efficacy ($N = 3$) and career attitude ($N = 2$). Overall, the results indicate that prior studies have primarily emphasized students' awareness and interest in careers, while relatively less attention has been given to affective and attitudinal career outcomes.

Figure 7

Distribution of career-related variables across extracted effect sizes (Total N = 35)



5.2 Overall effect size and Heterogeneity statistics

To consider the dependence of multiple effect sizes within the same study, this study conducted a multilevel random-effects meta-analysis. A total of 35 effect sizes from 27 studies were included in the analysis. The analysis revealed an overall average effect size of Hedges' $g = 0.45$, indicating a statistically significant positive effect (95% CI [0.30, 0.59], $p < .001$). This indicates that the educational intervention had a moderate effect on learning outcomes in Table 5. Also, the forest plot indicates the effect size of each study in Appendix 1.

A heterogeneity test revealed significant differences in effect sizes across studies ($Q(34) = 157.82$, $p < .001$). Therefore, the use of a random-effects model was deemed appropriate. A variance component analysis revealed that most of the variability was due to differences between studies ($\sigma^2 = 0.114$), with little variance observed between effect sizes within the same study. The prediction interval ranged from -0.23 to 1.12 , suggesting that the effect size may vary considerably across contexts in future similar research contexts. Sensitivity analyses excluding effect sizes computed under an assumed pre-post correlation ($r = 0.50$) yielded consistent results in both direction and magnitude.

Table 5

Summary of random-effects model

Outcomes	Effect size				Heterogeneity test					
	k	g ⁺	SE	95% for g ⁺	CI	Q	df(Q)	p	σ ² (study level)	σ ² (within- study)
Career Variables	35	0.45	0.07	[0.30, 0.59]		34	157.82	< .0001	0.114	0

5.3 Publication Bias Check and Sensitivity Analysis

A funnel plot was presented to illustrate the publication bias in Appendix 2. To assess the robustness of the findings, a sensitivity analysis was conducted excluding effect sizes computed under an assumed pre–post correlation ($r = 0.50$). The multilevel meta-analysis of the remaining 21 effect sizes from 16 studies yielded a statistically significant overall effect ($g = 0.40$, 95% CI [0.29, 0.51], $p < .001$) in Table 6.

The direction and magnitude of the effect were consistent with the primary analysis, indicating that the overall conclusions were robust to the inclusion of effect sizes computed under correlation assumptions. The prediction interval ranged from 0.09 to 0.71, suggesting that positive effects are likely across a range of study contexts.

Table 6

Multilevel Meta-Analysis Results

Analysis	k	studies	Hedges'g	SE	95% CI
Primary analysis	35	17	0.45	0.074	[0.30, 0.59]
Sensitivity analysis (excluding assumed r)	21	16	0.40	0.054	[0.29, 0.51]

6 DISCUSSION

This systematic literature review revealed several notable trends in STEAM education research related to students' career development in South Korea. First, the distribution of studies by school level showed a strong concentration at the elementary level. More than half of the studies (15 out of 27) targeted elementary school level, whereas relatively fewer studies examined middle school or high school. This pattern suggests that Korean STEAM research has primarily emphasized early exposure to STEAM experiences. Given that career exploration and decision-making become meaningful during secondary level, there's the need for additional research focusing on secondary level.

In terms of distribution of core disciplines in STEAM program design, most STEAM programs were developed with science as the central discipline, accounting for nearly two-thirds of the included studies. In contrast, mathematics, engineering and technology were far less frequently emphasized, and some programs were even situated in non-STEAM subjects such as social studies or Korean language arts. This finding suggests that, despite the integrative intent of STEAM education, implementation in Korea often remains science-centered. As a result, students' exposure to career pathways related to engineering and technology is comparatively limited.

Regarding implementation context, the majority of STEAM programs were embedded within the regular school curriculum rather than implemented as extracurricular or specialized programs. Although STEAM programs are implemented within the formal school curriculum, they are often organized around a dominant subject area, with other disciplines incorporated a supportive role.

Finally, most STEAM interventions were implemented over more than ten sessions, with programs consisting of 11–15 sessions or more being the most common. This suggests that Korean STEAM programs tend to involve sustained engagement rather than brief, one-off activities.

The analysis of career-related variables indicated that Korean STEAM research has predominantly focused on proximal career outcomes. Career awareness was the most frequently measured variable, followed by career interest. In contrast, fewer studies examined career development, self-efficacy, or career attitudes. This distribution suggests that most studies conceptualized career outcomes as immediate changes in students' perceptions or interests rather than as longer-term developmental constructs.

The strong emphasis on career awareness aligns with the instructional goals of many STEAM programs, which aim to introduce students to a broad range of careers and demonstrate the relevance of academic content to real-world occupations. However, awareness alone may be insufficient to support sustained career development if not accompanied by deeper engagement in career exploration or planning processes. Similarly, while increases in career interest were commonly reported, relatively few studies examined whether such interest translated into stronger confidence, decision-making capability, or persistence in STEAM-related pathways.

Overall, the findings indicate that Korean STEAM research has tended to prioritize easily measurable and short-term outcomes, such as awareness and interest, while underexamining developmental dimensions of career development. Future research would benefit from adopting

clearer conceptual frameworks and more comprehensive measures that capture both immediate and sustained career-related changes.

The multilevel meta-analysis revealed a statistically significant overall effect size of Hedges' $g = 0.45$, indicating a moderate positive effect of STEAM education programs on students' career-related outcomes. The findings suggest that, on average, participation in STEAM programs meaningfully enhances students' career awareness, interest, and related outcomes compared.

However, heterogeneity analysis revealed substantial variability in effect sizes across studies. Most of the variance was attributable to differences between studies rather than differences among effect sizes within the same study, indicating that contextual and design factors likely play an important role in shaping program effectiveness.

The sensitivity analysis supported the robustness of the findings, as excluding effect sizes computed under assumed pre-post correlations did not substantially change the magnitude or direction of the overall effect. This strengthens confidence in the conclusion that STEAM education has a positive impact on career-related variables.

This study analyzed only these and dissertations, which may limit the generalization of the findings. Future research should extend to include peer-reviewed journal articles in order to provide a more comprehensive understanding of the effects of STEAM programs on students. In addition, further studies should examine the effect sizes of specific career-related variables to better identify which aspects of career development are most strongly influenced by STEAM education.

7 DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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(* indicates studies included in the meta-analysis)

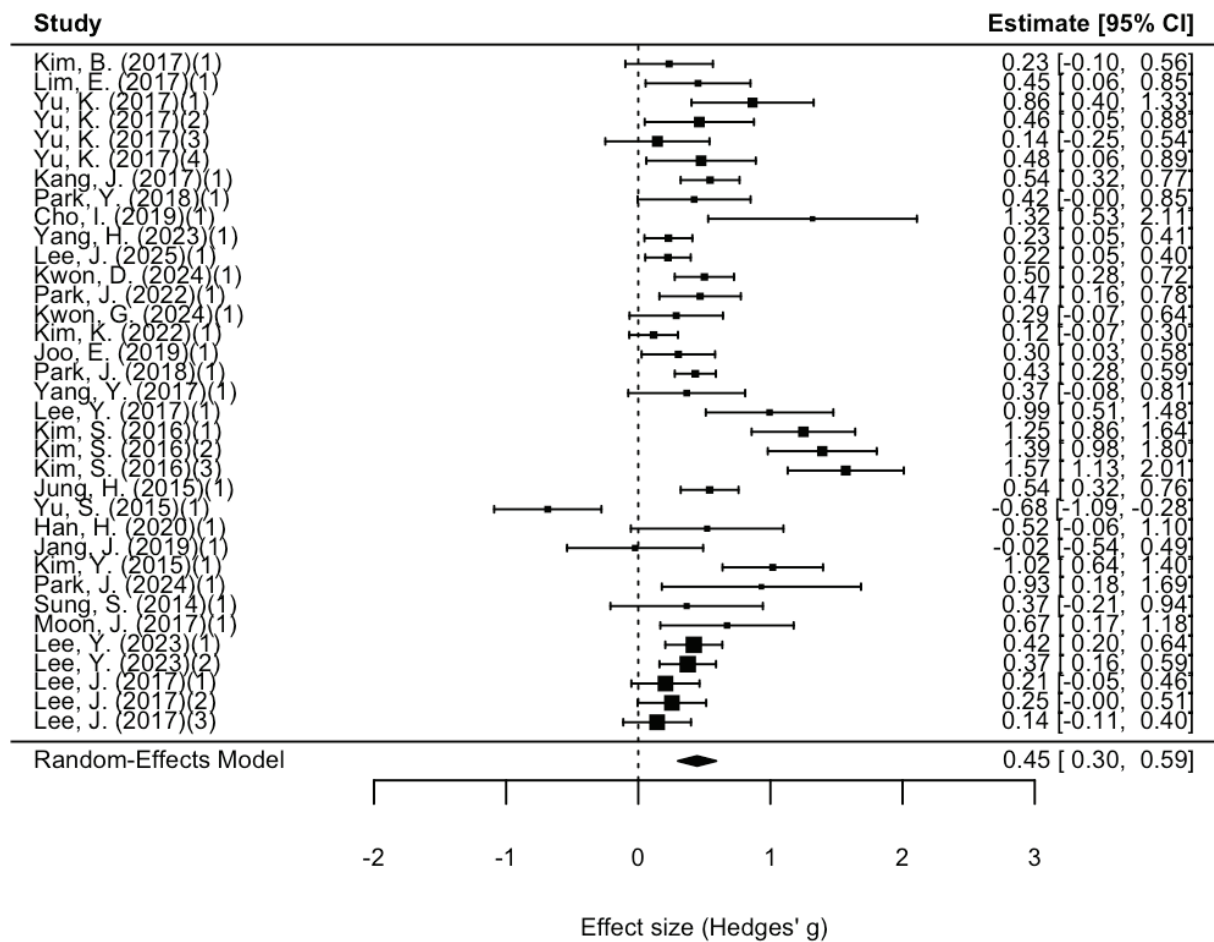
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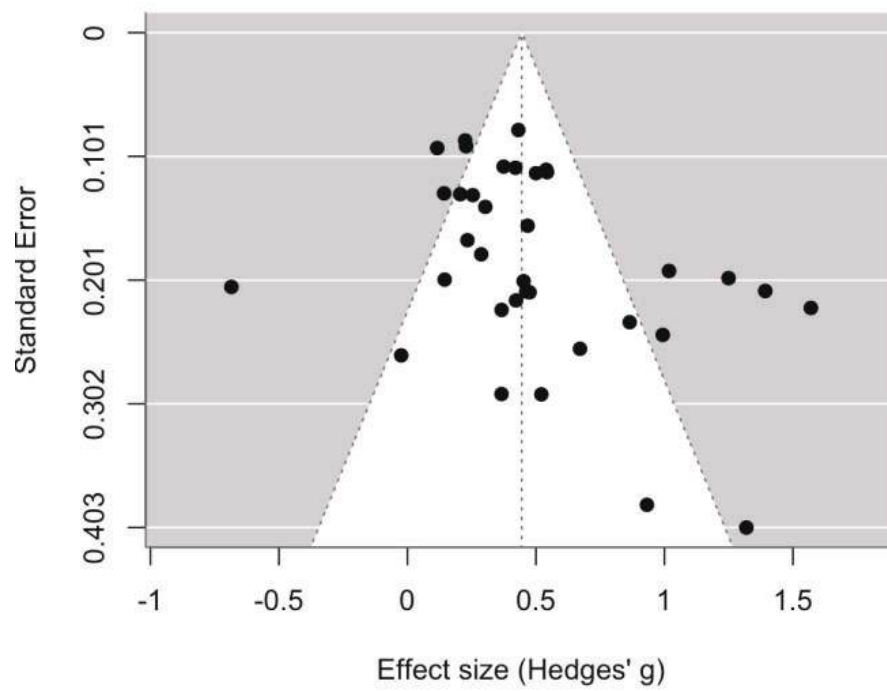
Appendix 1

Forest plot



Appendix 2

Funnel plot illustrating potential publication bias in the included studies



Workforce Development for Emerging STEM Career Areas: Upper Primary Student Career Perceptions in Microelectronics

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Abstract

Microelectronics (ME) are an important part of our everyday technologies and they represent an in-demand industry in many parts of the world. Early learning experiences may help students understand ME and become interested in ME-related careers. Guided by Social Cognitive Career Theory (SCCT), this preliminary study explored how upper primary school students perceive ME-careers and how these perceptions changed after participating in ME-focused instructional units. A total of 93 students in grades 3–5 from several schools in the Midwestern United States participated in the study. Students completed pre- and post-surveys that measured their exposure to ME and their motivation to learn about ME and ME careers. As the survey responses were collected in a dichotomous (Yes/No) format appropriate for this age level, a McNemar's test was used for the data analysis. Results showed significant increases in students' exposure to ME across all the related survey items. However, only one motivation-related survey item demonstrated a statistically significant increase. While a significant difference was found on only one motivation items, there was no indication of reduced motivation toward ME careers. These findings suggest that ME-focused instruction can increase elementary students' awareness of ME. However, short-term lessons alone may not be enough to strongly change motivation. Longer and repeated learning experiences may be desired to support early career development in ME.

Key Words: STEM Education, Microelectronics, Career Perception, Social Cognitive Career Theory

1 INTRODUCTION

In recent years, nations worldwide have invested heavily in microchip manufacturing to build innovative, resilient supply chains. In the United States, for example, the *CHIPS and Science Act of 2022* has channelled resources toward strengthening the domestic microelectronics (ME)

industry (U.S. Congress, 2022). With growing national interests in microchip development and manufacturing, there is a predicted talent shortage for the industry. Industry forecasts project that by 2030 approximately 67,000 semiconductor jobs in the United States could go unfilled if current education trends persist (Semiconductor Industry Association & Oxford Economics, 2023). Addressing this workforce concern will likely require earlier, and more intentional, K–12 engagement with ME concepts and careers.

As a result, a K–12 workforce development initiative focused on increasing awareness and engagement around the emerging ME industry has been initiated in the midwest region of the United States. While schools have seen a surge in STEM education activities, such as robotics and coding, over the past decades (Bybee, 2013), the ME industry presents an opportunity to create novel STEM-career focused curriculum and a rich site for research to understand children's career perceptions. However, given the novelty of ME integration within K-12 education, little is known about how students perceive this industry and the related careers, particularly at the elementary level. Elementary schooling typically occurs at a time in a child's life before their career choices become clear, and exposure to potential career fields during this time can influence motivation and learning choices (Super, 1990; Eccles & Wigfield, 2002; Hidi & Renninger, 2006). For this reason, this study focused on exploring the career perceptions of students in grades 3-5 before and after their experience with a ME-focused instructional unit.

The study is framed within the Social Cognitive Career Theory (SCCT), which links early self-efficacy and outcome expectations to emerging occupational interests (Lent et al., 1994). Within this framework, exposure to ME learning experiences is expected to influence students' motivation toward future engagement with the field.

- RQ1. How do children, across grades 3-5, perceive careers within ME industry?
- RQ2. To what extent does participation in a ME-focused, engineering design-based unit influence children, across grades 3-5, perceptions of the ME related careers?

Gaining insight into student experiences with ME and their perceptions of ME-related concepts and careers can inform K-12 workforce development initiatives aimed at students' exposure to, and motivation toward, the ME industry.

2 LITERATURE REVIEW

ME encompasses the knowledge, processes, and resources that enables the production and use of microchips which is a foundational technology that supports many systems and industries in society. The demand for workers in the ME field continues to grow with the expansions of the industry in the United States. The importance of introducing and teaching ME concepts to students beginning at the K-12 level has been seen as a strategy to motivate and prepare the domestic ME workforce (U.S. White House, 2025). To help begin to develop the ME workforce,

curriculum has been designed and implemented in the K-12 space in an effort to increase interest and knowledge of the ME industry (Lee et al., 2025).

While the K-12 range of schooling is vast, the goal of curriculum development and implementation across the grades is to provide students with different entry points to learn about ME. Prior research suggests that elementary school years are not a period for making concrete career decisions, but rather a critical stage for the development of interests, attitudes, and learning motivation related to future fields of study and work (Super, 1990). Early exposure to science and technology during this period has been shown to play an important role in shaping students' interests and engagement, which can influence learning, participation, and educational trajectories (Eccles & Wigfield, 2002; Hidi & Renninger, 2006). Therefore, this preliminary study was conducted to better understand students' perceptions and interests toward the ME industry in grades 3-5. Social Cognitive Career Theory (SCCT)

Lent, Brown, and Hackett (1994) proposed the SCCT, which is based on social cognitive theory and explains academic and career interests, choices, and performance through three key components: self-efficacy, outcome expectations, and goals. According to this theory, learning experiences help build individuals' self-efficacy and outcome expectations, which are central to the development of interests and career choices. Self-efficacy refers to an individual's belief in their ability to successfully perform specific tasks or activities. Self-efficacy is shaped through learning experiences, observing others, encouragement from others, and emotional states, and it plays an important role in determining which activities individuals choose to pursue and continue. Outcome expectations refer to beliefs about the expected results of performing a particular behavior, including material rewards, social recognition, and personal satisfaction. Together with self-efficacy, outcome expectations are key factors that influence the development of interests and career choices. Lastly, goals are the action plans that individuals intentionally set for themselves, ranging from short-term academic goals to long-term career goals. Within SCCT, interests lead to goal setting, and goals serve as a mechanism that guides actual choices and behaviors (Lent et al., 1994).

SCCT emphasizes the role of environmental factors as well as individual factors in career interests and choices. One of the key environmental elements highlighted in SCCT is learning experiences. Learning experiences can take various forms, including classroom instruction, participation in activities, observation, and exposure to media. These experiences can indirectly influence the development of self-efficacy and outcome expectations (Lent et al., 1994). Consistent with SCCT, the exposure items used within the context of this study—such as ME-related instruction, activities, media exposure, and teacher explanations—can be understood as forms of learning experiences. In addition, motivation in the context of this study reflects students' potential interest in ME, their willingness to learn more, and early career-related curiosity, which are conceptually aligned with interest and proximal goals in SCCT (Lent et al., 1994; Lent et al., 2000). Therefore, SCCT provides a theoretical framework for interpreting how ME educational experiences can influence students' career orientation toward the industry.

3 METHODOLOGY

3.1 *Data Collection*

This preliminary study explored children's perceptions of ME careers and concepts before and after an experience with an engineering design-based unit integrated with ME concepts and contexts. The study focused on children in grades 3-5 which can be a developmental stage sensitive to the formation of career perceptions. To collect the data to answer the study's research questions, a ME career-focused survey was administered as before and after the students participated in the one of the two units described in Section 3.4. The pre-survey was conducted before the instructional unit began, and the post-survey was administered immediately after the unit ended to examine changes. The surveys were completed in the classroom setting with guidance from the teacher, and students responded to the survey voluntarily after receiving their assent and parental/guardian consent. As a result, 93 student participants were a part of the pre-survey, whose ages ranged from 7 to 13. Of these, 40 participants (43.01%) identified as female, 43 participants (46.24%) identified as male, and 10 participants (10.75%) did not report their gender. For the post-survey, there were 80 participants, whose ages ranged from 7 to 13. Pre- and post-survey responses were linked using a student alias that did not allow individual students to be identified. This process enabled the analysis of pre- and post-responses at the individual student level. All data were used solely for research purposes and were managed in accordance with research ethics and student privacy protections.

3.2 *Ethical Consideration*

Following approved protocol from the Institutional Review Board, the students participated in the surveys. Parents and guardians received a written description of the study that outlined its purpose and explained how data was collected. They were asked to review and sign a consent form that specified the nature of the study activities, the expected duration of participation, any risks, the measures in place to protect participant confidentiality, and the rights associated with participation. Once the parents provided consent, the students were asked for their assent to participate.

3.3 *Instruments*

The survey instrument used was adapted from the ME exposure and motivation survey items reported by Gentry, Bermel, Holloway, and Douglas (2022). The original survey instrument was developed and administered with undergraduate students and provided evidence of content validity and reliability. However, the students in this study were in grades 3–5, and differences in developmental level and learning context were considered (authors, 2020). The items were adapted following a similar approach by (authors, 2020) that helps retain the original theoretical constructs and measurement intent while simplifying the wording and modifying some content to ensure that the items were understandable for elementary school students. While this approach has limitations, these modifications were made to preserve the core meaning of each item and align the language and examples with students' developmental level and lived experiences.

The survey items, which can be found in Appendices A and B, were designed to measure students' exposure to, understanding of, and interest toward learning about ME. The exposure items (Q1–Q6) asked whether students had experienced ME-related content through reading, watching videos, listening to teacher explanations, participating in related activities, and learning how microchips are used in everyday life. The motivation items (Q7–Q9) focused on students' intentions to learn more about ME and their willingness to continue participating in related learning activities.

All survey items (Q1–Q9) were presented in a dichotomous (Yes/No) format. The same survey instrument was administered to the same students at both the pre- and post-survey stages, allowing for comparison of responses before and after participation in the instructional unit. dichotomous response formats are appropriate for surveys with children because they can improve item clarity and support reliable responses, and they are well suited for analyzing pre–post changes within the same students (Borgers, de Leeuw, & Hox, 2000; Krosnick, & Presser, 2010).

Several limitations should be noted. Motivation was assessed using dichotomous (Yes/No) items, which may constrain variability in responses and reduce sensitivity to small but meaningful changes.

3.4 *Intervention*

This preliminary study examined students' perceptions of ME-related careers and explored the potential influence of ME curriculum units on these perceptions. The study was conducted in the Midwestern United States where there is an expanding ME industry. The curricular units were designed to engage 3rd through 5th grade students in solving real-world problems through engineering design while learning about ME and meeting the designated disciplinary-specific learning standards (Lucas et al., 2025). The two curricular units at the center of this research emphasized authentic, context-based problem situations and supported students in developing solutions that involve ME. These units were collaboratively developed by elementary teachers and faculty, staff, and students at a partnering university. The 2 different units (referred to as the *Integrated STEM Unit* and the *Engineering & Literacy Unit*) will be discussed in the following sections.

3.4.1 *Integrated STEM Unit*

The integrated STEM unit guided primary students through redesigning a community dog park, combining engineering design, circuits, and mathematics in a real-world context with authentic community connections. Students progress from creating simple circuits to make illuminated dog portraits to building automated safety features using micro:bits (tiny computers that allow students to explore how software and hardware work together) and servo motors, while learning about urban planning, budgeting, and community needs. Students design the park to keep gates closed, turn lights on automatically, and create a safe park. Students learn about sensors and how they can be controlled within electronic systems. The unit culminated in team presentations of their designs, where they demonstrated their understanding of engineering principles, mathematical concepts, ME, and collaborative problem-solving skills through their designed park

layouts. The unit includes 9 lessons. The total instructional time is about 11-12, 40 minute class periods. Figure 1 shows an example of a dog park created by the students.

Figure 1

Example of student created “dog park” using the micro:bit, sensors, and other electronics components.



3.4.2 Engineering & Literacy Unit

The second curricular unit focused on using classroom literature as context to engage students in STEM learning through the integration of engineering and literacy. The unit was tailored to each teacher's class using their desired book for reading. Then each teacher followed an instructional approach that integrated the chosen book with engineering design. This integration involved engaging students in reading the book and identifying problems encountered by characters that could be solved in connection with ME. Students treat challenges faced by the story's characters as authentic engineering problems and address them by following engineering design practices, including problem definition, idea generation, prototyping, testing, and refinement. To support authentic problem solving, the unit incorporated hands-on activities involving computational tools and basic electronics/ME components, allowing students to explore how engineering solutions can be implemented in real-world contexts. This approach enabled students to connect engineering practices and ME-related concepts with practical applications while working

collaboratively to develop and improve their designs. The instructional unit was designed to be implemented over a 4-week period, with 2 instructional sessions per week. Figure 2 provides an example of the Engineering & Literacy Unit that centered on reading a book titled *The Hundred Dresses* by Eleanor Estes. After reading the book, students identified a problem to solve to help the main character that involved electronics and coding using the micro:bit.

Figure 3

Example of Engineering & Literacy Unit.

The Hundred Dresses, Micro:Bit and Career Exploration

In this lesson, students will explore how coding and electronics work together by using a BBC micro:bit to control an LED light strip. You will learn how to connect and program the components to create patterns, colors, and interactive lighting effects. Through hands-on experimentation, you will develop problem-solving skills, practice basic programming logic, and understand how circuits transfer power and information. This activity also introduces you to real-world careers—such as electrical engineering, programming, robotics, and product design—that use similar technologies to create innovative and practical solutions in everyday life.

Making the Design Come Alive

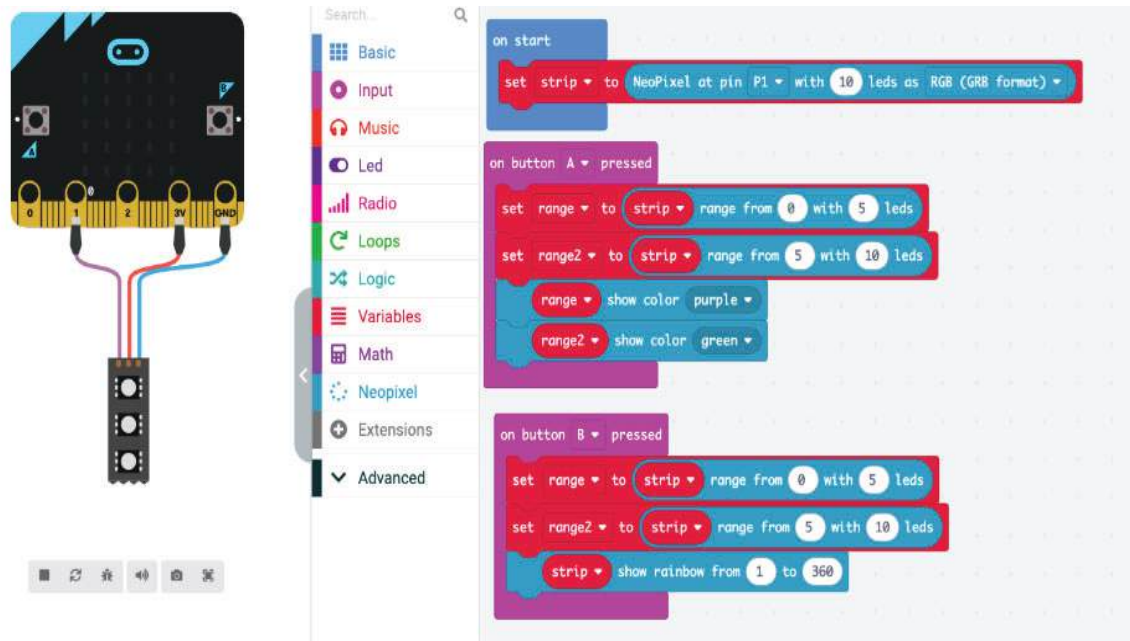
Materials Needed

- Felt and fabric scraps
- Cardboard for structure
- micro:bit microcontroller
- LED strips and connectors
- Basic craft supplies

Learning Goals

You will understand basic prototyping principles while creating illuminated dress designs that celebrate Wanda's creativity. This hands-on approach connects literature to real-world engineering applications.





3.5 Data Analysis

In this preliminary study, pre- and post-survey data collected from primary school students were analyzed to examine the effects of ME units on changes in students' ME exposure and motivations. All statistical analyses were conducted using the R statistical software (R Core Team, 2024). McNemar's test was performed using the package `mcnemar.test()`.

For survey items with binary responses, changes between pre- and post-survey responses were analyzed 'within-student level,' allowing comparisons of each student's response over time. Some students did not complete all survey items; missing responses occurred at the item level. Analyses were conducted using pairwise deletion, such that only students with complete pre- and post-test responses for a given item were included in the corresponding analysis (Enders, 2010).

To test changes in the binary pre- and post-survey responses, the McNemar test was used (McNemar, 1947). The McNemar test is a nonparametric method appropriate for analyzing changes in paired binary data collected from the same participants over time, making it suitable for the structure of the survey data in this study. For each survey item, the number of responses that changed from No to Yes and from Yes to No was calculated. These values were then used to test the statistical significance of changes in response distributions between the pre- and post-surveys.

To present patterns of response changes more clearly, descriptive statistics were calculated for each survey item, including the frequency and percentage (%) of responses that changed from No to Yes and from Yes to No. Because multiple statistical tests were conducted across survey items, a False Discovery Rate (FDR) correction was applied to the p-values to address the issue of multiple comparisons (Benjamini & Yekutieli, 2001).

Although students were recruited from schools in multiple districts, the primary unit of analysis in this study was the individual student. Therefore, statistical analyses comparing differences

across districts were not conducted. The ME units were implemented in the same manner across all regions, and school district-level effects were not a focus of the study. As a result, all analyses were performed at the individual student level.

3.6 *AI disclosure*

Generative AI tools (i.e., ChatGPT) were used only as a supportive tool for translation and language editing. All substantive writing, analysis, and interpretation were performed solely by the authors.

4 RESULTS

4.1 *Results for RQ1: Initial Exposure and Motivation*

Descriptive statistics from the pre-survey indicated that students' initial exposure to ME varied across items (see Table 1 for the results). Across the exposure items (Q1–Q6), the proportion of students responding “Yes” ranged from 24.1% to 62.2%, suggesting uneven prior exposure to ME-related concepts and experiences. In particular, fewer students reported knowing an adult who works with “microchips” (Q1 = 24.1%) or having participated in a ME-related activity (Q5 = 26.1%), whereas more students reported having learned about ME (Q4 = 62.2%) and watching a video about ME (Q3 = 53.4%).

For the interest-related items (Q7–Q9), students generally endorsed interest in learning more about ME, with 64.4% indicating interest in reading about ME (Q7) and 72.7% indicating interest in learning more (Q8). However, only 20.5% indicated wanting a future job involving ME (Q9), suggesting that career-oriented motivation was relatively low at the baseline.

Table 1

Initial “Yes” responses for exposure and interest items (Pre-test)

Item		N	Yes_N	Yes_Percentage (%)
Q1	Do you know any grown-ups whose job is to make or work with tiny computer parts called microchips (the chips that help phones and computers work)?	58	14	24.1
Q2	I have read something about microelectronics.	89	34	38.2

Q3	I have watched a vedio about microelectronics.	88	47	53.4
Q4	A teacher has talked to me about microelectronics.	90	56	62.2
Q5	I did an activity involving microelectronics.	88	23	26.1
Q6	I have learned about microelectronics.	90	50	55.6
Q7	I want to read books about microelectronics.	87	56	64.4
Q8	I want to learn more about microelectronics.	88	64	72.7
Q9	When I grow up, I want a job where I can work with microelectronics.	88	18	20.5

4.2 Results for RQ2: Pre–Post Changes in Exposure and Motivation

4.2.1 Exposure (Q1–Q6)

McNemar test results showed statistically significant pre–post changes for all exposure items (Q1–Q6). As expected, a substantially larger proportion of students changed their responses from No to Yes than from Yes to No across all of these questions. The percentage of No-to-Yes changes ranged from 41.8% to 72.7%, whereas Yes-to-No changes were minimal (0.0%–2.8%). All exposure items yielded statistically significant McNemar χ^2 values ($p < .001$), and these results remained significant after false discovery rate (FDR) adjustment.

Table 2

Pre-post changes in students' responses to exposure items

Item	N	No → Yes N (%)	Yes → N N (%)	χ^2	p (FDR)
Q1	58	17 (47.22)	1 (2.78)	12.50	< .001
Q2	89	30 (45.46)	3 (4.55)	20.49	< .001
Q3	88	30 (46.15)	1 (1.54)	25.29	< .001

Q4	90	28 (41.79)	0 (0)	26.04	< .001
Q5	88	48 (72.73)	0 (0)	46.02	< .001
Q6	90	33 (49.25)	1 (1.49)	28.27	< .001

Note. N reflects the number of students with complete pre-post responses for each item. McNemar's test was used to examine pre-post changes. P-values were adjusted using the false discovery rate (FDR) procedure.

4.2.2 Interest (Q7–Q9)

For the interest items, only Q8 demonstrated a statistically significant pre–post change ($\chi^2 = 6.72$, $p = .010$; FDR-adjusted $p = .012$). For this item, the proportion of No-to-Yes changes exceeded the proportion of Yes-to-No changes. In contrast, Q7 and Q9 did not show statistically significant changes ($p > .05$), with the majority of students maintaining the same response from pre- to post-test.

Table 3

Pre-post changes in students' responses to motivation items

Item	N	No → Yes	Yes → No	χ^2	p (FDR)
		N (%)	N (%)		
Q7	63	14 (22.22)	8 (12.70)	1.14	.286
Q8	65	15 (23.08)	3 (4.62)	6.72	.012
Q9	66	12 (18.18)	5 (7.58)	2.12	.164

Note. N reflects the number of students with complete pre-post responses for each item. McNemar's test was used to examine pre-post changes. P-values were adjusted using the false discovery rate (FDR) procedure.

Overall, the results indicate that participation in the ME-focused unit was understandably associated with consistent and significant increases in students' exposure to ME, as reflected across all exposure items. However, changes in motivation were more limited, with statistically significant differences observed for only one of the three motivation items. This result is related to the fact that the majority of the participants were already “motivated to learn more” about ME before the ME experience and still motivated to learn more after the experience. Therefore, there was no significant difference, and there was also no reduction in motivation toward ME.

5 DISCUSSION & FUTURE RESEARCH

The purpose of this preliminary study was to examine elementary students' exposure to and motivation toward the field of ME before and after participation in a ME-focused instructional unit. These early findings suggest that participation in the ME-focused units were associated with consistent gains in students' exposure to ME, while changes in motivation were more limited as students were already interested in learning about ME.

Results showed statistically significant pre–post differences across all exposure items (Q1–Q6), with a large proportion of students shifting from “No” to “Yes” responses and very few understandably shifting in the opposite direction. These findings indicate that the instructional unit was successful in increasing students' awareness of and familiarity with ME-related concepts and experiences. Given that microchips and semiconductor technologies are often embedded and invisible in everyday devices, such gains in exposure are noteworthy, particularly at the primary school level. These findings can suggest that instructional experiences that make underlying concepts and processes explicit can play an important role in supporting students' early awareness and understanding across complex, career-focused learning domains.

From a theoretical perspective, these results align well with SCCT, which emphasizes the importance of early learning experiences in shaping students' understanding of and engagement with career-related contexts. In this study, the ME-infused, engineering design-based activities appear to have served as meaningful learning experiences that increased students' exposure to ME, an important first step in the development of longer-term career-related interests.

In contrast to the consistent exposure gains, changes in motivation were observed for only one of the three motivation items (Q8). For the remaining motivation items (Q7 and Q9), most students maintained the same response from pre- to post-test, and no statistically significant changes were detected. This pattern suggests that students were initially motivated to learn about ME before the unit and maintained this motivation after their experience. Regarding career perceptions and interest, this can show that the topic of ME is one that is interesting to primary students and the ME learning experience does not change this interest.

The findings of this study are consistent with previous research on early STEM and industry-related learning experiences and students' career perceptions. Authors (2020) showed that industry-driven outreach programs helped broaden children's views of manufacturing careers but did not lead to clear or immediate career intentions. Similarly, Walls et al. (2024) found that STEM learning labs in industry settings improved students' career perceptions, without resulting in definite career commitments. In line with these studies, the current results show significant increases in students' exposure to ME concepts/careers after participating in an instructional units. These results can suggest that early learning experiences help increase students' awareness. However, these experiences appear to support early career interest foundations, rather than directly shaping final career choices.

Within the SCCT framework, motivation is influenced not only by exposure but also by factors such as self-efficacy, outcome expectations, and social supports. The current units may have

increased students' awareness of ME, but additional opportunities for hands-on success, reinforcement, and continued engagement may be necessary to produce broader motivational change.

The results indicate statistically significant increases in students' reported exposure to ME following participation in the ME-focused instructional activities. However, the limited motivation findings indicate that workforce development efforts should be designed as longer-term and scaffolded experiences rather than one-time interventions, particularly if the goal is to influence students' motivation toward ME-related learning and careers (Authors, 2025).

This preliminary study has a limited sample size. Therefore, future studies with larger and more diverse samples are needed to support these findings. And, future studies could incorporate multi-point Likert scales to capture more nuanced shifts in motivation. Finally, the study focused on short-term pre–post changes; longitudinal research is needed to examine whether increased exposure leads to sustained motivation and later career-related outcomes.

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Appendix A

Pre-Survey Questionnaires

3-5 Microelectronics Pre-Survey

Name : _____

Instructions: Read each question (or have a grown-up read it to you). There are no right or wrong answers. Pick the choice that sounds most like what you think or feel. Take your time, and remember—your answers are private.

Please read the definitions below before you answer the questions.

Microelectronics are tiny parts or microchips that are inside electronic devices like phones and computers. They help these devices send messages and do smart things! Parts of the microelectronics are so tiny that you can't even see them with your eyes.

Microelectronics Careers are jobs where people design, make, test, or fix the tiny computer parts—called microchips—that make phones, tablets, cars, and other electronics work.

1. Do you know any grown-ups whose job is to make or work with tiny computer parts called microchips (the chips that help phones and computers work)?

☐ Yes ☐ No ☐ I'm not sure.

2. I have read something about microelectronics.

☐ Yes ☐ No

3. I have watched a video about microelectronics.

☐ Yes ☐ No

4. A teacher has talked to me about microelectronics.

☐ Yes ☐ No

5. I did an activity involving microelectronics.

☐ Yes ☐ No

6. I have learned about microelectronics.

☐ Yes ☐ No

Appendix B

Post-Survey Questionnaires

3-5 Microelectronics Post-Survey

Name : _____

Instructions: Read each question (or have a grown-up read it to you). There are no right or wrong answers. Pick the choice that sounds most like what you think or feel. Take your time, and remember—your answers are private.

Please read the definitions below before you answer the questions.

Microelectronics are tiny parts or microchips that are inside electronic devices like phones and computers. They help these devices send messages and do smart things! Parts of the microelectronics are so tiny that you can't even see them with your eyes.

Microelectronics Careers are jobs where people design, make, test, or fix the tiny computer parts—called microchips—that make phones, tablets, cars, and other electronics work.

1. Do you know any grown-ups whose job is to make or work with tiny computer parts called microchips (the chips that help phones and computers work)?

☐ Yes ☐ No ☐ I'm not sure.

2. I have read something about microelectronics.

☐ Yes ☐ No

3. I have watched a video about microelectronics.

☐ Yes ☐ No

4. A teacher has talked to me about microelectronics.

☐ Yes ☐ No

5. I did an activity involving microelectronics.

☐ Yes ☐ No

6. I have learned about microelectronics.

☐ Yes ☐ No

7. I want to read books about microelectronics.

☐ Yes ☐ No

8. I want to learn more about microelectronics.

☐ Yes ☐ No

9. When I grow up, I want a job where I can work with microelectronics.

☐ Yes ☐ No

10. What is your gender? _____

11. How old are you? _____

12. Which categories describe you? Select all that apply to you:

☐ American Indian or Alaska Native

☐ Asian

☐ Black or African American

☐ Hispanic, Latino or Spanish

☐ White

☐ Other: _____

☐ I prefer not to answer.

13. What did you like about this microelectronics experience?

14. What would you change about this microelectronics experience?

Rethinking Vocational and Academic Pathways in Senior Secondary Education

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Abstract

This paper presents the preliminary phase of a structured literature review, establishing conceptual, historical, and policy foundations for an analysis of how senior secondary curricula can disrupt entrenched hierarchies, positioning vocational and academic learning as mutually reinforcing rather than oppositional.

Particular attention is given to the Aotearoa New Zealand context, where recent reforms highlight tensions between policy intent, system design, and educational outcomes. Drawing on national and international literature, the paper examines how curriculum design, assessment structures, and pathway architectures shape perceptions of knowledge, credibility, and progression. It introduces a set of preliminary codes to guide the full review: status and hierarchy; pathway permeability; curriculum and assessment architecture; and equity.

The review identifies a range of strategies employed internationally, including rebranding initiatives, hybrid school-work learning models, and multiple entry routes to higher education, with mixed evidence of effectiveness.

The findings suggest design principles and structural conditions associated with more equitable access and credible progression. As a preliminary paper, these insights will inform and shape the subsequent structured literature review and contribute to ongoing discussions about how senior secondary pathways in Aotearoa might be redesigned to support diverse learner trajectories without reinforcing existing hierarchies.

Key Words: Vocational Education, Curriculum Hierarchy, Senior Secondary Pathways

1 INTRODUCTION

This paper examines how senior secondary education systems have attempted to reconcile longstanding divisions between academic and vocational pathways. While these pathways are often presented as complementary, they remain hierarchically organised, shaping learners' future opportunities. The paper serves as a first phase in a structured literature review, establishing the conceptual, historical, and policy context necessary to examine how curriculum design, assessment structures, and pathway architectures contribute to hierarchies or attempt to disrupt them. Particular attention is given to the Aotearoa New Zealand context, where recent reforms have sought to reconfigure vocational education while raising new questions about knowledge, equity, and system design.

2 DEFINITIONS

The field of vocational and academic education is complex. Clarity of terminology is essential, as key concepts are often used inconsistently across policy and research. Some believe high school/secondary education should prepare learners for the workforce, whilst others believe it should develop well-rounded citizens, and others perceive it as a time to prepare for university study (Parada et al., 2024; Young, 2008).

Across many systems, there exists a hierarchy of knowledge, sustained through senior secondary school curriculum, assessment, and institutional rules. Many refer to the trajectory into university study as an 'academic pathway', typically associated with theoretical disciplinary knowledge (Ferm, 2021). Vocational pathways are associated with programmes oriented toward specific occupations or industries, often combining practical skill development with applied knowledge, assisting students to transition from school to a career (Curtis, 2008). Academic pathways are frequently framed as the 'default' route to status, mobility, and future opportunity, while vocational pathways are framed as second-choice options associated with lower prestige, lower expectations, and narrower futures (Niemi & Rosvall, 2013).

The concept of parity of esteem refers to efforts to position vocational and academic pathways as equally valuable. However, as this paper will argue, such parity is often more aspirational than realised, with structural features of education systems continuing to reproduce hierarchies between forms of knowledge.

3 CONTEXT

Aotearoa New Zealand is currently engaged in an ongoing review and reform of its education and training system, including the redesign of senior secondary pathways, with attention to the coherence, credibility, and status of secondary–tertiary transitions.

In Aotearoa, the distinction between academic and vocational pathways has been shaped by history and tradition. Technical and trade-oriented education has long been positioned alongside, but separate from, academically-oriented schooling, with different institutions, qualifications, and

progression routes reinforcing this divide (Abbott, 2000). These foundations originated in the late nineteenth century, when class-based differentiation positioned secondary schooling as preparation for university, while technical and manual education was oriented toward trades and industry. Mid-twentieth-century reforms sought to democratise access through a universal and comprehensive secondary system; however, differentiation persisted, particularly through streaming.

Reforms in the 1980s and 1990s, followed by the introduction of the National Certificate of Educational Achievement in the early 2000s, aimed to provide greater flexibility, recognising both academic and vocational learning, and enabling more diverse recognition of learning. In practice, qualifications associated with academic subjects have continued to carry higher status, with examination results remaining a dominant signal of success and privileging academic pathways.

Policy initiatives (e.g., Trades Academies, Youth Guarantee, Vocational Pathways, and the NCEA Review) have aimed to strengthen alignment between schooling and vocational education, with limited impact on underlying hierarchies. Recent policy discourse frames this as a misalignment between schooling and industry, advocating clearer vocational pathways and stronger transitions into work-based learning (Chand et al., 2024; Johnston, 2025). While these approaches may improve participation, they tend to frame the problem as one of alignment and efficiency, rather than addressing deeper questions of knowledge, status, and purpose. These, together with other recent policy changes, have raised questions about how the rate of change is not sufficiently supported by policy evaluation.

These developments highlight a persistent systemic challenge: the academic–vocational divide is embedded in institutional structures, cultural expectations, and competing purposes of education. As such, achieving parity of esteem is better understood as a complex or ‘wicked’ problem (Head, 2022), shaped by contested values, interdependencies, and no straightforward solution. For technology educators, this is not abstract. Technology learning sits at the boundary between conceptual knowledge and applied practice, and between schooling and the world of work, making it particularly sensitive to how knowledge is defined, valued, and credentialled within curriculum and assessment systems.

This paper synthesises international research relevant to reimagining senior secondary curricula and pathway structures so that vocational and academic learning are positioned as mutually reinforcing rather than oppositional.

4 CONCEPTUAL FRAMING

Three concepts are used throughout this paper to interpret the literature: parity of esteem (Cort, 2025), permeability (Schmees et al., 2025), and wicked/complex problem framing (Head, 2022).

4.1 *Parity of esteem*

Parity of esteem holds that vocational learning should be valued as highly as academic learning. In the analysed literature, parity is closely tied to credibility signals such as progression rights (who can enter higher education), the perceived quality of programmes, and the conceptual status of knowledge taught in different tracks. The disjuncture between parity rhetoric and learner experience has been the basis for international reviews (Polesel, 2010; Tarabini & Jacovkis, 2022; Wahlberg & Gleeson, 2003).

4.2 *Permeability*

Permeability refers to how easily learners can move between pathways and progress into higher learning or work without being trapped by earlier choices. The literature treats permeability as both a structural feature (rules, entry requirements, bridging routes) and a lived experience (do students feel options are real?). Publications include: examples of multiple entry routes and outcomes (Biemans et al., 2020; Schmees et al., 2025), institutional constraints and early differentiation shaping aspirations long before formal pathway choices are made (Dörffer & Tieben, 2025), and systems that offer ‘routes’ on paper but still reproduce sorting and unequal outcomes in practice (Dörffer & Tieben, 2025; Doroftei & da Silva, 2024; Tarabini & Jacovkis, 2022).

4.3 *Wicked vs complex problems*

A recurring warning in the literature is that making vocational pathways ‘attractive’ and ‘equal’ often presents a wicked, or at least complex, problem rather than a technical problem with a stable solution. A Danish case explicitly frames parity as a wicked problem, noting that policymakers draw on familiar reform strategies but find them insufficient to shift participation and status (Cort, 2025). This framing matters for technology educators because it discourages simplistic fixes (for example, rebranding alone) and instead points to multi-layered change across curriculum design, assessment, institutional rules, and public narratives.

5 METHOD

This paper addresses the following research question:

How do senior secondary curriculum designs integrate vocational and academic pathways in order to achieve parity?

This paper presents an initial phase of a structured literature review, focusing on the development of an analytical framework and emphasising the identification of patterns, tensions, and conceptual categories to inform subsequent analysis.

Searches were conducted across ERIC, Scopus/Web of Science, Google Scholar and ProQuest Education using terms related to curriculum integration/reform, academic–vocational divides, parity of esteem, pathways, and senior secondary contexts.

Initial searches that included New Zealand terms produced very limited (sometimes zero) returns in peer-reviewed literature, leading to a principled widening of search parameters to include international studies while retaining relevance to senior secondary curriculum and pathways, particularly Technology education.

5.1 *Inclusion and screening*

Peer-reviewed journals, theses, policy reports, and curriculum analyses published between 2006 and 2026, written in English, with full text available, were included. Studies were screened by title and abstract and then assessed for eligibility. For each included study, data collection captured: the aim/purpose, theoretical framing (where provided), methodology, key findings, and any implications for Aotearoa New Zealand.

5.2 *Coding*

A set of codes was developed both deductively and inductively to guide the analysis of the full set of literature. A subset of studies addressing senior secondary or upper-secondary pathway structures, perceptions of VET, academic–vocational divides, school–work integration designs, and transition to higher education was used to test the codes and identify the initial themes reported here. The codes provided an analytical lens for identifying recurring patterns, tensions, and design features across systems, forming the basis for the subsequent full synthesis.

5.3 *Trustworthiness*

The initial phase of this study, as reported here, aimed to enhance the trustworthiness of the analysis and subsequent presentation of findings. The development of codes was a collaborative process in which the authors discussed their reading and suggested codes. Intercoder reliability was assessed by comparing the coding of specified articles across the authors. The themes emerging from the analysis were also discussed and jointly agreed on.

6 INITIAL FINDINGS

6.1 *Theme 1: The hierarchy is reproduced through discourse, credibility signals, and curriculum design*

Across the analysed subset, the academic–vocational hierarchy appears to be reproduced through the way systems structure and signal what counts as legitimate knowledge, not only through public perception. A recurring pattern is the disjuncture between policy rhetoric and lived experience. A UK case study, for example, highlights a gap between the promise of high-status vocational pathways and the realities reported by students and tutors, including constrained progression and lower expectations (Wahlberg & Gleeson, 2003). Similarly, Australian research identifies ongoing contestation around the quality and purpose of vocational provision in schools, with concerns about outcomes and participation reinforcing its lower status (Polesel, 2010).

Curriculum design and structural relationships play a key role. While integration of vocational learning into senior secondary systems can expand options and reshape practice (Polesel, 2010), such changes do not necessarily disrupt hierarchy unless accompanied by shifts in credibility signals, including assessment status and access to further education. Several systems attempt to address status through rebranding and promotion. Examples from Hong Kong and Bulgaria show that positioning, language, and perceived quality can influence student perceptions and participation (Lee et al., 2018; Teofana et al., 2025). However, these strategies appear insufficient where underlying structures remain unchanged (Cort, 2025; Tarabini & Jacovkis, 2022).

A consistent underpinning of this hierarchy is epistemic. Academic pathways are typically associated with abstract, theoretical knowledge, while vocational pathways are framed as context-specific or applied (Tarabini & Jacovkis, 2022). This distinction has direct implications for Technology in New Zealand: when applied learning is positioned as ‘skills’ rather than knowledge-rich practice, these areas risk lower status within curriculum and assessment systems.

Achieving parity requires more than expanding vocational options or improving an image. It depends on how systems define, structure, and credential knowledge, and on whether applied learning is recognised as conceptually rigorous and capable of supporting credible progression (Cort, 2025; Polesel, 2010; Tarabini & Jacovkis, 2022).

6.2 *Theme 2: Permeability is promised, but pathway structures often reproduce inequity and sorting*

Systems frequently present multiple pathways and transitions as evidence of flexibility and choice. However, these arrangements often appear to reproduce, rather than disrupt, existing inequalities. A key issue is the role of early differentiation and institutional context in shaping learner trajectories. Evidence from Germany suggests that aspirations are strongly influenced by school type and socio-economic composition, with institutional constraints shaping options well before formal pathway decisions are made (Dörffer & Tieben, 2025). Similarly, analyses from Spain position the academic–vocational divide as a central mechanism in the reproduction of social inequality, as different groups are channelled into pathways with unequal access to high-status knowledge and credentials (Tarabini & Jacovkis, 2022).

While some systems have introduced multiple entry routes to support permeability, their effects are uneven. Norway, for example, provides vocational pathways into higher education (Schmees et al., 2025), and Dutch evidence suggests that alternative routes can support positive learner experiences (Biemans et al., 2020). However, the presence of pathways does not guarantee equitable access or outcomes; routes vary in accessibility, navigability, and legitimacy, and may be more readily utilised by learners with greater resources or institutional support.

Structural and logistical features of programmes can further shape participation. Studies of vocationalised curricula in England highlight the demands of portfolio-based assessment and workplace engagement, which may require access to time, transport, and networks beyond the school (Bell & Donnelly, 2009). These conditions can introduce additional barriers, particularly for learners with fewer resources.

6.3 *Theme 3: Reform strategies exist, but parity behaves like a complex or wicked problem*

A third recurring pattern is that reforms aimed at strengthening vocational pathways and achieving parity tend to be partial, contested, and limited in their impact. This supports the view that parity is less a technical problem with a clear solution and more a complex or ‘wicked’ problem. Comparative analyses identify recurring reform strategies, including enhancing vocational provision, creating linkages between pathways, and developing hybrid models of school–work learning. However, evidence suggests that no single approach has been consistently successful in shifting participation or status (Cort, 2025).

A critical issue is how the problem itself is framed. Policy analyses indicate that problem definitions, whether framed as issues of participation, relevance, or system alignment, shape the range of solutions considered (Luimes, 2023). The current draft New Zealand curriculum positions knowledge and practice side-by-side on equal footing across all eight learning areas. Where vocational pathways are positioned as alternatives for those not succeeding academically, reforms tend to reinforce separation. Where they are framed as knowledge-rich and future-oriented, there is greater potential for integration and credibility.

Hybrid and boundary-crossing models offer one avenue for reform, particularly through integrative learning environments that connect school and work (Bouw et al., 2021). However, their effectiveness depends on design choices, including how learning is structured, assessed, and supported. Without careful alignment, such models may increase complexity or logistical burden without improving status or outcomes.

Rebranding and promotional strategies are commonly employed (Lee et al., 2018; Teofana et al., 2025). While these can influence perceptions, evidence suggests they are insufficient in isolation. Without corresponding changes to progression pathways, knowledge structures, and assessment systems, efforts to improve attractiveness may remain superficial (Cort, 2025; Tarabini & Jacovkis, 2022).

Technology educators often face pressure to provide ‘practical options’ while also ensuring academic credibility. Theme 3 suggests that enduring change requires systems thinking: aligning curriculum intent, assessment and credential rules, transitions, industry relationships, and public narratives. It also implies that Technology education can provide knowledge-rich applied learning, or can be absorbed into the hierarchy if treated as low-status electives. Overall, this theme reinforces the importance of treating parity as a systemic challenge requiring coordinated change across curriculum, assessment, institutional structures, and public narratives. Isolated or single-layer reforms are unlikely to disrupt entrenched hierarchies.

7 DISCUSSION: WHAT THIS MEANS FOR TECHNOLOGY EDUCATORS AND FOR AOTEAROA PATHWAY DESIGN

7.1 *Parity is epistemic and structural, not just reputational*

The literature repeatedly shows that the hierarchy is sustained through what the system signals about knowledge. If academic learning is coded as abstract and vocational learning as specific and contextual (e.g., Tarabini & Jacovkis, 2022), then parity requires intentional effort to convey the conceptual depth of applied learning. This provides a strategic opportunity for Technology to explicitly foreground conceptual knowledge-building through design, systems thinking, modelling, and critique. However, credibility is also structural: if assessment and credentialing arrangements limit progression, parity cannot be achieved by pedagogy alone.

7.2 *Permeability must be real for learners, not just present in policy*

Multiple routes into higher education (e.g., Biemans et al., 2020; Schmees et al., 2025) demonstrate that permeability can be designed, but equity depends on accessibility, navigability, and legitimacy. For technology educators, this means pathway guidance and curriculum design should assume diverse futures and deliberately avoid ‘dead-end’ framing. If applied pathways require extensive portfolio management or workplace access (e.g., Bell & Donnelly, 2009), schools must also design supports to prevent inequitable participation (e.g., time, transport, supervision, networks).

7.3 *Treat the problem as complex/wicked: design for iterative improvement, not one-off reform*

The wicked problem framing (e.g., Cort, 2025) suggests that reforms will tend to under-deliver if systems treat parity as a technical policy adjustment. Instead, systems may need iterative, multi-level approaches that include curriculum coherence, hybrid learning designs (e.g., Bouw et al., 2021), assessment and transition rules, and public narratives (e.g., Lee et al., 2018; Teofana et al., 2025). For Aotearoa, the apparent scarcity of New Zealand peer-reviewed studies directly aligned with this framing (as observed in the search process) can be framed as a research and practice gap. This can be framed as a call for field-building: documenting innovations, evaluating integrative models, and analysing how Technology can work as credible, future-facing pathways without reproducing hierarchy.

8 LIMITATIONS

This paper presents an initial phase of a structured literature review and is, therefore, intentionally partial. The analysed subset represents approximately one-third of the intended corpus, and coding categories are still being refined through iterative analysis.

Rather than aiming for exhaustive coverage, this phase prioritises developing an analytical framework to guide subsequent synthesis. The findings should therefore be interpreted as indicative of emerging patterns and tensions, rather than definitive conclusions.

9 CONCLUSION

This preliminary analysis suggests that the persistence of the academic–vocational hierarchy in senior secondary education is embedded in how systems define, structure, and credential knowledge, and in how progression opportunities are organised and signalled. Across the analysed subset, efforts to address this divide (through expanded pathways, hybrid models, and rebranding strategies) appear to have limited impact where underlying epistemic and structural conditions remain unchanged. This reinforces the framing of parity of esteem as a complex or wicked problem that requires coordinated change across curriculum, assessment, institutional arrangements, and public narratives.

The primary contribution of this paper is the development of an initial analytical framework, centred on status and hierarchy, permeability, curriculum and assessment architecture, and equity, to guide a more systematic examination of these issues.

For Aotearoa New Zealand, the findings highlight a policy challenge and a research opportunity. While reforms continue to focus on alignment and participation, the deeper question of how knowledge is valued within the system remains unresolved. At the same time, the limited presence of New Zealand-focused research within this framing suggests a need for further empirical and conceptual work.

The next phase of the review will extend the dataset and refine the analytical framework, with the aim of producing a more comprehensive account of how senior secondary pathways can be designed to support diverse learner trajectories without reproducing hierarchy.

10 DISCLOSURE STATEMENT

Generative artificial intelligence (GenAI) tools were used as a 'critical friend' to help enhance clarity, structure and argumentation. The writing of the article was a human-led collaborative process. All substantive ideas, theoretical perspectives, analyses, and interpretations are the authors' own.

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Analysing Teaching Materials for Interdisciplinary Technology Education Through a Didactic Model

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Abstract

Interdisciplinary STEM education is increasingly promoted in compulsory schooling, yet the role of the technology subject within such approaches remains unevenly articulated. This study examines how technology is positioned in pre-designed teaching materials intended to support interdisciplinary instruction in Swedish lower and upper secondary education. Fourteen materials were analysed using a qualitative, theory-informed content analysis guided by a didactic framework conceptualising teaching practices in terms of what is taught, how teaching is organised, and why activities are framed as educationally meaningful. Through iterative comparison across materials, three recurring configurations of technology emerged: technology-centered, thematically embedded, and tool-oriented projects. While many materials emphasise societal relevance, sustainability, and student engagement, explicit opportunities for students to develop technological knowledge and core design-related practices are often limited. Technology is frequently positioned as contextual support for scientific or societal themes rather than as a distinct epistemic domain. The findings highlight tensions between interdisciplinary ambitions and the disciplinary visibility of technology education and contribute a conceptual framework for understanding how technology is represented in interdisciplinary STEM contexts.

Key Words: Technology Education, STEM, Interdisciplinary Teaching, Didactic Model, Teaching Materials

1 INTRODUCTION

Interdisciplinary STEM education has become an increasingly prominent feature of compulsory schooling, often promoted to address complex societal challenges and to support student engagement through authentic, real-world contexts (Chaojing, 2023). In such teaching designs, technology frequently plays a central yet ambiguous role. While technological solutions, artefacts, and systems are commonly invoked in interdisciplinary themes related to sustainability, energy, or future societies, it is less clear how technology as a school subject is represented and made visible to students within these contexts.

In the Swedish compulsory school system, technology is regularly taught together with science and other subjects, often through thematic or interdisciplinary projects. These arrangements are shaped by curricular intentions as well as by organisational conditions, such as shared teaching responsibilities across subjects. As a result, technology education is often embedded in broader instructional designs rather than taught as a standalone subject. This creates both opportunities and tensions: opportunities for meaningful integration, but also a risk that technology becomes subordinated to other disciplinary perspectives or reduced to a supporting function within interdisciplinary work.

Previous research has shown that when technology is included in interdisciplinary projects, its role can vary considerably. Technology may be foregrounded as a distinct area of knowledge and practice, embedded as contextual content within a broader theme, or rendered largely invisible when technological activities are used primarily to support learning in other subjects. These different configurations shape what kinds of technological knowledge and abilities students are given opportunities to develop. Importantly, such variation has been linked to how technology is understood and positioned by teachers within interdisciplinary teaching designs.

While existing studies have primarily examined teachers' perspectives and instructional practices, less attention has been paid to the role of teaching materials in shaping how technology is articulated within interdisciplinary education. Teaching materials constitute an important interface between curricular intentions and classroom practice. They frame purposes, suggest activities, and implicitly communicate what counts as relevant knowledge within a given teaching design. In interdisciplinary contexts, teaching materials may therefore play a decisive role in how technology is positioned in relation to other subjects and how visible its disciplinary contribution becomes for students.

The didactic model applied in this study builds on a tradition of didactic theorising that conceptualises teaching through three interrelated dimensions: what is taught and learned, how teaching is carried out, and why educational activities are undertaken (Ongstad, 2006; Jank & Meyer, 1997; Dudas, 2019). These dimensions function as analytical questions that make it possible to examine how subject content, teaching practices, and educational purposes are articulated and related in instructional designs.

The model was developed in a previous empirical study of teachers' practices in interdisciplinary STEM education, where it was used to analyse how technology emerges within cross-curricular projects. The results showed that the role of technology varies considerably depending on how these three dimensions are combined in practice. Based on this variation, three recurring configurations were identified: technology-centered, thematically embedded, and tool-oriented projects.

In technology-centered configurations, technology appears as a distinct subject domain with its own content and practices. Here, students are given opportunities to engage in technological processes such as design, problem-solving, and the development of solutions, and technology shapes both the content and the organisation of the teaching. In contrast, thematically embedded configurations position technology within broader interdisciplinary themes, such as sustainability

or innovation. In these cases, technology is present but primarily as contextual content, often linked to scientific explanations or societal issues, with limited emphasis on technological ways of knowing or working. In tool-oriented configurations, technology is further marginalised and mainly functions as a means for learning in other subjects. Technological tools or activities are used to support scientific or mathematical investigations, while technological knowledge and processes remain implicit or underdeveloped.

These configurations illustrate how the visibility and integrity of the technology subject shift across interdisciplinary teaching practices. While all configurations may involve technological artefacts or activities, they differ in the extent to which students are offered opportunities to develop technological understanding as a specific form of knowledge. From a social realist perspective, this can be understood as differences in how knowledge is organised and given status within educational practices, where certain configurations foreground technological knowledge while others subordinate it to other disciplinary aims.

In the present study, this model is used as an analytical lens for examining teaching materials. The three didactic dimensions guide the analysis of how technology is represented in terms of content, activities, and purposes, while the three configurations serve as interpretative tools for identifying patterns in how technology emerges. In this way, the model enables an analysis of not only whether technology is included, but how it is positioned and what kinds of learning opportunities it affords within interdisciplinary contexts.

Against the background of increasing emphasis on interdisciplinary STEM education and ongoing concerns about the disciplinary visibility of technology in such contexts, this study investigates how technology education is epistemically positioned in pre-designed interdisciplinary STEM teaching materials. By analysing how technological knowledge, processes, and purposes are articulated in instructional resources, the study aims to contribute to a conceptual understanding of how disciplinary visibility and integrity are negotiated in interdisciplinary instructional designs. The research question guiding the study is:

How does the technology subject emerge in pre-designed teaching materials intended for interdisciplinary instruction?

2 LITERATURE REVIEW

Research suggests that interdisciplinary approaches are preferable when the aim is to support students' development of meaningful connections and authentic forms of knowledge (You, 2017; Kumar, 2025). By situating subject content within broader interdisciplinary contexts, students are better able to understand their knowledge and abilities in relation to real-world phenomena (Dyachenko, Mukanova, & Erkibayeva, 2024; Ye & Xu, 2023) which in turn has been shown to increase students' interest in the subject (Widjaja, Hubber, & Aranda, 2019; Michelsen, & Sriraman, 2009; Tonnetti, & Lentillon-Kaestner, 2023).

However, interdisciplinary themes that are taught across several subjects require carefully considered purposes and learning activities. The content, aims, and knowledge bases of the

participating subjects need to be made visible to students, a process that has been shown to be challenging, and therefore requires the formulation of specific learning objectives that make all participating subjects explicit (Cassidy & Puttick, 2022; Chaojing, 2023). To realise the ambitions of interdisciplinary teaching, it is important to work systematically with how interdisciplinary learning is described and how the contributions of different subjects within a theme are articulated (Stevens et al., 2005; Cassidy & Puttick, 2022). Research indicates that certain subjects tend to be marginalised in interdisciplinary collaborations (Yang, Luo, Seah, & van Driel, 2025).

Technology education is particularly at risk of being represented in highly variable ways, depending on how the subject is interpreted by the teacher and positioned within the teaching context (Nordlöf, Hallström, & Höst, 2019). Unlike subjects such as chemistry, physics, or mathematics, technology is a broad subject and cannot be understood as a simplified version of an academic discipline. Previous research has demonstrated that technology education is interpreted in markedly different ways depending on teachers' professional backgrounds, for example whether they are trained as craft teachers, physics teachers, or engineers with teacher education (Bjurulf, 2008; Fahrman, Gumaelius & Norström, 2015). When teachers with different professional backgrounds collaborate in interdisciplinary teaching, or when individual teachers are responsible for implementing interdisciplinary themes, the representation of the technology subject is therefore likely to vary. Similarly, teachers may interpret and enact pre-designed teaching materials in different ways (Kanmaz, 2022).

There are numerous ready-made teaching materials intended to support interdisciplinary instruction that teachers can readily adopt in their practice (Wilcox, Shoulders, & Myers, 2014). These materials typically centre on a contemporary theme and aim to assist teachers in efficiently teaching multiple subjects within a single instructional design. Research indicates that teachers are inclined to use pre-designed teaching materials, but that they relate to and engage with these materials in different ways (Andree & Hansson, 2022). This makes it particularly relevant to examine how subjects are presented within such materials, and how individual subjects are foregrounded or marginalised.

Interdisciplinary education is commonly defined as an approach that involves two or more disciplines and requires explicit integration to address questions or problems that cannot be adequately handled within a single disciplinary perspective. Recent syntheses highlight an emerging consensus that interdisciplinarity is not achieved through thematic alignment alone, but through the integration of disciplinary knowledge and modes of thinking (Boix Mansilla, 2005; see also RTI International, 2022).

Several scholars have further conceptualised interdisciplinarity as part of a continuum ranging from disciplinary and multidisciplinary approaches to interdisciplinary and transdisciplinary ones (Drake & Burns, 2004, Klein, 2006). Within this continuum, multidisciplinary or cross-disciplinary approaches juxtapose subjects without requiring synthesis, whereas interdisciplinary approaches are characterised by explicit integration of disciplinary perspectives. This distinction is particularly relevant when analysing how technology is positioned in interdisciplinary STEM materials, as thematic coherence does not necessarily imply epistemic integration.

Instructional materials research highlights how teaching resources shape both curriculum enactment and disciplinary meaning-making (Remillard, 2005; Davis & Krajcik, 2005). Pre-designed materials not only structure teaching activities but also communicate implicit assumptions about knowledge, pedagogy, and educational purposes. In interdisciplinary contexts, such materials often provide ready-made thematic or project-based designs, thereby influencing how disciplinary connections are articulated and how subject-specific epistemic practices are foregrounded or marginalised. Analysing pre-designed materials therefore offers insight into how technology education is positioned within broader interdisciplinary STEM teaching.

3 METHODOLOGY

This study employed a qualitative, theory-informed content analysis of pre-designed teaching materials intended to support interdisciplinary STEM projects in Swedish lower and upper secondary education. Pre-designed materials are understood as instructional resources developed outside individual classrooms (e.g. by educational organisations, public agencies, museums, NGOs, or educational initiatives) and made available for teachers to use, adapt, or implement. Such materials constitute mediators between curriculum intentions and classroom practice (Remillard, 2005; Davis & Krajcik, 2005).

Selection of materials followed purposive sampling aimed at analytical variation rather than representativeness. Materials were included if they (1) explicitly addressed interdisciplinary themes involving technology and at least one other subject, (2) were intended for Swedish compulsory schooling, and (3) provided structured teaching guidance such as lesson plans or project descriptions. Fourteen materials meeting these criteria were selected from widely used national repositories and portals. The sampling aimed to capture variation in thematic orientation, institutional origin, and intended educational level, in order to explore different ways in which the technology subject is positioned across interdisciplinary teaching materials.

The analysis was guided by a didactic framework conceptualising teaching practices along three dimensions: what is taught and learned, how teaching is organised and enacted, and why activities are framed as educationally meaningful (Lennholm & Engström, 2025). This framework was used as an analytical lens to examine how technological knowledge, activities, and purposes were articulated across the material set.

The analytical procedure followed an iterative process inspired by qualitative structuring content analysis (Mayring, 2014). Materials were first read holistically, then segments related to technological content, activities, and purposes were coded in relation to the analytical dimensions. Through iterative comparison across materials, three recurring configurations were identified: technology-centered, thematically embedded, and tool-oriented projects. These configurations were empirically derived and not predetermined by the framework.

Analytical credibility was strengthened through iterative comparison, joint interpretation by the authors, and refinement of category boundaries to ensure consistency in the identification of patterns. Category stability was assessed through repeated comparison across the dataset, and interpretations were refined through collaborative analytical discussions between the authors.

Importantly, the analytical framework did not predetermine the configurations presented in the results. Rather, the dimensions of what, how, and why functioned as an interpretive lens guiding the examination of how technological knowledge, activities, and purposes were articulated across the material set. Through iterative comparison and synthesis, three recurring patterns emerged describing different ways in which the technology subject was positioned within interdisciplinary teaching designs. These configurations therefore represent empirically derived analytical constructs rather than direct extensions of the framework's dimensions. The *why* dimension was operationalised through explicit statements of educational purpose, societal framing, or intended competencies articulated in the materials, such as references to sustainability, innovation, or student engagement.

A generative artificial intelligence (GenAI) tool (ChatGPT, OpenAI) was used as a supportive tool in the writing process, including for language editing, structuring of sections, and refinement of arguments. The tool was also used for discussing ideas and improving clarity of presentation. It was not used to generate empirical data, conduct analysis, or produce substantive research findings. All research design, analysis, interpretation, and final decisions regarding the manuscript were undertaken by the authors, who bear full responsibility for its content.

4 RESULTS

In total, 14 lesson plans/teaching materials were analysed. All of these are provided by well-known and well-established actors, most of whom are not primarily oriented towards the school sector but have developed educational programmes as part of their decision to also contribute to school education. In the results section below, we describe for each teaching material how the content, knowledge, and abilities of the technology subject are presented, addressed, and made visible. This is discussed in relation to the model described above as well as through other themes that emerge from the analysis. The analysis of commonly used teaching materials for interdisciplinary STEM projects in Swedish lower and upper secondary education reveals three distinct configurations of how the technology subject is positioned: technology-centered, thematically embedded, and tool-oriented projects. Across these configurations, recurring patterns emerge regarding what aspects of technological knowledge are foregrounded, how activities are structured, and why projects are framed as educationally meaningful.

The configurations describe recurring patterns in how technology is epistemically positioned within interdisciplinary instructional designs, rather than representing distinct pedagogical models or mutually exclusive categories. The analysis revealed systematic variation in how the technology subject was articulated and positioned within interdisciplinary STEM teaching materials. While all materials addressed interdisciplinary themes and emphasised societal relevance, they differed in the extent to which technological knowledge, processes, and evaluative practices were made explicit. Across the material set, technology was framed either as a primary object of learning, as contextual content within broader thematic narratives, or as a practical means of supporting learning in other subjects. Through comparative analysis, three analytically distinct configurations were identified: technology-centered, thematically embedded, and tool-oriented projects. These configurations represent dominant tendencies rather than mutually exclusive categories.

Table 1 illustrates how some commonly used Swedish repositories align with the three identified configurations. While all materials emphasise relevance and engagement, explicit opportunities for technological inquiry vary considerably across configurations. Overall, the distribution of examples across configurations indicates a predominance of thematically embedded approaches, with comparatively fewer technology-centered designs. This pattern suggests that while interdisciplinary ambitions are strongly represented in the materials, explicit articulation of technological knowledge and design-related reasoning is less consistently foregrounded. The findings therefore point to a tension between thematic integration and disciplinary visibility, where the organisational logic of interdisciplinary projects may shape how technological knowledge is framed as an object of learning.

Table 1

Examples of Swedish teaching materials mapped to configurations of technology in interdisciplinary STEM projects

Repository / Example (link)	Dominant what	Dominant how	Dominant why	Typical omission / tension
Technology- centered				
1 CETIS – Teknik tillsammans https://liu.se/cetis	Technology concepts + tech-society relations	Structured work areas	Strengthen technology as a school subject	Iterative design, evaluation criteria, systems thinking under- developed
2 NTA – Smartare produkter (micro:bit) https://www.nta.se	Technical problem-solving, programming	Practical construction & testing	Capability & interest in technology	Design often linear; limited optimisation reasoning
3 Komtek – municipal tech workshops https://komtek.se/	Hands-on technology making	Workshop- oriented activities	Build confidence & practical skills	Technology framed as “making” rather than reasoning
Thematically embedded				
4 Naturskyddsföreningen – school materials https://www.naturskyddsforeningen.se/skola/skolmaterial/	Energy, climate, society	Theme-based interdisciplinary lessons	Sustainability & citizenship	Technology mainly illustrative
5 NTA – Energi och hållbar utveckling https://www.nta.se	Societal challenges	Student participation in SSI	Engagement & relevance	Tech knowledge progression unclear

6 Tekniska museet – Zero City https://www.tekniskamuseet.se/skola/stem-skolprojekt-som-inspirerar/	Future cities & sustainability	Pre/during/after visit activities	Motivation & future orientation	Tech processes depend on teacher-follow-up
7 Tekniska museet – Hyper Human (self-guided visit) https://www.tekniskamuseet.se/skola/skolbesok-pa-egen-hand/hyper-human/	Human–technology relations	Exhibition-based exploration	Engagement with tech & society	Minimal scaffolding of tech reasoning
8 Unga Innovatörer – Fossilfrihet challenge https://ungainnovatorer.se/utmaningar/fossilfrihet	Innovation linked to climate action	Challenge-based project work	Relevance, innovation, action	May remain thematic without deep tech processes
9 Globala målen – school materials https://globalamalen.se/skola/skolmaterial/	UN SDGs across subjects	Cross-curricular lessons	Sustainability & global awareness	Technology not treated as distinct inquiry
10 Skogen i skolan – “Mitt liv som träfiber” https://www.skogeniskolan.se/laromedel/mitt-liv-som-trafiber-lararhandledning/	Bioeconomy, materials	Hands-on + reflection	Systems understanding of forest use	Design/evaluation steps weakly articulated
Tool- oriented				
11 UR – Typiskt teknik https://urplay.se/amne/teknik	Everyday technology	Media-supported short tasks	Accessibility, engagement	Descriptive rather than evaluative
12 Digitala lektioner Teknikhistoria: Gladys & GPS https://digitalalektioner.se/lektion/teknikhistoria-gladys-och-gps-tekniken/	Tech history & navigation	Online lesson + narrative	Understanding technological development	Limited engagement with design reasoning
13 ESERO – Moon Camp Mission https://www.esero.se/moon-camp-mission/	Space technology context	Digital inquiry & modelling	Motivation through real-world STEM	Technology as environment/tool
14 Nobel Prize Museum – school programs (lower & upper secondary) https://www.nobelprizemuseum.se/skola/skolprogram/#hogstadiet	Science & innovation history	Museum programs & activities	Inspiration & recognition of knowledge	Tech inquiry often historical /descriptive

5 DISCUSSION

The findings contribute to discussions in both technology education and interdisciplinary education research concerning the conditions under which disciplinary knowledge becomes visible or diluted in interdisciplinary teaching contexts. While interdisciplinary STEM approaches are often promoted for enhancing relevance and engagement, the analysis suggests that such ambitions do not automatically ensure explicit integration of technological knowledge and reasoning. The predominance of thematically embedded and tool-oriented configurations indicates that instructional designs frequently prioritise thematic coherence over systematic development of technological knowledge. Practically, this highlights the importance of making technological processes such as design iteration, evaluation, and systems reasoning explicit when designing interdisciplinary STEM instruction. Strengthening the epistemic visibility of technology may support more robust learning outcomes and clearer positioning of the subject within interdisciplinary practice.

Technology-centered projects are comparatively rare in the material analysed. When present, they typically express strong ambitions to foreground innovation, future solutions, or technological development. However, these ambitions are only partially realised in practice. While students are often encouraged to generate ideas or propose solutions, opportunities to engage in core technological processes—such as iterative design, evaluation against criteria, optimisation, or systematic comparison of alternatives—are limited. Systems thinking, although implicitly relevant in themes such as sustainability or infrastructure, is seldom articulated as an explicit object of student reasoning. As a result, technology tends to appear primarily as a source of solutions rather than as a discipline characterised by distinct ways of knowing and reasoning.

Thematically embedded projects constitute the dominant configuration across the materials. These projects are organised around broad societal or environmental themes—such as climate change, sustainable development, or future cities—and integrate content from science, social studies, and technology. Within this configuration, interdisciplinarity is primarily achieved at the thematic level rather than through epistemic integration of disciplinary perspectives.

Technology is frequently positioned in an illustrative or supportive role, providing examples of existing solutions or applications within a broader narrative largely shaped by scientific explanations or societal considerations. While the materials emphasise values such as sustainability, collaboration, and student engagement, they rarely specify how technological understanding is expected to develop over time or how it differs from scientific or social knowledge. Consequently, technology's disciplinary contribution risks being diluted, as thematic coherence takes precedence over conceptual clarity within the technology subject.

In tool-oriented projects, technology is primarily framed as a means for learning rather than as an object of learning. Digital tools, simulations, programming environments, or prototyping materials are commonly used to support investigations in science or mathematics, or to visualise societal problems. Although such activities may involve building or modelling, the learning objectives are seldom articulated in explicitly technological terms.

Students are rarely required to justify design choices, evaluate solutions using explicit criteria, or reflect on the limitations and consequences of technological decisions. As a result, technological activity tends to become procedural rather than epistemic. While this configuration often supports practical classroom implementation and student engagement, it reinforces a view of technology as an auxiliary or service subject rather than as a field of inquiry with its own knowledge structures and evaluative practices.

Across all three configurations, the materials consistently articulate strong educational purposes related to sustainability, problem-solving, and societal relevance. Similar patterns are described in broader analyses of interdisciplinary education, which point to accountability pressures, organisational constraints, and uneven access to professional support as factors that tend to favour low-risk forms of interdisciplinarity, where disciplinary integration remains implicit (RTI International, 2022). However, these purposes are only weakly connected to explicit technological knowledge development. Technology is frequently mobilised to address *why* questions—such as *why* sustainability matters or *why* innovation is needed—without sufficient attention to what constitutes technological understanding or how such understanding is developed through teaching.

Taken together, the findings suggest that while interdisciplinary STEM materials successfully promote thematic breadth and student engagement, they often underrepresent technology as a distinct epistemic domain. This imbalance has implications for how students encounter technological knowledge and for how teachers navigate the role of the technology subject within interdisciplinary STEM practices.

Across repositories, thematic coherence and motivational purposes are well developed, while explicit opportunities for technological reasoning remain limited. Even in materials where technology appears central, technological processes such as evaluation, iteration, and systems thinking are weakly articulated. The configuration of technology strongly shapes what kinds of knowledge students are invited to develop.

This study contributes to technology education research by conceptualising how instructional materials mediate the disciplinary visibility of technology within interdisciplinary STEM contexts. By extending interdisciplinary education research through a technology-specific analytical lens, the study highlights the importance of epistemic clarity when designing interdisciplinary learning environments. It also demonstrates how teaching materials function as key mediators between curriculum intentions and classroom practice, shaping the conditions under which technological knowledge is recognised as a distinct domain of learning.

Taken together, the findings suggest that strengthening the epistemic visibility of technology is essential if interdisciplinary STEM education is to support both thematic relevance and disciplinary learning progression.

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Technology Education Across Boundaries: The 'Project Approach in Learning' Model for Cultivating Engineering Thinking

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Abstract

An ongoing challenge in contemporary technology education lies in bridging the gap between students' initial ideation and the development of practical, tangible solutions. While project-based learning is widely recognized as an effective approach, its success depends on a structured pedagogical framework that systematically cultivates Engineering Thinking (ET). This paper introduces the Project Approach in Learning (PAL), a comprehensive model developed and refined over the past five years to provide educators with a robust blueprint for fostering meaningful innovation.

The PAL model emerged from longitudinal action research rooted in a 10-year school-wide STEMaker program and was further consolidated through a 5-year initiative supporting 14 primary schools. Analysis of this work revealed that impactful projects require a holistic system. Consequently, the PAL framework is organized into three integrated components: 1) Project Planning, which defines a project's architecture through five key features—Scenario Leading, Problem Based, Knowledge Connectedness, Exploration & Elaboration, and Tangible Production; 2) Lesson Arrangement, which structures delivery using a "Three-Act" narrative framework; and 3) Instruction Strategy, guided by the "4Cs" of Connectedness, Coherence, Continuity, and a unique fourth C—Convergence—to ensure all activities align toward tangible outcomes.

This paper explores the theoretical underpinnings of the PAL framework and its alignment with the cultivation of Engineering Thinking. It then deconstructs the model's components, presenting concrete examples, lesson plans, and project guidelines drawn from validated practice. By offering a practical and replicable structure, this research provides a proven strategy to guide students across the critical boundary from abstract ideas to robust solutions, transforming technology education and equipping students to become adaptive, innovative problem-solvers.

Key Words: Project Approach in Learning, Engineering Thinking, STEM Education

1 INTRODUCTION

It is widely acknowledged that the objective of engineering education in K-12 schooling is not to turn every student into an engineer, but rather to cultivate Engineering Thinking (ET) (National Academy of Engineering [NAE], 2010). In an era of rapid technological change and digital transformation, ET equips students with the ability to use technological means and design cycles to create tangible products that solve authentic, real-world problems. However, a significant challenge for students often lies in transforming an initial idea into a concrete, demonstrable solution.

While project-based learning (PBL) can indeed guide students through the complete process from ideation to a mature solution, traditional PBL methodologies present certain limitations in STEM contexts (English & King, 2015; Kelley & Knowles, 2016). Conventional PBL emphasizes a student-centered approach, revolving around a complex, authentic, and challenging problem or task that allows for extended inquiry. This model permits students to use diverse methods and means for research and design, resulting in a variety of output formats. While this flexibility fosters creativity, without appropriate pedagogical scaffolding, it can sometimes lead to a lack of focus on tangible engineering outcomes, potentially diluting the rigorous application of engineering principles.

Moreover, there were numerous papers and discussions on different pedagogies and different thinking frameworks, but the systematic mapping, analysis and comparison between an operational pedagogical model and a clear cognitive framework are rare. There is a need to find a suitable model for bridging a pedagogical model to a thinking framework.

Another paper presented at this conference proposes a concrete framework for Engineering Thinking known as IDTEM (Leung & Yau, 2026b). This framework integrates the domains of design, technology, and engineering, explicitly stating the need for students to develop mindsets and habits encompassing Materialization, Visualization, Systemization, Optimization, Internalization, and Documentation. This provides a clear roadmap for transitioning from diversified STEM activities to structured engineering education.

This paper will reference the Project Approach in Learning (PAL) model (Leung & Yau, 2026a) as a structured pedagogical framework to address the implementation difficulties of traditional PBL. The PAL model is built on three pillars: Project Planning, Lesson Arrangement, and Instructional Strategies. Within Project Planning, PAL identifies five essential features for a high-quality STEM project: Problem Based, Scenario Leading, Knowledge Connectedness, Exploration & Elaboration, and Tangible Production. For Lesson Arrangement, it proposes a three-act structure for each lesson, including: a Setup phase using the INTRO strategy to motivate students and connect to the previous session; a Confrontation phase using the "Onion Approach" to break the project into smaller, manageable challenges; and a Resolution phase. The Instructional Strategies are guided by the "4Cs": Connectedness of technological elements, Coherence of objectives, Continuity of lessons, and Convergence of learning outcomes.

This paper will first review relevant theories and then analyze in detail how each component of the PAL model corresponds to the six thinking elements proposed by the IDTEM framework. In doing so, it provides a pedagogical context for resolving the student's challenge of developing initial ideas into concrete solutions.

1.1 Development of the PAL Model: An Action Research Approach

The Project Approach in Learning (PAL) model presented in this paper is not a purely theoretical construct. It is the result of a decade-long action research cycle conducted within two primary contexts: a 10-year school-wide STEMaker program and a 5-year professional development initiative supporting 14 local primary schools. The methodology involved iterative cycles of implementation, observation, analysis, and refinement. Initial pedagogical strategies were applied in real-world project settings, student outcomes and learning processes were systematically observed, and teacher feedback was collected. This analysis consistently revealed that isolated project activities, without a holistic structure, often failed to cultivate deep-seated Engineering Thinking. The PAL model, with its three pillars—Project Planning, Lesson Arrangement, and Instructional Strategy—was progressively developed and codified to address these identified gaps, providing a robust and replicable framework. This paper, therefore, focuses on deconstructing the finalized model and mapping its components to the IDTEM cognitive framework, rather than detailing the extensive empirical data from which it emerged, which is the subject of another study (Leung & Yau, 2026b).

2 THE NEED FOR A PEDAGOGICAL BRIDGE

2.1 Beyond Process Maps: The Limits of Traditional Frameworks

In recent years, scholars have argued that the aims of school engineering education should extend beyond mastering design procedures to cultivating characteristic ways of thinking about problems, systems and improvement (Honey et al., 2014; Katehi et al., 2009). One influential response has been the notion of “engineering habits of mind” (EHoM) (e.g., Lucas et al., 2014), which foregrounds tendencies such as systems thinking, problem-finding, visualizing and a persistent orientation towards improving solutions through iteration. While this paper does not adopt any particular EHoM framework and instead develops an independently derived conception of engineering thinking, it shares the underlying concern that classroom pedagogies must explicitly support higher-order engineering thinking rather than focusing only on stepwise task completion.

STEM projects are goal-oriented, aiming to solve problems by providing students space to learn through the problem-solving process. This learning is not confined to the content of individual subjects; rather, it enhances subject understanding by integrating and applying different knowledge bases. The knowledge students genuinely acquire in this process is largely at the technological level. Traditional pedagogical frameworks, however, often focus on learning outcomes—what students are expected to learn—and emphasize processes and steps. Design thinking, for example, provides a structured guide for divergent and convergent problem-solving. Yet research on engineering habits of mind and engineering design practice suggests that core

engineering ways of thinking—such as systems thinking, problem-finding and an orientation towards continuous improvement through iterative refinement—depend on opportunities for students to revisit, test and modify their designs over time (De Guzman, 2021; Jordan & McDaniel, 2023; Lucas et al., 2014; National Research Council, 2012). When design thinking is implemented rigidly as a linear checklist in classrooms, it risks foregrounding procedural completion over iterative experimentation and may therefore constrain the development of these higher-order forms of engineering thinking.

The traditional engineering design cycle faces a similar challenge. School versions of the cycle are often derived from procedural engineering manuals and project-management models, which codify design as a sequence of distinct stages (Honey et al., 2014; National Research Council, 2012). By contrast, work on engineering design challenges emphasizes that ill-structured problems and iterative redesign are crucial for nurturing students' engineering habits of mind and problem-solving capabilities (De Guzman, 2021; Householder & Hailey, 2012). Consequently, the goal of STEM projects is problem-solving that requires students to develop their own modes of engineering thinking—continually adjusting their cognition through iterative processes of inquiry, testing and optimization to overcome difficulties (De Guzman, 2021; Jordan & McDaniel, 2023).

2.2 *Defining the Destination: Recapping Engineering Thinking (IDTEM)*

To enable students to arrive at genuinely executable solutions, framing the task as an engineering project is a viable choice. Employing the IDTEM framework of Engineering Thinking can effectively address the difficulties in transitioning from creative concepts to implemented solutions. The Materialization emphasized by ET compels students to consider the feasibility and authenticity of a solution from the outset. Visualization focuses on the communication of ideas, whether with teachers or peers, allowing these ideas to be validated and learned from, thereby building a community of practice. The Optimization methods within ET provide ample room for students to engage in iterative design revisions and layered refinements, elevating their thinking to deeper levels.

The Systemization mindset prevents students from being deterred by the scale or complexity of a problem. Systematic thinking is the skill of breaking large problems into smaller, manageable tasks that can be planned and executed sequentially. This cognitive approach is invaluable for tackling any major challenge in the future. Through the practice of Visualization, Materialization, Optimization, and Systemization, engineering concepts gradually become ingrained and Internalized as habits. Finally, IDTEM also stresses the importance of Documentation, the habit of meticulously recording ideas and the problem-solving process. This practice serves as a form of reflection that enhances metacognitive awareness and learning.

2.3 *The Missing Link: From Pedagogy to Mindset*

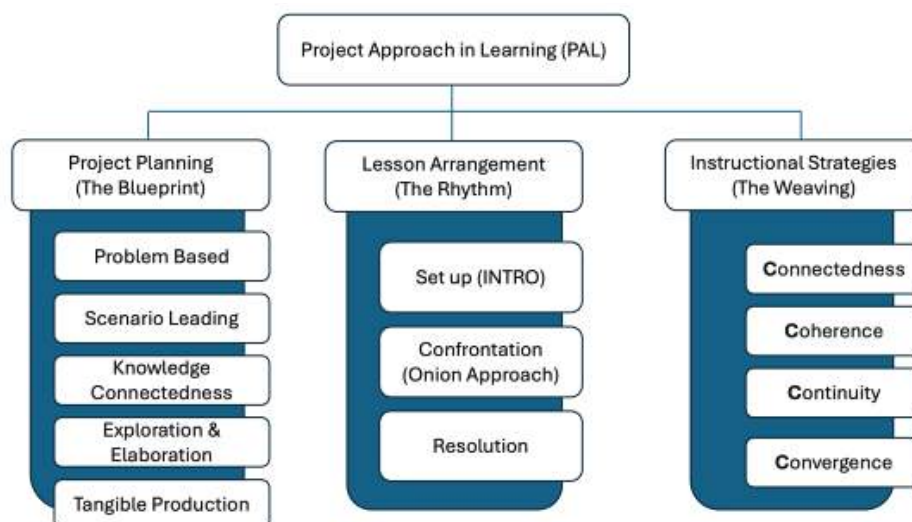
The core problem this paper seeks to address is the need for a pedagogical bridge that connects the activities of classroom instruction with the ultimate task of a STEM project: the cultivation of Engineering Thinking as a higher-order mindset. We posit that the Project Approach in Learning (PAL) model serves precisely as this bridge.

3 THE PAL MODEL AS A VEHICLE FOR ENGINEERING THINKING

How exactly does the PAL model align with the IDTEM framework? The following sections will analyze and compare the relationship between these two core frameworks to demonstrate how PAL can be used to build a mindset structured by IDTEM.

Figure 1

The PAL Framework Overview



3.1 Overview of the Mapping

The following table presents the three pillars of the PAL model and their constituent parts. These are broadly categorized as Project Planning, Lesson Arrangement, and Instructional Strategies. Project Planning outlines the five essential features of an exemplary project. Lesson Arrangement presents a "three-act" structure for planning each lesson, with the Confrontation phase notably using the "Onion Approach" to deconstruct the main task into smaller, sequential steps. Finally, the Instructional Strategies employ the 4C framework. This mapping is not merely theoretical but represents the synthesized pedagogical insights derived from our longitudinal action research, illustrating how specific instructional scaffolds activate corresponding cognitive processes.

3.2 Project Planning

Project Planning does more than just outline a project; it constructs the very blueprint for Engineering Thinking. Each of its five essential components contributes to different facets of ET.

- **Scenario Leading:** An authentic scenario is a complex system comprising users, the environment, and socio-cultural factors. When introducing a project, we must guide students to immerse themselves in the scenario and analyze its intricate elements. Every detail matters, much like the opening moment of a play: the setting, lighting, music,

atmosphere, props, and background. This process of immersive experience is, in effect, a systematic deconstruction of the scenario into finely tuned components, cultivating the concept of Systemization. To better understand the scenario, students can use tools like storyboards, scenario maps, or mind maps to clarify its various branches and details. These techniques are themselves an embodiment of Visualization in ET.

- **Problem Based:** While the problem initially presented to students represents the overarching core challenge (e.g., constructing a bridge that can support a specific weight), the path to a solution is rarely straightforward. Students must deconstruct this main challenge into several 'sub' or 'mini' problems. By doing so, the true complexities of the main problem are revealed, allowing students to understand how each part can be addressed and solved. This is a direct application of Systemization. For instance, when tackling questions in high-school public examinations, we often require students to transform a single problem into ten or more "design opportunities," each becoming a smaller, solvable problem. Concurrently, understanding a problem accurately requires extensive background research, user interviews, needs analysis, and even market positioning surveys. This background information is crucial in the problem identification phase. Students need to systematically record this information and analyze it for useful insights, which then form the design considerations and specifications. This is key to project success and simultaneously cultivates the habit of Documentation.
- **Exploration & Elaboration:** To transform an idea into a tangible solution, research is essential. This may involve simulated experiments of the proposed idea or testing different materials. For STEM projects involving mechanical structures, creating prototypes like cardboard models for testing and refinement is necessary. This process is rarely successful on the first attempt. The inquiry process requires constant, iterative adjustments, which is the essence of Optimization in ET. When faced with a large-scale exploration, students need to systematically break down the optimization process into different parts and prioritize their inquiries, which again reflects Systemization.
- **Knowledge Connectedness:** Knowledge connection in a STEM project is not about directly learning subject-specific content but about applying knowledge from various disciplines to solve problems. When the applied disciplinary knowledge is properly recorded in the project log, it not only reinforces the student's academic foundation but also cultivates the habit of Documentation. Knowledge is a powerful driver of improvement and Optimization. For example, a student designing a robotic car might find it doesn't move, despite finding no errors in the mechanical assembly or programming. Physics knowledge could be crucial here. By recalculating the total energy output and battery matching, they might discover that a battery with a higher power output is needed. This point of knowledge connection becomes a resource for optimization. Not all knowledge connections require online searches or AI assistants. As a result, many problems can then be solved intuitively—through fast, experience-based judgements that rely on automatic, proceduralised knowledge—

without the need to consciously search memory or rehearse explicit rules on every occasion (Anderson, 1982; Kahneman, 2011; Moors & De Houwer, 2006). For example, in observations of experienced robotics teams, coaches can often identify construction errors in students' robots through visual inspection alone, without using any tools. A common mistake is unequal lengths in left and right structural components, causing a connecting cross-beam to be non-horizontal. With experience, coaches can confidently tell students which side is longer or which angle is not 90 degrees, without rulers or protractors. Students typically achieve a similar level of internalized expertise after about two years of training.

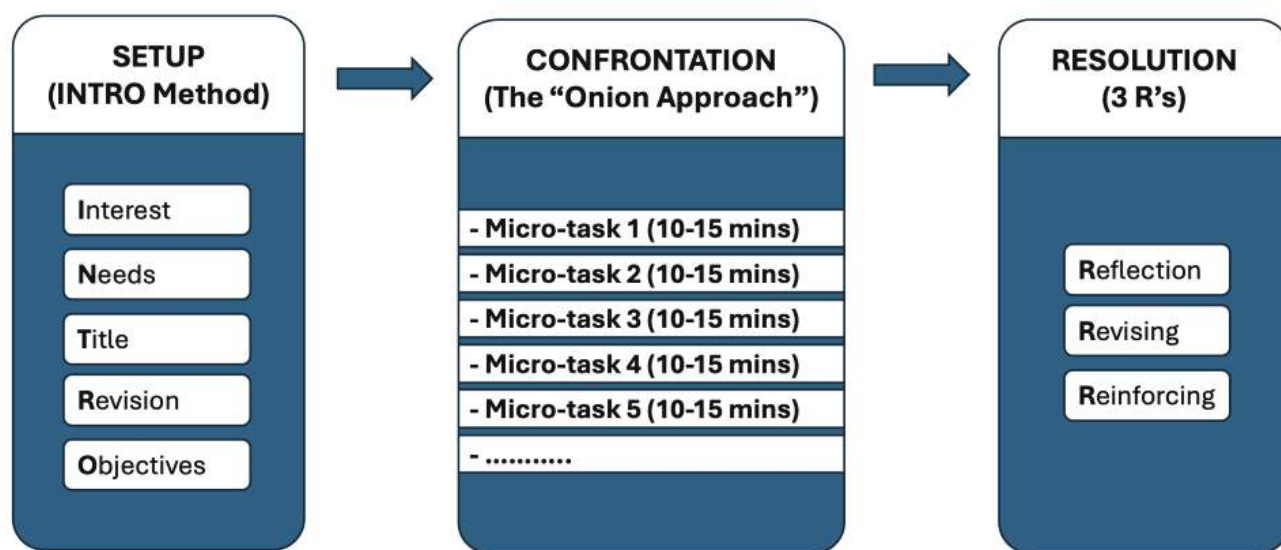
- **Tangible Production:** This has the most direct link to Materialization in ET. Tangible Production is a firm requirement of PAL, expecting students to solve real-world problems by creating functional, testable artifacts. While our primary context often emphasizes physical objects, "tangible" is not strictly limited to physical materials; it equally encompasses robust, executable digital products (such as coded software or interactive applications). However, it explicitly excludes mere theoretical exercises or static digital documents (such as PowerPoint presentations or written reports) acting as the final solution. The core objective is to move beyond mere theoretical proposals. This process of linking abstract ideas with the manufacturing processes, material properties, or logical constraints of the real world is the core of Materialization. During this process, designs and ideas must be communicated to teachers and peers. This necessitates presenting one's ideas in various visual formats, including sketches, engineering drawings, or CAD renderings. Thus, Tangible Production indirectly reinforces the need for Visualization.

3.3 Lesson Arrangement

The Lesson Arrangement in PAL transforms potentially chaotic class sessions into a structured, rhythmic learning experience. STEM classes differ from other subjects; being interdisciplinary, they often lack a dedicated, regular slot in the school timetable. Practices vary, with some schools allocating time from within a specific subject, while others set aside a dedicated period each week. Regardless of the arrangement, it is rare for a project to be completed in a single session. While this might be possible in primary school, high school projects often require over ten hours, spanning five to six consecutive class periods. This means students may have to wait a week, or even a month, between sessions. Here, the Documentation habit (from IDTEM) becomes essential, serving as a bridge that sustains learning and facilitates independent inquiry during these intervals. PAL's Lesson Arrangement provides an optimal method for creating tight connections between lessons, achieving excellent coherence.

Figure 2

The “Three-Act” Lesson Structure

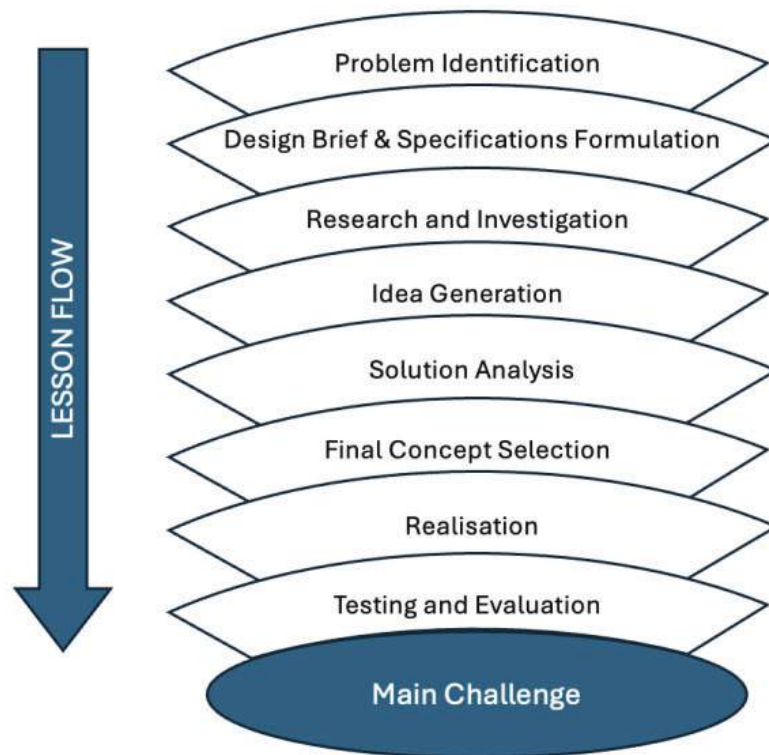


PAL's Lesson Arrangement adopts a three-act structure: Setup, Confrontation, and Resolution.

- **Setup (INTRO Method):** The INTRO method aligns perfectly with ET's **Visualization, Systemization, and Documentation**. The entire INTRO process—establishing **Interest**, clarifying **Needs**, giving a **Title**, conducting **Revision**, and defining **Objectives**—serves as a powerfully illustrative introduction to the lesson. Even if a teacher only verbally articulates these five parts, it creates a vivid mental picture. This is **Visualization**. Breaking down the lesson's goals into five distinct parts within the first few minutes is **Systemization**. Formally recording these lesson tasks in a plan constitutes **Documentation**.
- **Confrontation (Onion Approach):** The main part of the lesson is broken down into 10-15 minute micro-tasks. This is a clear manifestation of **Systemization** and a model for systematic teaching. It allows students to solve problems step-by-step and provides moments for reflection and refinement within each segment. Given the hands-on nature of the class, this stage is inseparable from **Visualization** and **Materialization**. Difficulties will inevitably arise, requiring repeated corrections and adjustments through an iterative process, which is **Optimization** in ET.

Figure 3

The “Onion Approach” Diagram



- **Resolution:** The Resolution phase uses a structure of Reflection, Revising, and Reinforcing to conclude the lesson. It effectively employs **Systemization** to systematically summarize the class and to review and consolidate the knowledge involved. Teachers should use this time to ask questions that systematically deconstruct the students' making process, prompting them to recall and reflect.

3.4 Instructional Strategy

PAL's Instructional Strategy employs a comprehensive 4C framework: Connectedness, Coherence, Continuity, and Convergence. The foundation of this framework builds upon the principles of effective instruction highlighted by Moreland et al. (2016), who emphasize the critical importance of establishing connectedness, coherence, and continuity in students' learning experiences.

The collective function of these first three Cs is to weave disparate learning experiences into a holistic cognitive structure, specifically targeting the problem of long-time gaps between lessons. Coherence ensures students understand that all sessions are aimed at the same project goal.

Connectedness links each lesson to knowledge from different disciplines. Continuity extends learning beyond the classroom. This consolidation of fragmented learning experiences is a powerful act of reinforcement that fosters Internalization, gradually transforming knowledge into stable, intuitive strength. Of course, managing these scattered pieces of knowledge while maintaining connections between lessons makes the habit of Documentation indispensable.

Building on this established foundation, PAL introduces a unique fourth C: Convergence, which focuses on assessment. All learning converges to a single point. The assessment evaluates not only the completeness of the final product but also the skills and attitudes acquired, and indirectly, the students' cognitive growth. Therefore, this final focal point is relevant to and shared by all six elements of Engineering Thinking. The goal of assessment is to ensure the entire project demonstrates the thinking abilities of Visualization, Materialization, Systemization, Optimization, Internalization, and Documentation.

Convergence acts as an evaluative lens through which all project activities are assessed against the IDTEM framework. For instance, assessment would focus on: the feasibility and quality of the final artifact (Materialization); the clarity of the process communicated through drawings and plans (Visualization, Documentation); the elegance and efficiency of the solution's architecture (Systemization); the rigor of the iterative refinement process (Optimization); and the depth of the student's acquired understanding, evidenced by their ability to explain and adapt their solution (Internalization). However, assessing the depth of Internalization solely based on the final product of a single project is challenging. True Internalization is more accurately reflected in the efficiency and intuition with which students tackle similar authentic problems in future iterations.

Table 1

Mapping of Project Approach in Learning (PAL) to Integrated Design and Technology Engineering Mindset (IDTEM)

Project Approach in Learning (PAL)		Integrated Design and Technology Engineering Mindset (IDTEM)					
		Materialization	Visualization	Optimization	Systemization	Internalization	Documentation
Project Planning	Problem Based				✓		★
	Scenario Leading		★		✓		
	Knowledge Connectedness			★		★	✓

		Exploration & Elaboration				✓	★
		Tangible Production		✓	★		
Lesson Arrangement	Setup	Interest		✓		✓	✓
		Needs		✓		✓	✓
		Title		✓		✓	✓
		Revision		✓		✓	✓
		Objectives		✓		✓	✓
	Confrontation	Onion	★	★	★	✓	
	Resolution	Reflection				✓	
Revising					✓		
Reinforcing					✓		
Instructional Strategies		Connectedness				✓	★
		Coherence				✓	
		Continuity				✓	
		Convergence	✓	✓	✓	✓	✓

Note: The star (★) indicates a primary connection or core focus, meaning the PAL activity is primarily designed to train or apply this specific IDTEM mindset. The checkmark (✓) indicates a secondary association, where the activity supports the mindset but it is not the main focus.

4 DISCUSSION: SYNERGY AND IMPLICATIONS

As demonstrated, PAL and IDTEM exhibit a powerful synergy. PAL effectively promotes the ET framework of IDTEM, while IDTEM, in turn, injects clear cognitive goals into PAL. Students are not just completing a project; they are learning a way of thinking. Research suggests that well-structured hands-on STEM projects can induce higher-order thinking and enhance overall

learning efficacy (Bybee, 2013). This implies that the benefits extend beyond merely improving students' performance in STEM, but to their overall learning effectiveness. This leads to a compelling hypothesis for future research: that the cultivation of Engineering Thinking through the IDTEM framework, may have a transferable effect on a student's overall academic efficacy.

Understanding the operation of this framework is not difficult, but for frontline teachers to master its application is no easy feat. The teacher's role shifts from a purveyor of knowledge to a project supervisor or a cognitive coach. Similar to athletic coaching, a teacher can provide direction and encouragement, but true cognitive development requires the student's own sustained effort and iterative practice. The training of the mind follows the same principle. Through PAL, teachers can act as cognitive coaches, guiding students and gradually witnessing their intellectual growth.

A significant challenge in implementing PAL lies in teacher self-efficacy when facilitating open-ended inquiry. Teachers may feel hesitant to guide projects that extend beyond their own technical expertise. To overcome this, professional development must encourage educators to adopt the role of co-learners, to grow alongside our students, learning knowledge, skills, and attitudes together in the process.

These models place high demands on teachers. If teachers themselves possess a degree of internalized thinking, a broad and robust knowledge base, and proficient problem-solving skills, leading such projects becomes significantly more effective. Therefore, the future direction of teacher training is critically important. How to enable teachers to understand the importance and techniques of training student thinking will be a vital direction for future educational research.

5 CONCLUSION

In this paper, we have clearly analyzed how the PAL model can be mapped onto the IDTEM thinking framework to establish an innovative teaching model. This model is the culmination of over 30 years of teaching experience by one of the authors. Rooted in a decade-long STEMaker program, the PAL framework has been specifically developed and validated over the past five years. Both authors have successfully applied this model to support 14 local primary schools, training hundreds of teachers. We are confident that this model holds significant potential for broader implementation and scaling in K-12 education.

The proposed teaching model, through its structured planning, narrative arrangement, and convergent strategies, effectively guides students across the boundary from creative ideation to practical implementation. Looking ahead, this model provides a replicable and scalable paradigm for technology education, holding the promise of cultivating a new generation of adaptive and innovative problem-solvers on a large scale.

6 STATEMENT REGARDING THE USAGE OF AI

During the preparation of this work, the authors used Generative AI tools primarily for translation and language editing purposes to improve the readability of the manuscript. After using these

tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Technology Education Inspires Innovation: The Value and Framework of Engineering Thinking

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Abstract

The rapid advancement of Generative AI (GAI) and Large Language Models (LLMs) is fundamentally reshaping the K-12 educational landscape, disrupting traditional, siloed subject-based teaching methods. This paradigm shift calls for reimagining pedagogy, moving beyond the conventional transmission of knowledge to nurturing creative, adaptive problem-solvers capable of thriving in an AI-driven world. While STEM education has laid a foundation for interdisciplinary approaches, a critical gap remains between theoretical advocacy for innovation and its practical application in classrooms. Observations reveal that when students are tasked with solving authentic, real-world problems, many struggle to move beyond initial brainstorming stages. Few succeed in conceptualizing and developing their ideas into robust, actionable solutions.

Although established frameworks such as the Engineering Design Process and Design Thinking provide procedural guidance, these models often prioritize process over the cultivation of the cognitive skills and mindsets essential for genuine innovation. This paper argues that operationalizing engineering thinking offers a viable pathway to bridging this gap. Through a systematic review of innovation methodologies, engineering principles, and design theories, we propose the “The Integrated Design and Technology Engineering Mindset (IDTEM)”. This model translates abstract principles and mindsets into six actionable components: Materialization of Ideas, Visualization of Designs, Optimization of Solutions, Systemization of Structures, Internalization of Physical Intuition and Spatiotemporal Sense, and the Habit of Documentation.

To demonstrate its practical utility, the paper presents teaching examples that integrate this framework into classroom practice, providing educators with a clear, actionable guide for fostering innovation. By equipping students with structured and flexible tools for problem-solving, this research offers a replicable strategy for cultivating the next generation of innovators in the context of rapidly evolving AI technologies. Ultimately, the proposed framework bridges the gap between theoretical aspirations for innovation and the practical realities of K-12 education, empowering students to thrive in an increasingly complex world.

1 INTRODUCTION

1.1 The Shifting Educational Paradigm in the Age of AI

Generative AI (GAI) and Large Language Models (LLMs) have become some of the hottest topics in recent years, extending their influence on almost every domain, social sector, and even everyday life. Education cannot remain untouched by this transformation. Acquiring knowledge has long been considered a central aim of education, and this belief has guided societies for centuries. However, with the emergence of GAI and LLMs, the traditional model of knowledge transmission is being challenged; students can now access vast amounts of relevant information within seconds. Scholars argue that in this new paradigm, professional value is shifting from mere knowledge retention to the critical and creative application of information (Bates et al., 2020; Touretzky et al., 2019). Therefore, the goal of education must increasingly emphasize cultivating creativity and innovation alongside foundational knowledge.

1.2 The Implementation Gap in STEM Education

The rise of STEM education has paved the way for cultivating innovative abilities. However, researchers have noted a significant gap between theoretical frameworks and classroom practice (Kelley & Knowles, 2016). While hands-on activities like maker spaces are popular, studies suggest that without proper pedagogical scaffolding, these activities may focus more on the act of building rather than the underlying scientific or engineering principles, potentially limiting opportunities for iterative design and deeper reflection (Bevan, 2017).

On the other hand, Design Thinking has become another major driving force behind STEM education. Its emphasis on creativity, empathy, and strategic problem-solving offers strong potential for cultivating innovation. Nevertheless, the lack of real implementation and follow-through means that many Design Thinking initiatives fail to move beyond ideas or classroom prototypes. As a result, while there are many Design Thinking competitions and pitching events, the educational journey often concludes at the conceptual stage, rather than extending into the valuable later phases of iteration, production, and real-world testing. Therefore, there is a strong need to review and refine the current strategies of STEM education.

1.3 Research Objectives

While the advent of GenAI and LLMs serves as a timely catalyst, highlighting the urgent need for educational reform, the underlying challenge—the lack of deep cognitive engagement in K-12 technology and engineering education—is a long-standing systemic issue. To address these ongoing challenges, this paper proposes a pedagogical tool: 'The Integrated Design and Technology Engineering Mindset (IDTEM) Framework.' The name reflects our central thesis: that targeted engineering thinking processes, when systematically practiced, combine into a durable professional mindset.

Specifically, this paper is guided by the following research questions:

- RQ1: What are the core cognitive components that contribute to authentic K-12 STEM education?
- RQ2: How can these cognitive components be operationalized into a pedagogical framework to support student innovation?

By answering these questions, this framework aims to bridge the gap between abstract ideas and real-world execution, offering a broad response to the evolution of technology education.

2 THEORETICAL UNDERPINNINGS AND THE REALITY CHECK

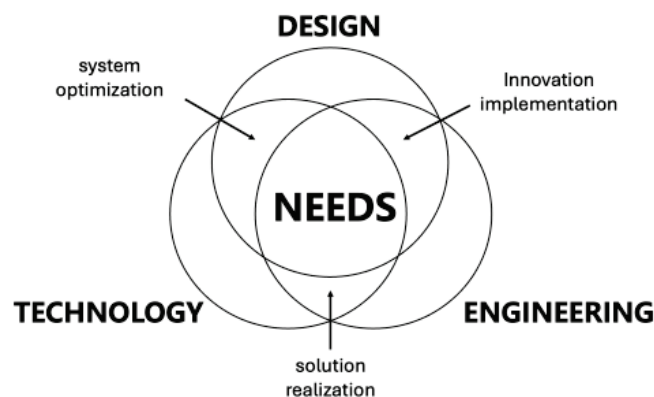
2.1 *Redefining the Core: Design, Technology, and Engineering*

To clarify these concepts within the educational context, we can draw upon definitions established by technology and engineering education organizations (e.g., ITEEA, 2020) and scholars:

- Design: Often focused on human needs and empathy, it is a divergent process of conceptualizing solutions (Cross, 2011).
- Technology: The tools, systems, and processes used to modify the natural world to meet human needs (ITEEA, 2020).
- Engineering: The systematic, iterative application of scientific and mathematical principles to optimize solutions under specific constraints (National Academy of Engineering, 2010).

Figure 1

Concept diagram showing the interconnected roles of Design, Technology and Engineering



Current frameworks often fail to balance these. Some are too generic (like Critical Thinking models), while others are too domain-specific (like physics-based models). We need a holistic framework that integrates these pillars into a cohesive mindset. True innovation demands clarity:

Design sparks possibilities, Engineering refines them to reality, and Technology provides the tools.

2.2 *Insights from Frontline Educators*

To explore how these concepts are perceived in practice, an unpublished internal pilot study was conducted in November 2025. The convenience sample consisted of 27 K-12 educators drawn from a professional support network of frontline STEM teachers established over the past decade. Data was collected during a teaching research symposium via a highly detailed, scenario-based questionnaire. To prevent vague responses, the survey presented multiple specific teaching scenarios and items for teachers to evaluate.

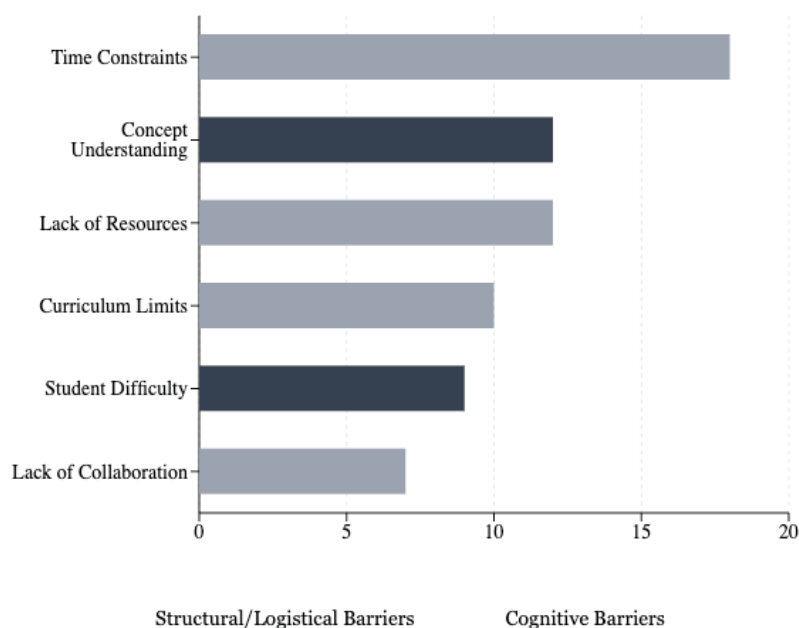
While the sample size is limited and the findings cannot be broadly generalized, the exploratory results were remarkably consistent, highlighting potential areas of conceptual ambiguity:

- The "Execution" Trap: When asked to define Engineering, 77.8% of teachers selected "Construction and Execution." This suggests a reductionist view where engineering is seen not as a cognitive process of optimization, but merely as the manual labor of building what has already been designed.
- The "Design-First" Fixation: 88.9% of teachers ranked "Design" as the mandatory first step of problem-solving. This rigid linearity prevents students from learning how to innovate from a technological breakthrough or an engineering constraint.

These preliminary findings suggest a need for further, larger-scale research to understand how teachers conceptualize engineering design.

Figure 2

Top Challenges in EDT Implementation



Even though the sample size is small, the consistency of the misconceptions (77.8% and 88.9%) indicates a strong trend that warrants further investigation. These findings highlight that the primary barrier to effective STEM education is not merely infrastructural, but cognitive. Teachers theoretically understand that these concepts should be intertwined, yet in practice, they default to a segmented, linear approach. This "broken map" is why students get stuck: they lack the engineering thinking required to debug, pivot, and optimize when their initial designs fail.

2.3 *Evaluating Existing Frameworks through the D-T-E Lens*

To justify the need for a new model, we must first evaluate the frameworks currently dominating K-12 education. The most ubiquitous is the standard Engineering Design Process (EDP), often taught as a linear or cyclical checklist (e.g., Ask, Imagine, Plan, Create, Improve). While EDP provides a necessary roadmap for project management, it often falls short in cultivating deep cognitive skills. In practice, students frequently treat EDP as a passive administrative task—checking off "Plan" to get to "Create"—rather than engaging in the rigorous, analytical thinking required to optimize a solution. A process map tells a student what to do next, but not how to think about the problem.

Beyond the standard EDP, we examined prominent academic frameworks against our defined D-T-E pillars. The Paul-Elder Critical Thinking Model, for example, is a key framework frequently referenced in engineering education (Paul & Elder, 2019). It comprises three interconnected parts: Elements of Thought, Intellectual Standards, and Intellectual Traits. While this model provides a robust and generic framework for critical analysis, its focus remains at the metacognitive level. It does not adequately address the practical, hands-on aspects central to the authentic engineering process, such as iterative prototyping, trade-off analysis, or systems integration.

Another contemporary reference is the WoT4EDP (Ways of Thinking in Engineering Design-based Physics) framework, proposed by Subramaniam (2025). This model commendably integrates design, science, mathematics, and computational thinking for physics-based engineering challenges. However, its application is intentionally specific to physics education. Consequently, it does not fully encompass the broader, discipline-agnostic workflows of engineering, which involve project management, resource allocation, and navigating non-technical constraints like economic viability and user adoption.

In essence, while existing frameworks offer significant value, they tend to be either too generic—lacking the procedural specificity of engineering practice—or too domain-specific, limiting their applicability. There remains a clear gap for a holistic framework that balances high-order critical thinking with the tangible, process-oriented workflow of engineering, while properly situating the roles of design and technology within that process.

2.4 *The Necessity of a New Integrated Framework*

From our studies, even experienced teachers and those with STEM training exhibit ambiguity regarding engineering thinking, their expectation and understanding exist with some contradiction. The preliminary findings from our pilot study align with concerns raised in broader

literature regarding the potential for STEM activities to focus heavily on procedural tasks rather than deep cognitive engagement (e.g., Bybee, 2013).

One reason for the absence of a holistic and balanced framework is the historical marginalization of technology education's role. Design emphasizes on addressing human need and places significant weight on empathic concerns and the variation of ideas outweigh physical constraints and practical difficulties. Meanwhile, many engineering processes, while adopting a design cycle—a concept arguably pioneered by engineering disciplines like NASA through Systems Engineering before being popularized in the design field (NASA, 2007; Simon, 1969)—tend to prioritize analytical precision and accuracy, sometimes at the expense of broader technical and systemic concerns.

To ensure STEM education fulfills its potential to empower students in solving authentic problems, there is a need to integrate design and technology concepts more cohesively within an engineering context. This calls for a new framework that places greater emphasis on "cognitive skills and thinking patterns," directly addressing the challenge of teachers' "insufficient conceptual understanding" and bridging the gap between abstract ideas and real-world execution.

3 THE INTEGRATED DESIGN AND TECHNOLOGY ENGINEERING MINDSET (IDTEM) FRAMEWORK

Based on the comprehensive review of relevant literature, we have developed an integrated framework grounded in design, technology, and engineering: "The Integrated Design and Technology Engineering Mindset (IDTEM) Framework." This framework is process-oriented, focusing on the active application of cognitive skills through the operational layers of Materialization, Visualization, Optimization, and Systemization. Simultaneously, it encompasses the outcomes derived from these thought processes, emphasizing the development of Internalized Intuition and a Habit of Documentation, which are cultivated through rigorous practice of the former skills. Conceptually, IDTEM aligns with and extends existing literature on "Engineering Habits of Mind" (e.g., Lucas et al., 2014) and systems thinking in education, but it specifically operationalizes these concepts into actionable steps for K-12 environments.

This framework is designed to effectively address common challenges students face during creative projects in the classroom, such as:

- Struggling to synthesize vast amounts of collected information, leading to a sense of being overwhelmed and unable to start.
- Generating numerous ideas that often lack feasibility.
- Being unable to realize ideas due to a lack of relevant knowledge and fabrication skills.
- Discovering only in the final stages that their creation is non-functional.

What follows is a detailed explanation of this framework. At its core, an engineering mindset is a specific way of thinking; it encompasses thought processes, modes of thinking, and thinking

habits. The foundational concepts of this framework were first introduced in a 2017 article (Leung, 2017) and are elaborated here into six primary components.

3.1 *Materialization of Ideas*

Materialization is the practice of immediately considering the tangible realization of an idea.

The mind instantly asks: How can this be made? Is it manufacturable? A student with this mindset would contemplate how many panels are assembled to form it. When observing a cabinet, they would analyze how the side and front panels are joined—is the side panel overlaid, or is it concealed by the front panel? How was it constructed? If you possess this concept of materialization, you will instinctively analyze the construction of any object you see, whether it was molded, forged, assembled, or 3D printed.

Materialization is a fundamental basis for understanding the physical world. This is why we assert that innovation must be objectified. When you have a profound understanding of how things are made, your efforts become more effective and efficient, preventing you from pursuing unviable paths. Any design you sketch or concept you devise will already have, to some extent, considered the fabrication process.

With a materialization mindset, seeing a car goes beyond appreciating its exterior styling; you would ponder its engine type, gearbox specifications, and shifting mechanism. Upon seeing an automatic faucet in a restroom, you would question what type of sensor it uses, its power source, how water flow is controlled, and how it is engineered to prevent electrical hazards. This pursuit of knowledge about how things are constructed motivates students to learn proactively, driving them to conduct online research or hands-on investigations.

Why it matters: Innovation must be materialized. Without this mindset, student ideas remain "castles in the air." Materialization forces the brain to bridge the gap between imagination and fabrication instantly, preventing the pursuit of unviable paths. It transforms a vague concept into a set of physical requirements.

3.2 *Visualization of Designs*

Visualization is the critical skill of rendering ideas into a visible format for communication and analysis. It is not about artistic talent but technical clarity.

Visualization is more than simple drawing. In the contemporary architecture industry, Building Information Modeling (BIM) serves as a powerful example of visualization, meticulously detailing every window frame and electrical conduit route within a structure. In university labs, students designing custom robots must be able to draw the printed circuit boards (PCBs) for their control systems. In many robotics competitions that utilize pneumatics, the ability to represent the system using a pneumatic circuit diagram is an essential visualization skill.

Why it matters: If a student cannot visualize their design, they cannot effectively communicate it to teammates or teachers. Visualization externalizes the thought process, allowing for collaborative debugging and refinement before resources are wasted on construction.

3.3 *Optimization of Solutions*

Optimization is the relentless pursuit of the *best possible solution* within constraints.

It moves beyond "making it work" to "making it work efficiently." In a robotics competition, a functional robot is just the starting point. The engineering mindset drives the student to reduce weight, increase speed, or refine code. It involves trade-offs, redundancy planning, and fail-safes.

Grounded in this optimization mindset, the iterative process emphasized in the design cycle becomes more concrete and meaningful. It is not merely about repetition, but about purposeful refinement toward a superior outcome

Why it matters: This transforms the "iterative process" from a repetitive chore into a purposeful refinement. It teaches students that the first solution is rarely the best one and that constraints are opportunities for innovation, not just obstacles.

3.4 *Systemization of Structures*

Systemization is the ability to deconstruct complex objects into manageable subsystems.

For instance, a chair can be broken down into its constituent parts: the seat, legs, armrests, and backrest. A more complex example, an electric toy car, can be divided into a power control system, a steering control system, an obstacle avoidance mechanism, and the chassis. An Arduino-based self-balancing robot can be viewed as a large system comprising multiple subsystems: a logic processing subsystem, a signal control subsystem (e.g., Bluetooth), a power supply subsystem, a motor driver subsystem, and a PID balance control subsystem.

When students can apply this concept of systemization during the design and creation process, they learn to deconstruct tasks independently, allowing them to refine and design each component individually. This approach not only makes the overall project more manageable but also, from a macroscopic perspective, enables the entire design to be more robust, complete, and successfully implemented.

Why it matters: When students learn to systemize, they are no longer overwhelmed by large projects. They can isolate problems ("The robot isn't moving—is it the power subsystem or the code?") and design robust architectures. It enables independent troubleshooting and modular design.

3.5 *Internalization of Physical Intuition and Spatiotemporal Sense*

This is the most subtle yet powerful component. It refers to a developed intuition for the physical world—a "Spatiotemporal Sense" cultivated through practice.

Consider the ancient Chinese story of the Oil Seller (The Oil Seller, 賣油翁), who could pour oil through a coin's tiny hole without spilling, attributing it simply to "practice" (唯手熟爾). Similarly, in traditional markets, experienced butchers could slice meat to an exact weight without a scale.

For an engineer, this translates to an intuitive sense of the physical world. How long is this wooden plank? They might estimate it with their hands before verifying with a ruler. A seasoned mechanic can often diagnose a machine's problem by sound alone, without a detailed inspection. We have an alumnus, now a mentor for a university robotics team, who demonstrates this profound familiarity. During a visit, while conversing with us, he suddenly paused, turned to a group of students assembling a robot, and stated, "That robot's motor is broken." He had deduced this simply from the sound made as a student turned the wheels. This is internalization—the ability to know something at a glance or through subtle sensory cues.

Michael Polanyi articulated the concept of tacit knowledge in *The Tacit Dimension*, famously stating, "we can know more than we can tell" (Polanyi, 1966, p. 4). This principle directly aligns with the Internalization pillar of the IDTEM framework, where engineers develop an intuitive mastery ("心中有數") through extensive hands-on practice that resists full articulation.

Why it matters: This intuition allows for rapid decision-making. It is the difference between a novice who needs to calculate everything and an expert who "senses" when a structure is too weak. It is the ultimate outcome of "learning by doing."

3.6 *Habit of Documentation*

The quality of engineering work is often directly reflected in the habit of thorough documentation.

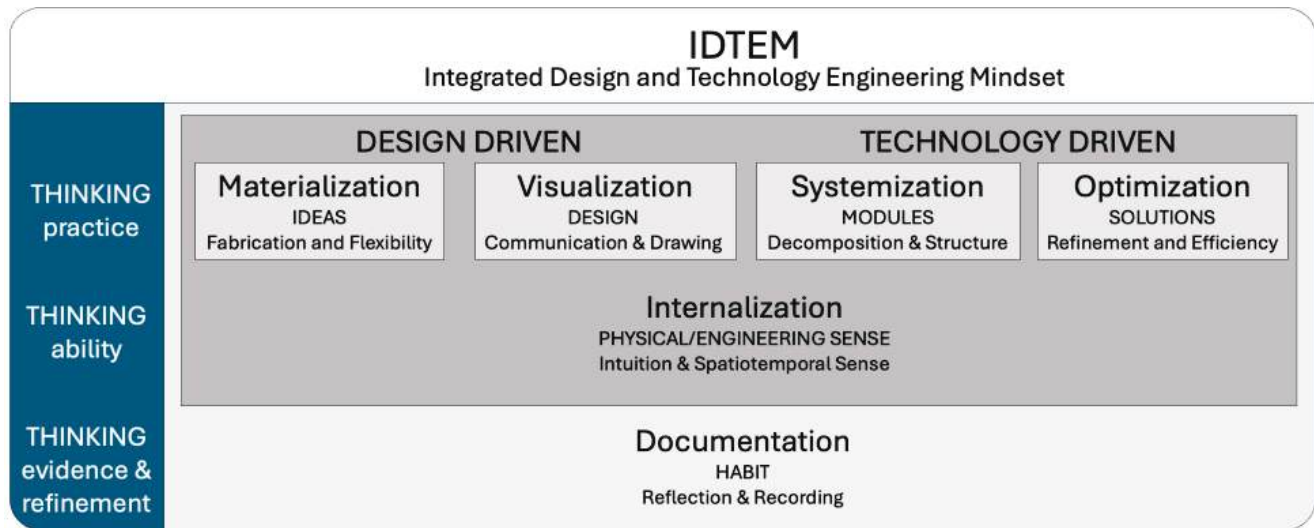
The "Engineering Notebook" is standard in professional practice. The act of writing things down is crucial because it is also a powerful form of reflection. The book *Learning by Doing* proposes a reflection framework (Gibbs, G., 1988) that guides students to process their feelings and experiences, not just list their actions. We can prompt students with questions like: "What progress did you make today? What difficulties did you encounter? Record it in your engineering notebook with sketches or words." or "Why did you decide to abandon Plan A in favor of Plan B? Document your decision-making process." These are common and effective methods for guiding students to maintain records.

Why it matters: Writing is a form of thinking. By forcing students to document their failures and pivots, we shift the focus from the final product to the process of learning. It provides authentic

evidence of the student's journey and encourages metacognitive reflection ("Why did I make this decision?").

Figure 3

The Integrated Design and Technology Engineering Mindset (IDTEM) Framework



4 PEDAGOGICAL APPLICATION: BRINGING IDTEM TO THE CLASSROOM

Historically, project-based learning often relied on providing students with step-by-step instruction manuals. This practice must be reconsidered. To cultivate the IDTEM mindset, we must empower students to navigate ambiguity.

- To foster Materialization: Move beyond concepts and sketches quickly. Challenge students to build a physical model using cardboard or clay. Ask: "You have drawn a beautiful drone, now build a non-flying model to show me how the battery fits." This validates physical feasibility immediately and avoids "armchair engineering." Typically, it happens mainly during the initial stage of the design cycle and relates more to the design aspect of the D-T-E framework.
- To foster Visualization: Make technical drawing a language, not a chore. Test their internalized sense of scale with exercises like, "Draw a 20mm by 20mm square without using a ruler." Use diagrams to communicate instructions, forcing them to interpret visual data. It provides concrete strategies on enhancing conceptual ideas to workable solutions during the design stage.
- To foster Optimization: Introduce artificial constraints. "Your bridge holds the weight, excellent. Now, can you build it again using 30% less material?" or "Can you make it work at half the size?" Constraints create the necessity for

optimization. Optimization provides opportunities for design iteration and requires technological strategies to achieve the ultimate result.

- To foster Systemization: Ask decomposition questions. "If you were to explain your project simply, could you describe it in three main distinct modules?" Encourage them to see the architecture within their creation. Many automation-related topics provide rich content regarding systems and sub-systems. Technological strategies are inevitably involved.
- To foster Internalization: Encourage sensory engagement. "Tap the structure. Where does it sound hollow? Where do you feel the tension?" Help them calibrate their physical senses to the materials they use. Indeed, internalization is more difficult to achieve, as it is rooted in the former mindset components. Once the practices of materialization, visualization, optimization, and systemization are sufficiently developed, the ability of internalization will gradually grow.
- To foster Documentation: Grade the process, not just the product. Require an "Engineering Notebook" that includes sketches, failed attempts, and reflections. Ask: "Why did you decide to abandon Plan A? Document your decision-making process." Documentation serves here not only as a record of the habit of mind, but an opportunity to reflect and refine all the mindset established.

5 CONCLUSION

The transition from "STEM activities" to "Engineering Education" requires a fundamental shift in mindset. We must stop treating engineering as the final step of assembly and start teaching it as a rigorous way of thinking.

The IDTEM framework provides a conceptual roadmap for this transition. By integrating Materialization, Visualization, Optimization, Systemization, Internalization, and Documentation, this framework has the potential to equip students with more than just technical skills; it offers the cognitive agility required to thrive in an increasingly complex world, of which the AI-driven future is just one contemporary example. We need Design to dream, Technology to enable, and Engineering to realize. It is our hope that this framework empowers educators, informs future curriculum design, and cultivates the next generation of true innovators.

6 STATEMENT REGARDING THE USAGE OF AI

During the preparation of this work, the authors used Generative AI technologies primarily for translation and language editing purposes to improve the readability of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Generative Artificial Intelligence in STEM Learning Assessment: A Technology Education Perspective

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Abstract

In STEM education research, a primary concern among many researchers is the issue of assessment, particularly in evaluating interdisciplinary STEM competencies. For example, when assessing interdisciplinary problem-solving skills, there is a notable lack of appropriate assessment tools. STEM learning environments often involve complex problem designs, requiring students to deconstruct the context collaboratively during the problem-solving process. How to effectively apply knowledge from various STEM fields remains a challenge that existing assessment tools have not yet fully addressed. With the development of generative artificial intelligence, there are now more tools available to analyze students' discussions throughout their learning journey. The aim is to explore what do AI-based analyses of students' group discussion discourse reveal about their interdisciplinary problem-solving processes in STEM projects. Besides, based on these findings, what are the potential limitations of using AI to assess students' interdisciplinary problem-solving processes. By applying generative AI tools to analyze group discussion dialogues, the research aims to uncover critical areas for future focus in STEM education.

Key Words: Assessment, Generative Artificial Intelligence, Interdisciplinary Problem-Solving Skill, STEM.

1 INTRODUCTION

As Artificial Intelligence (AI) has become increasingly prevalent, a growing body of research has focused on examining the feasibility of AI applications in K–12 educational contexts. Among these efforts, one of the most frequently discussed approaches involves leveraging AI to refine instructional assessment practices, thereby enabling teachers to more accurately monitor students' learning performance and subsequently improve instructional decision-making. In the context of STEM education, teachers may adopt various integration approaches—such as multidisciplinary, interdisciplinary, and transdisciplinary models (Drake & Burns, 2004; English, 2016; Sanders, 2009). However, regardless of the approach employed, how to assess students' performance in interdisciplinary learning remains a critical yet underexplored gap (Gao et al., 2020).

In particular, many STEM education researchers adopt project-based approaches to enact interdisciplinary STEM integration. However, assessments of student performance often concentrate primarily on final products, making it difficult to capture students' actual interdisciplinary competencies as they emerge throughout the learning process. This situation closely parallels instructional practices in technology education, where teachers frequently emphasize the evaluation of completed artefacts, while paying comparatively less attention to systematically assessing students' enactment of technological knowledge and skills during the design and making processes. As a result, opportunities to reflect on and refine instructional design in technology education based on students' process-level performance remain limited.

Through a systematic literature review examining STEM projects implemented at the middle and high school levels, McLure et al. (2022) found that, between 2000 and 2021, STEM projects predominantly focused on evaluating their effects on students' *disciplinary knowledge, skills, and learning motivation and attitudes*. In contrast, there was a notable lack of research investigating how teachers and students actually enact integration in classroom settings. Similarly, Gao et al. (2020), in their analysis of assessment approaches in interdisciplinary STEM education, pointed out that current assessments tend to emphasize single-discipline knowledge and affective outcomes, while effective evaluation of students' ability to connect and integrate knowledge across disciplines remains insufficient.

In light of these gaps, a central aim of this study is to explore how AI can be appropriately employed to authentically assess preservice teachers' performance during STEM project-based learning processes, and to provide empirically grounded evidence to inform future STEM curriculum and instructional design. Accordingly, the research questions guiding this study are as follows: (1) What do AI-based analyses of preservice teachers' group discussion discourse reveal about their interdisciplinary problem-solving processes in STEM projects? (2) Based on these findings, what are the potential limitations of using AI to assess preservice teachers' interdisciplinary problem-solving processes?

2 LITERATURE REVIEW

To address the research questions of this study in depth, the following sections focus on a comprehensive review of AI in STEM education and interdisciplinary problem-solving skills in STEM education, which together serve as the theoretical foundation of this research.

2.1 *AI in STEM education*

Many scholars have advanced important arguments concerning artificial intelligence (AI) and STEM education, with a shared emphasis on the integration of AI and STEM learning. For example, Lee and Perret (2022) argued that artificial intelligence (AI) and data science (DS) constitute two critical technologies that make substantial contributions to exploration and innovation across STEM fields. In addition, systematic literature reviews have provided clearer insights into this emerging trend. For instance, Takeuchi et al. (2020), through a critical analysis of 154 research articles published between 2007 and 2018, examined the interdisciplinary characteristics of STEM education and argued that STEM education research should move beyond its traditional focus on attracting a greater number of interdisciplinary STEM talents. Instead, they emphasized the necessity of fostering greater diversity in STEM education research agendas.

Similarly, Xu and Ouyang (2022), based on their review of scholarly publications from 2011 to 2021 on AI applications in STEM education, highlighted the substantial potential of AI technologies to enhance STEM education and called for sustained and in-depth investigations by future STEM education researchers.

At present, six major applications of AI in STEM education have been identified (Xu & Ouyang, 2022): (1) learning prediction, including prediction of learning performance and student risk; (2) intelligent tutoring systems, such as instructional content delivery, personalized learning pathway recommendations, and resource suggestions; (3) student behavior detection, including behavior analysis and monitoring; (4) automation, encompassing automated assessment and automated question generation; (5) educational robotics, including programming robots and social robots; and (6) other applications, such as AI-enhanced textbooks and group formation. Building on these developments, Maiorca et al. (2025) integrated AI into technology and engineering education as well as STEM education, with a particular focus on supporting purposeful questioning through AI.

Among the aforementioned application domains of AI in STEM education, the present study primarily focuses on automation, specifically automated assessment and automated question generation. For example, Maiorca et al. (2025) employed Webb's (2002) Depth of Knowledge (DOK) framework to analyze the cognitive depth of AI-generated questions. Their findings indicated that, within STEM education contexts, AI-generated questions tended to exhibit higher quality and align with higher DOK levels. One possible explanation for this result is that STEM education contexts provide more concrete and action-oriented language, which more effectively guides AI systems to generate educationally meaningful questions.

In addition to the aforementioned advantages of applying AI in STEM assessment, several potential limitations warrant attention. For example, STEM teachers may lack sufficient understanding of artificial intelligence and may be unable to effectively integrate it into the design of interdisciplinary teaching (Nazaretsky et al., 2022; Ng et al., 2023). Moreover, many STEM teachers may hold the misconception that human-AI collaboration necessarily leads to synergistic benefits. However, research by Vaccaro et al. (2024) indicates that the effects of human-AI collaboration may vary depending on the type of task—for instance, decision tasks versus creation tasks. Therefore, when applying AI to STEM learning assessment, it is important to consider different types of STEM project tasks and adopt corresponding AI-based assessment strategies accordingly.

The primary concern of the present study lies in automated assessment, with a particular emphasis on the assessment of interdisciplinary problem-solving skills. Research on the assessment of interdisciplinary problem-solving skills remains relatively limited. For instance, Lin et al. (2023a) developed an online assessment system incorporating scenario-based tasks to evaluate students' interdisciplinary problem-solving performance. However, this approach requires substantial time and resources to develop test items and system infrastructures, and it remains insufficient for capturing students' performance throughout the complex problem-solving process. Consequently, exploring how AI can be effectively integrated to achieve automated assessment of interdisciplinary problem-solving processes represents a promising and worthwhile direction for future research.

2.2 *Interdisciplinary problem-solving skill in STEM education*

In their recommendations for STEM learning assessment, Gao et al. (2020) emphasized that STEM learning processes and practices are highly diverse and complex, particularly given the distinct characteristics that different disciplines may exhibit throughout these processes and practices. Addressing this challenge, several scholars have identified key competencies that are essential for strengthening problem-solving training in STEM education. Among them, Lin et al. (2022b) analyzed problem-solving processes from the perspectives of science, technology, engineering, and mathematics, and proposed five core transformative competencies that characterize interdisciplinary problem-solving in STEM education.

The first competency is contextual decomposition, which refers to learners' ability to deconstruct real-world problem situations in order to identify critical elements for problem solving. Effective contextual decomposition enables learners to more appropriately define and analyze problems, thereby forming a solid foundation for subsequent problem-solving processes (Kirschner et al., 2010). The second competency, predictive analysis, involves the ability to generate multiple solution alternatives during problem solving and to systematically evaluate these alternatives using evidence or data, in order to anticipate potential constraints and expected outcomes (Jonassen, 2011).

The third competency is analogical reasoning. When confronted with everyday problems, learners often rely on prior knowledge and experience to construct potential solutions. By identifying analogous concepts or models from previous experiences, learners can use them as references for interpreting data or deriving conclusions. Accordingly, the ability to engage in analogical reasoning enables learners to meaningfully connect prior knowledge and experience to the problem situations they encounter (Jonassen, 2011). The fourth competency, quantitative thinking, is particularly critical in STEM problem-solving contexts. Learners frequently struggle to propose feasible solutions due to insufficient quantitative reasoning skills. Consequently, the ability to process and interpret data, apply mathematical models, and engage in computational and quantitative reasoning constitutes a key transformative competency in interdisciplinary STEM problem solving.

The fifth competency is reflective thinking. Because real-world problem-solving contexts rarely involve a single correct answer, learners are required to iteratively seek optimal solutions. In other words, once a proposed solution has been tested, learners must engage in reflective thinking to evaluate and refine their approaches, thereby enhancing their problem-solving capability and progressively moving toward optimized solutions.

The transformative competencies for interdisciplinary STEM problem solving identified by Lin et al. (2022b) provide a cross-disciplinary framework for evaluating learners' performance in terms of contextual decomposition, predictive analysis, analogical reasoning, quantitative thinking, and reflective thinking throughout the problem-solving process. Accordingly, the present study adopts this framework as a set of key indicators for assessing students' interdisciplinary problem-solving skills and further leverages AI to conduct automated assessment, with the aim of capturing learners' performance in interdisciplinary STEM problem-solving processes.

3 METHOD

3.1 *Research design*

To investigate the research questions of the present study, two primary research methods were employed: expert interviews and an exploratory research approach. First, with regard to the identification of indicators for interdisciplinary problem-solving skills, expert interviews were conducted to rigorously develop appropriate indicators that could serve as a critical reference framework for AI-based assessment of interdisciplinary problem-solving performance. In addition, to examine the feasibility of applying AI to assess learners' performance in interdisciplinary problem-solving skills, an exploratory research approach was adopted. Through an in-depth analysis of a specific instructional context, this approach aimed to explore the practical feasibility and potential of employing AI for the assessment of interdisciplinary problem-solving processes.

3.2 *Research subjects*

This study adopts an exploratory research approach to investigate the application of AI in STEM learning assessment. Accordingly, purposive sampling was employed to recruit participants. Regarding the research participants, this study involved two distinct groups. (1) Expert interviews: A group interview was conducted with four experts, including two specialists in science education, one specialist in mathematics education, and one specialist in technology and engineering education. Through group-based discussions on interdisciplinary problem-solving skills, these experts collaboratively contributed to the development and refinement of indicators for interdisciplinary problem-solving competence. (2) Case study: The case study focused on a project-based group of preservice teachers in the field of technology education.

With regard to STEM experts, four experts were selected based on the following criteria: (1) more than ten years of experience in science education, technology and engineering education, or mathematics education; (2) expertise in assessing problem-solving abilities within their respective disciplines; and (3) affiliation with leading teacher education universities. Among these four experts, the two science education experts are both over 50 years old, have more than twenty years of experience in science education research, are female, are affiliated with top teacher education universities, and have each received the National Science and Technology Council (NSTC) Outstanding Research Award three times. The mathematics education expert is also over 50 years old, has more than twenty years of experience in mathematics education research, is female, is affiliated with a leading teacher education university, and has received the NSTC Outstanding Research Award once. The expert in technology and engineering education is between 45 and 50 years old, has more than fifteen years of experience in technology and engineering education research, is male, is affiliated with a leading teacher education university, and has received the NSTC Young Scholar Research Award.

This group served as the focal case for examining their practical engagement with AI-supported assessment of interdisciplinary problem-solving skills. Through an in-depth analysis of their assessment processes and outcomes, reflections were generated and limitations were identified, which subsequently informed recommendations for future research and practice.

3.3 *Data collection and analysis*

In this study, data collection was primarily conducted through focus groups. Multiple in-depth discussions were carried out—either face-to-face or online—focusing on interdisciplinary STEM problem-solving ability. The related indicators were carefully reviewed and revised line by line to ensure the appropriateness of the proposed indicators. For the pre-service teachers, data were collected mainly through face-to-face semi-structured interviews and project-based learning portfolios. In the first phase, pre-service teachers in the field of technology independently defined interdisciplinary problem-solving ability. In the second phase, however, the indicators of interdisciplinary STEM problem-solving ability developed by STEM experts were incorporated to guide pre-service teachers in applying AI for STEM learning assessment.

For data collection, this study primarily employed AI-based audio recording and analysis tools. After obtaining informed consent from the participants, interviews and group discussions were recorded using AI-enabled recording tools. Upon completion of each interview or discussion session, AI tools were used to generate verbatim transcripts, which were subsequently returned to the participants for verification. Only after participants had confirmed the accuracy of the transcripts were the data subjected to further analysis.

With regard to data analysis, this study followed the qualitative analysis procedures proposed by Patton (1990). First, all raw data collected from the semi-structured interviews were compiled and subjected to open coding. Second, the coded data were systematically organized, categorized, and refined to generate clearly identifiable and revisable themes and suggestions. Third, in alignment with the research purposes, cross-analysis was conducted to derive concrete revisions and insights, which served as the basis for refining the analytical framework and informing subsequent improvements in the study.

To ensure the trustworthiness and validity of the qualitative data analysis, members of the research team engaged in cross-checking and peer debriefing throughout the analytical process. This collaborative review process was intended to enhance content validity and to ensure that interpretations were grounded in the data. In addition, the research team maintained a neutral and reflexive stance during data interpretation in order to minimize bias and to faithfully represent the perspectives and processes captured in the collected data.

3.4 *Trustworthiness*

Regarding the trustworthiness of this study, the researcher primarily employed triangulation by drawing on multiple data sources—including semi-structured interviews with pre-service teachers, project-based learning portfolios, and project outcomes—to illustrate the process and results of their improvement in applying AI for STEM learning assessment.

However, in terms of research limitations, this study only asked participants to verify the interview transcripts and did not, in accordance with Merriam (2009), invite them to validate the research findings. This is an aspect that can be further improved when the study is formally submitted to an academic journal.

4 RESULTS

4.1 *Indicators of interdisciplinary problem-solving skill*

Based on the expert interviews, five key indicators of interdisciplinary problem-solving skills were identified and operationalized as follows.

4.1.1 *Contextual Analysis*

Contextual analysis refers to learners' ability to analyze real-world problem situations in order to identify potential influencing factors or conditions and to incorporate critical elements into the problem-solving process. Effective analysis and decomposition of a problem context are essential for appropriately defining and analyzing problems. (1) **High level:** Students are able to identify relevant influencing factors or conditions, systematically analyze and deconstruct the problem context, and incorporate key elements into the problem-solving process. (2) **Moderate level:** Students are able to identify potential influencing factors or conditions; however, they fail to adequately analyze and deconstruct the context when incorporating these factors into the problem-solving process, resulting in ineffective solutions. (3) **Low level:** Students are only able to identify a limited number of less relevant factors or conditions and fail to incorporate these factors into the problem-solving process.

4.1.2 *Predicting (Anticipation)*

Predicting, or anticipation, involves the ability to propose multiple solution alternatives and to apply evidence or data to evaluate these alternatives in order to anticipate potential challenges and expected outcomes. (1) **High level:** Students are able to propose multiple solution alternatives and appropriately apply evidence or data to evaluate and compare these alternatives. (2) **Moderate level:** Students are able to propose multiple solution alternatives; however, the evidence or data used to evaluate these alternatives may be inappropriate or insufficient. (3) **Low level:** Students are only able to propose a single solution alternative that fails to address the problem and are unable to apply evidence or data to evaluate the proposed solution.

4.1.3 *Analogical Reasoning*

Analogical reasoning refers to learners' ability to draw upon prior knowledge (e.g., models or principles) and past experiences to identify similarities across problem situations and to use these similarities as references for interpreting data or deriving conclusions. (1) **High level:** Students are able to identify similarities between prior knowledge (models or principles) and the problem situation and appropriately apply these similarities during the problem-solving process. (2) **Moderate level:** Students are able to identify similarities between prior knowledge and the problem situation; however, they encounter difficulties or apply these similarities inaccurately during problem solving. (3) **Low level:** Students are only able to identify non-analogous situations or counterexamples and are unable to apply these distinctions meaningfully to the problem-solving process.

4.1.4 *Quantitative Thinking*

Quantitative thinking involves learners' ability to analyze and process data and to apply mathematical models and computational thinking to support quantitative reasoning and argumentation. Insufficient quantitative thinking often prevents learners from weighing solution alternatives appropriately and from proposing feasible solutions or products. (1) **High level:** Students are able to analyze and process data effectively and apply mathematical models and computational thinking to conduct quantitative reasoning and argumentation. (2) **Moderate level:** Students are able to analyze and process data; however, errors or limitations emerge when applying mathematical models or computational thinking for quantitative reasoning. (3) **Low level:** Students rely only on partial data or simple calculations to make judgments.

4.1.5 *Reflective Ability*

Reflective ability refers to learners' capacity to critically evaluate the outcomes of implemented solutions and to propose improvements based on reflective analysis. Given that real-world problems rarely have a single correct answer, reflective thinking is essential for identifying optimized solutions. (1) **High level:** Students are able to engage in systematic reflection and propose concrete improvement strategies based on their evaluations. (2) **Moderate level:** Students are able to reflect on the outcomes of their solutions; however, proposed improvements are not consistently aligned with the results of their reflections. (3) **Low level:** Students are able to reflect on solution outcomes by referencing prior knowledge, but fail to propose improvement strategies.

4.2 *Applying AI in evaluating interdisciplinary problem-solving skill*

The preservice teacher project group in the field of technology education used a robot vacuum cleaner activity as an illustrative case to discuss middle school students' performance in interdisciplinary problem-solving skills. Based on this activity, the pre-service teachers engaged in discussions following the steps of problem solving in order to propose appropriate solutions. During this process, the researcher recorded the discussions using AI-based audio tools, uploaded the recordings to a cloud-based transcription platform to generate verbatim transcripts, and subsequently employed ChatGPT to analyze the discussion data.

To assess discussion performance in this STEM project activity, the pre-service teachers established the following evaluation criteria: (1) The ability to identify and clarify the key issues and core aspects of the problem. (2) The ability to consider the feasibility of potential solutions. (3) The ability to formulate appropriate design criteria and directions based on the analysis. During the discussion, the pre-service teachers applied these criteria to evaluate the group's interdisciplinary problem-solving performance and to provide corresponding feedback. In addition, ChatGPT generated individualized suggestions regarding each preservice teacher's discussion performance. However, following each round of evaluation, the preservice teacher group continuously revised and refined both the analysis criteria and the prompts in order to improve the precision and relevance of the assessment results.

Despite its usefulness, this assessment approach was limited to the robot vacuum cleaner activity and could not be readily generalized to other STEM learning contexts. At this stage, the researcher introduced the *Indicators of Interdisciplinary Problem-Solving Skill* developed in Section 4.1 and

invited the participants to apply these expert-derived indicators to conduct a more comprehensive assessment of interdisciplinary problem-solving abilities. After further discussion with the group, the researchers suggested developing a ChatGPT-based project that incorporated relevant literature on interdisciplinary problem-solving skills as reference materials. Within this project, the following prompt was employed:

“Please act as an assessment expert in STEM education. Drawing primarily on the materials provided in the attached files, design a learning scenario connected to the Sustainable Development Goals (SDGs). Based on this scenario, generate several questions for users to answer (these questions should align with the five indicators listed below) in order to assess middle and high school students’ interdisciplinary problem-solving skills. After all questions have been answered, please analyze students’ responses according to these five indicators and provide feedback and suggestions regarding their interdisciplinary problem-solving performance.”

Using this approach, ChatGPT was able to draw upon the reference materials to autonomously generate SDG-related learning scenarios and corresponding questions, thereby enabling flexible and randomized assessment of students’ interdisciplinary problem-solving skills. In addition to generating assessment questions, ChatGPT also provided guiding prompts highlighting key aspects of each question to support students’ thinking and responses, as illustrated in the subsequent examples.

Question 1: In the context of the above scenario concerning water scarcity on campus or within the community, please identify at least four key factors or conditions that may influence water-related issues. In your response, explain: (1) whether and how these factors are interrelated; and (2) which factor(s) you consider to be the most critical and why. Assessment focus: The extent to which the learner is able to comprehensively deconstruct the problem context, rather than focusing on a single or surface-level factor.

Through this approach, the pre-service teachers found that ChatGPT was able to generate appropriate STEM project scenarios aligned with the specified indicators and use targeted questioning to assess interdisciplinary problem-solving performance. Moreover, for indicators where a high level of proficiency was not achieved, ChatGPT could provide relevant and actionable suggestions to support learners’ improvement.

5 DISCUSSION

Based on the findings of this study, employing AI to assess interdisciplinary problem-solving skills appears to be feasible. Such an approach can assist teachers in timely monitoring students’ discussion performance during the design process and in identifying potential problems and gaps in students’ interdisciplinary problem-solving competencies. Nevertheless, several limitations remain and warrant further refinement in future research.

First, regarding discourse analysis during the design process, the study initially sought to evaluate an individual student’s interdisciplinary problem-solving performance by analyzing that student’s contributions in small-group discussions. However, because discussions were conducted collaboratively, students did not necessarily articulate their reasoning in a complete manner. In particular, when peers had already expressed similar viewpoints, students often refrained from

repeating the same arguments. This interactional feature of group work may constrain the completeness of evidence available for individual-level assessment, thereby creating potential omissions or inaccuracies in identifying students' specific strengths and weaknesses. This limitation suggests the need for improved strategies for capturing and eliciting individual reasoning within collaborative dialogue.

Second, concerning the development of a ChatGPT-based project for interdisciplinary problem-solving assessment, the generation of learning scenarios may be constrained by the materials uploaded into the project and thus may not fully support randomized scenario generation across diverse SDG targets. Moreover, because the assessment design involved generating multiple questions across five dimensions, students may not consistently provide comprehensive and carefully reasoned responses to every question. This limitation may reduce the interpretability and diagnostic value of the resulting assessment, indicating the need for more manageable task designs and improved prompting strategies to support sustained student engagement and response quality.

In summary, this study demonstrates that applying AI to assess interdisciplinary problem-solving skills is broadly feasible and holds promise for supporting STEM teaching and learning. However, further careful consideration of methodological and design details is required to enhance assessment precision and to enable more robust and scalable implementation in STEM educational contexts.

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Student-Generated Visualisations and the Development of Technological Literacy in Technology Education

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Abstract

In technology education, knowledge is often communicated through visualisations such as artefacts, models, sketches, and images (Citrohn et al., 2023; de Vries, 2016; Svensson et al., 2019). However, less is known about how student-generated visualisations support students' development of technological literacy through classroom interactions.

By engaging with student-generated visualisations alongside verbal interactions, students are provided with opportunities to develop technological literacy while gradually advancing their representational competence. This paper theoretically explores this relationship by examining how representational competence functions in students' meaning-making with visualisations. Representational competence, understood as the ability to use and interpret representations to make sense of and communicate understanding (Kozma & Russell, 2005; Daniel, 2018), becomes visible through work with visualisations in classroom interactions, which provide opportunities to elaborate, negotiate, and discuss ideas about technological issues (Lind, 2025).

Drawing on Kozma and Russell's (2005) conception of representational competence, this paper proposes an analytical framework for examining how student-generated visualisations are used to express and develop technological understanding. The contribution is thus an analytical framework rather than a finished didactic model, offering teachers and researchers a conceptual tool for analysing how student-generated visualisations can support representational competence and students' development of visual and technological literacy.

Key Words: Representational competence, Student-generated visualisations, Technological literacy, Verbal interactions, Visual literacy

1 INTRODUCTION

An important goal for technology education is for students to develop technological literacy, including an understanding of technology's manifestations (Mitcham, 1994). Visualisations are commonly used to support students' understanding of technological concepts (cf. Citrohn et al., 2023; de Vries, 2016; Svensson et al., 2019), for example, to communicate understanding of technological systems. However, visualisations can also be used as tools for reasoning, explaining, negotiating, and reflecting in interaction (cf. Kim & Jin, 2022), providing common grounds, building on prior understanding of technology for discussions (Lind, 2025). Despite this potential, less is known about *how* students use their own, self-generated visualisations to engage in disciplinary reasoning. In particular, limited attention has been given to how such visualisations support students in moving from a simple depiction of artefacts toward discussing underlying, non-visible aspects of technology.

Student-generated visualisations can serve as meaningful contexts in which students develop knowledge, explain and reason about technological issues, and communicate their ideas and thoughts about technology (e.g., Lind et al., 2024). Visualisations can function as tools for students to develop, refine, and discuss everyday and disciplinary understanding of technology. To achieve this, teachers need to recognise the meaning-making potential of visualisations in order to use them effectively (e.g., Linder, 2013), thereby supporting students' development of both technological and visual literacy.

Serafini (2015) argues that students need to develop knowledge of the features of visualisations and the meaning-making possibilities involved in the process of generating them. The focus should be on what student-generated visualisations do, how they function as meaning-making tools, rather than merely on what they represent. Visualisations function as meaning-making resources (cf. Lind, 2025). For example, Lind et al. (2024) demonstrate that visualisations, such as self-taken photographs, support students' development of technological literacy during small-group interactions. In such classroom settings, visualisations are embedded within social, verbal, and artefactual interactions (cf. Kress, 2010).

In this paper, visualisations are understood as external visual representations that students use to express, communicate, and reason about technology. Student-generated visualisations are those produced by students themselves, rather than provided by teachers. In the empirical study by Lind et al. (2024), which serves as an illustrative example in this paper, these visualisations take the form of photographs capturing students' perceptions of technology during classroom activities. While the empirical example emphasises photographs as visualisations, the notion of student-generated visualisations is not limited to this medium. Rather, it refers more broadly to visual representations produced by students themselves, such as sketches, models, or other visual artefacts, each providing different representational affordances. Such visualisations become sites where different manifestations of technology (Mitcham, 1994) are made visible, negotiated, and discussed in interaction. In this context, visual artefacts mediate reasoning and reveal developing understanding of technology (Lind et al., 2024). These understandings move between the concrete and the abstract, engaging conceptual, mode-related, and reasoning aspects of representational competence (Schönborn & Anderson, 2009).

To better understand *how* student-generated visualisations support students' development of technological literacy, this study examines the relationship between visual and technological literacy by using representational competence as an analytical tool.

1.1 *Aim and research questions*

The primary aim of this research paper is to theoretically explore how student-generated visualisations support students' development of visual and technological literacy. The study contributes to the field of technology education by employing representational competence as the analytical tool.

In this study, the relationship between students' visual literacy and their developing technological literacy is central (cf. Nickel et al., 2025). Drawing on Kozma and Russell's (2005) conceptualisation of representational competence and Mitcham's (1994) manifestations of technology, the paper examines how students' engagement with student-generated visualisations can be understood by viewing representational competence and technological understanding as interdependent.

The following research questions guide this paper:

How can student-generated visualisations be understood as supporting students' development of visual and technological literacy?

In what ways does representational competence shape students' opportunities to understand the manifestations of technology?

2 THEORETICAL STARTING POINTS

2.1 *Visual literacy*

Visual literacy refers to the ability to read visuals and to recognise, analyse, discuss and evaluate both explicit depictions and implied meanings (cf. Bamford, 2003; Dey & Munshi, 2025; International Visual Literacy Association, n.d.). Within an educational context, visual literacy has been described as a vital competence, both in constructing visualisations and in reading visualisations in a meaningful way (e.g., Bamford, 2003). In this paper, visualisations are considered specific forms of representations used to communicate and reason about technology.

2.1.1 *Student-generated visualisations*

Student-generated visualisations refer to external representations of students' internal understanding of technology (Kozma & Russell, 2005). Their persistent character (Kress, 2010) allows students to return to them in classroom interactions when needed, for example, using them as a focus for discussion and meaning-making (Lind, 2025). From this perspective, each student-

generated visualisation involves disciplinary affordances (Fredlund et al., 2012), that is, an inherent potential for supporting communication and access to technological knowledge.

2.2 *Representational competence*

The ability to interpret and reason about visual representations, as described by Schönborn and Anderson (2006, 2009), aligns closely with the concept of representational competence (Kozma & Russell, 2005). Representational competence refers to the ability to use different perceptions of reality to make sense of and communicate their understanding (Daniel et al., 2018; Kozma & Russell, 2005), for example, of technology, through student-generated visualisations. It encompasses how a student reflectively uses various visualisations to think about an underlying meaning. Such activities constitute meaning-making processes where students use self-generated visualisations to develop their understanding of subject-specific concepts, such as technological systems (cf. Kozma & Russell, 2005; Lind, 2025). In this way, students move from surface-level understanding toward deeper, technological knowledge, as the visualisations encourage collaborative explanations.

Kozma and Russell (2005) propose a five-level structure for recognising representational competence, ranging from a surface-level understanding to a reflective use of representations. In short, the five-level structure can be explained as describing how students generate and use representations of a phenomenon, where students at the first level generate representations based on its physical features: *Representation as Depiction*. At the second level, students add symbolic elements to strengthen the representation of the phenomena: *Early Symbolic Skills*. At the third level, students use representations that include both observed and unobserved underlying entities: *Syntactic Use of Formal Representations*. At the fourth level, students transform one representation into another and use representations to explain and solve problems: *Semantic Use of Formal Representations*. At the fifth level, students use representations to describe the relationship between physical features and underlying entities. Furthermore, they can select and create appropriate representations for specific situations and explain why one representation is more relevant than another, demonstrating *Reflective, Rhetorical Use of Representations*.

This development reflects students' growing representational competence rather than a fixed, stage-like progression, in which physical, symbolic, and social situations are central to meaning-making and students can move flexibly between levels depending on the task and their understanding of the phenomenon. While these levels were developed in the context of chemistry education and rely on representational conventions not directly applicable to technology education, the formulations presented here are reinterpreted in relation to the technological literacy perspective of this study.

The five levels of representational competence can, therefore, be described as:

- (i) **Depiction:** the student recognises and describes what is represented in the representation.
- (ii) **Elaboration:** the student identifies and explains something that is not directly visible in the representation, such as underlying concepts.

- (iii) **Connection:** the student links the depiction to ideas or phenomena outside the representation.
- (iv) **Integration:** the student uses concepts accurately, moves between different representations, and explains underlying processes.
- (v) **Reflection:** the student selects an appropriate representation, justifies the choice, and uses the representation to motivate, argue, or convince others.

At the higher levels of representational competence, students begin to engage with what is not directly visible in a representation, attending to the abstract or implied dimensions of technology. This shift aligns with the notion of *appresentation* (Linder, 2013; Marton & Booth, 1997). Appresentation refers to the ability to perceive not only what a representation explicitly shows but also what lies behind it, that is, the disciplinary affordances to which the representation provides access (Linder, 2013), which relates to the *Integration* level.

Representational competence is closely intertwined with students' technological literacy, as visualisations serve both as representations and as tools for disciplinary reasoning. The framework of representational competence provides a tool for analysing how students construct and communicate their understanding of technology through different representations (Daniel et al., 2018; Kozma & Russell, 2005).

While representational competence helps clarify how students use visualisations to explain technology, a complementary perspective is needed to examine which aspects of technology students relate to in their discussions. Technological literacy provides this disciplinary lens by focusing on students' capabilities, knowledge, and competencies in action when engaging with these representations.

2.3 *Technological literacy*

In technology education, applying knowledge in social situations is central for developing competencies in action (Ingberman & Collier-Reed, 2011) and technological literacy (Collier-Reed, 2008; Larsson et al., 2024). Technological literacy encompasses capabilities, knowledge, and ways of thinking and acting (ITEEA, 2007, 2020; Pearson & Young, 2002), including the ability to communicate technological concepts (Grysko & Zygouris-Coe, 2019). In this regard, student-generated visualisations can function as mediational tools supporting students' reasoning about technology (cf. Lind et al., 2024).

To further examine students' development of technological literacy, technology can be viewed through Mitcham's (1994) proposal of four manifestations, which offers a framework for analysing students' meaning-making when interacting with visualisations (cf. Lind et al., 2024).

2.4 *Mitcham's manifestations of technology*

Technology can be manifested as *objects*, referring to human-made artefacts such as tools and machines; as *knowledge*, encompassing the skills and understanding required to design, make and use artefacts; as *activity*, including designing, constructing, and using technologies; and as

volition, involving the intentions, values, and motives that guide development and use (Mitcham, 1994).

In the next section, the analysis examines how student-generated visualisations and verbal interactions support the development of technological literacy and representational competence.

3 ANALYSIS AND DISCUSSION

To illustrate *how* student-generated visualisations may function as mediational tools in classroom interactions, the study by Lind et al. (2024) is used as an example. The purpose is not to present new empirical findings, but to show how the analytical framework proposed here can be applied to interpret students' engagement with visualisations. In Lind et al. (2024), students discuss their perception of technology through verbal interactions around self-taken photographs. This example illustrates how the reasoning presented in this paper can be understood in relation to students' engagement with visualisations. When students discuss their perceptions of technology, the photographs function as mediational tools that frame what technology might be and highlight technological aspects (Lind et al., 2024). Through these teacher-guided interactions, students gradually deepen their understanding of technology, including its different manifestations (Mitcham, 1994).

The proposed analytical framework draws on five aspects of representational competence introduced earlier: *depiction*, *expression*, *connection*, *integration*, and *reflection* (cf. Kozma & Russell, 2005), which together serve as an analytical tool for examining how student-generated visualisations are analysed in relation to Mitcham's (1994) manifestations of technology. Combining these frameworks enables the analysis to capture how verbal and visual meaning-making intertwine in students' development of technological literacy. As shown in Lind et al. (2024), self-taken photographs supported students' discussions and meaning-making about technology's manifestations. Interpreting these results through the five-level framework of representational competence clarifies how students gradually move from surface-level depiction to reflective integration, revealing how their meaning-making can be understood through Mitcham's manifestations of technology.

Integrating Kozma and Russell's (2005) structure of representational competence with Mitcham's (1994) framework of the manifestations of technology establishes a conceptual bridge between how students represent and what they understand. The framework enables analysis of how these are intertwined in students' development of technological literacy. This integration reveals how students' visual and verbal meaning-making not only depict technological objects but also contribute to their technological literacy. Thus, it emphasises how representational competence supports the development of technological literacy through interaction.

At the first level of representational competence, **depiction** (cf. Kozma & Russell, 2005), student-generated visualisations typically illustrate an understanding of technology as **objects** (Mitcham, 1994), as students generally tend to photograph artefacts they perceive as technology (cf. Lind et al., 2024). This was illustrated through representations of technology as objects that function with electricity. At this level, visualisations generally focus on recognising visible technological

artefacts. The representational work involves describing what is shown in the photograph rather than engaging with underlying technological systems or activities. For example, a visualisation of a bike may highlight identifiable components such as the chain and the wheel without describing how they work together. In this sense, depiction emphasises observable artefacts rather than technological processes or purposes.

At the level of **expression** (cf. Kozma & Russell, 2005), student-generated visualisations illustrate an understanding of technology as **activity** (Mitcham, 1994), as students begin to identify aspects that are not directly visible in the photograph. This was illustrated through representations of technological systems in a picture of a bike, in which the function of human input became part of the explanation. At this level, the representational work involves discerning underlying concepts within the visualisation and relating them to what is shown, rather than making explicit connections beyond the depicted visualisation (Lind et al., 2024).

At the level of **connection** (cf. Kozma & Russell, 2005), student-generated visualisations illustrate an understanding of technology as **knowledge** (Mitcham, 1994), as the verbal and visual representations begin to link the visualisation to technological ideas beyond what the visualisation itself depicts. This was illustrated when the bike was connected to surrounding technological systems, such as traffic lights and bike lanes, and technological concepts, such as components and technological systems, were used to explain its function (Lind et al., 2024). An emerging understanding of technology as **volition** (Mitcham, 1994) becomes evident as students recognise purpose and human intention behind the technological systems they describe. The representational work becomes a tool for reasoning, framing details and making sense of technological functions beyond the immediate visualisation.

At the level of **integration** (cf. Kozma & Russell, 2005), student-generated visualisations demonstrate how different manifestations of technology as **objects, activity, knowledge, and volition** (Mitcham, 1994) begin to interrelate as students switch between representations and transform understanding. This was demonstrated when multiple representations, such as a real bike and a visualisation of it, were used together to explain abstract concepts (Lind et al., 2024). The representational work enables the explanation of underlying processes, such as energy transfer and the interaction between mechanical parts. Visual and verbal reasoning become intertwined, revealing an emerging awareness of how technological artefacts, human actions, intentions, and conceptual knowledge are connected.

At the level of **reflection** (cf. Kozma & Russell, 2005), student-generated visualisations illustrate a reflective and purposeful use of representations, drawing on different manifestations of technology (Mitcham, 1994) to explain, justify, and argue for specific interpretations. In Lind et al. (2024), this was shown when visualisations were deliberately selected, such as those depicting the chain, pedals, and cogs of a bike, to motivate and justify explanations of how and why these components are needed to make the bike move. The representational work foregrounds an understanding of technology as **volition** (Mitcham, 1994), as students' selections and justifications reveal an awareness of human desire, purpose, and intention to use technology to solve problems or fulfil needs.

It should be noted that students may engage simultaneously with multiple manifestations of technology and move between different aspects of representational competence depending on the context and purpose of the activity.

4 CONCLUSION

This paper has examined the interrelation between student-generated visualisations and students' development of technological literacy. As students reach higher levels of representational competence, they move from initial depictions of technology (e.g., photographs of electrical devices) to using visualisations as tools for reflection and for negotiating aspects that are not immediately visible in the visualisation, that is, the visualisation's appresentation (Linder, 2013).

As students photograph artefacts and develop an understanding of technology, visual literacy can be understood as emerging through engagement with visualisations. In the classroom, strategies for developing visual literacy may therefore be particularly relevant because activities such as photographing technological objects create opportunities to focus on how and why visualisations are used, supporting students' representational competence.

This paper emphasises that as students deepen their understanding of technology's manifestations, they also develop technological literacy enacted through social interactions, such as small-group discussions in which technological knowledge is used and negotiated (Hallström & Stolpe, 2025; Ingeman & Collier-Reed, 2011). Previous research (Lind, 2025; Lind et al., 2024) suggests that student-generated visualisations function as mediational tools in this process, supporting them in articulating and refining technological understanding.

The analysis indicates that representational competence plays a central role in this development, as visualisations enable students to reason about technology through visual and verbal interaction in increasingly sophisticated ways. Taken together, this theoretical analysis addresses the research question by showing how student-generated visualisations support both the development of visual literacy and students' emerging technological literacy. Further research may elaborate on the relationship between representational competence and the manifestations of technology by extending Mitcham's (1994) framework to further nuance students' utterances and understandings of technology.

The proposed analytical framework in this paper contributes to technology education by relating representational competence to the manifestations of technology. This relationship allows for an analysis of how students' visual and verbal reasoning emerges as they engage with visualisations, rather than focusing only on how they perceive technology. In this way, the framework provides a conceptual lens for interpreting how students move between the manifestations of technology while developing their representational competence, thereby supporting the development of visual and technological literacy.

From a didactic perspective, the framework may serve as a tool for teachers to identify how students' reasoning about technology is supported by visualisations. It may also support teachers in designing learning activities where visualisations are deliberately used to scaffold students'

reasoning and discussions about technology. In this way, student-generated visualisations can become an important resource for supporting students' development of technological literacy.

5 DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance the clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were developed by the author.

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Bringing the Philosophy of Technology into Dialogue with Educational Practice: Reflections on Artificial Intelligence in Technology Education

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Abstract

Technology has long been interwoven with education, and over the past decades digital tools have played a central role in shaping both pedagogical practices and conceptions of what it means to learn, and to teach. When emerging technologies such as accessible artificial intelligence (AI) enter the educational landscape, they bring with them a complex interplay of promise and peril, sparking tensions around how and when AI can or should be used – or deliberately avoided. While much attention has been given to questions of implementation and ethics, less focus has been placed on how these technologies reshape the very conditions of education. Such questions cannot be resolved merely through practical or ethical guidelines; they require reflection not only on what AI can do, but also on how it mediates human intentions, judgment, and responsibility. The aim of this paper is therefore to explore how philosophical perspectives can illuminate the reflections that underpin technology teachers' choices and support a more reflective engagement with AI in technology education. These reflections are grounded in interviews with three technology teachers who describe their encounters with AI in their teaching. The analysis is guided by philosophical dialogues, engaging teachers' reflections with the work of philosophers whose ideas resonate in today's debates on emerging technologies. By bringing together philosophers' and practitioners' reflections through our analysis, the paper situates AI in technology education within a broader societal context, under the themes AI technology as potential, as disruption, and with awareness. Such an orientation invites teachers to view AI not merely as a pedagogical tool, but also as a technology that both shapes and is shaped by human actions.

Key Words: Technology Education, Artificial Intelligence, Philosophy of Technology, Technology Teachers

1 INTRODUCTION

Technology has long been interwoven with education, and over the past decades digital tools have played a central role in shaping both pedagogical practices and conceptions of what it means to learn, and to teach. When emerging technologies such as accessible artificial intelligence (AI) enter the educational landscape, they bring with them a complex interplay of promise and peril, sparking tensions around how and when AI can or should be used – or deliberately avoided. While much attention has been given to questions of implementation (e.g., individualization of learning) and ethics (e.g., plagiarism and protection of student data), less focus has been placed on how AI technologies reshape not only subject content but also the very conditions of technology education in a democratic society, especially from teachers' point of view. Teachers are central classroom actors, though in research often overlooked, and they have to make active choices on what and how to bring up AI in technology education when curricular guidelines are few (Mouta et al., 2025). Such choices require ethical and philosophical reflections that are also under-researched as such and as part of teachers' discourses, while much philosophical research seems to be directed toward the possible replacement of teachers by AI (e.g., Jin & Wang, 2025). In this paper we focus on the philosophy of technology, in particular philosophical frameworks that could engage teachers in making sense of AI in technology education, in relation to society and the environment. Methodologically, therefore, we want to bring the philosophy of technology into dialogue with technology education (e.g., Hansson, 2008).

The aim of this paper is to explore how philosophical perspectives can illuminate the reflections that underpin technology teachers' choices and support a more reflective engagement with AI in technology education. The contribution to technology education lies in providing conceptual resources for understanding what is at stake when AI is introduced to educational practice.

2 BACKGROUND AND LITERATURE REVIEW

Technology education in compulsory school should provide students with opportunities to develop skills in creating and using technology, including both practical applications and understanding of the contexts in which they can be used. AI, as a broad and multifaceted technology, is included naturally in technology education and also enables meaningful integration of knowledge across multiple subjects. However, it also carries risks, such as how systems are trained, potential biases in algorithms, and the impact on students' critical thinking (Mannila et al., 2025). Education must therefore address how AI can be used, and when its use is appropriate. AI is described as a technology with major implications for future societal development, which means that students need knowledge about AI to critically engage with its applications and consequences (Rawas, 2024). This requires space for reflection and discussion where these concerns can be raised by both students and teachers. Such considerations may thus be reflected in how teachers describe their encounters with AI in education.

To address these considerations, we employ philosophical analyses of arguments and views that relate to AI. The philosophy of artificial intelligence is an important facet of the philosophy of computing. However, it has arguably also been one of the most researched topics in the philosophy of technology as a whole for several decades, although much of the research pre-

dating the 2000s was carried out under different conditions compared to today. Currently, the research is extensive on topics such as natural language, cognition, and general intelligence as well as robotics and artificial agents (e.g., Boddington, 2023; Brey & Hartz Søraker, 2009; Stolpe & Hallström, 2024; Weizenbaum, 1976). The area of AI ethics has grown a great deal in recent years but it also has a longer history dating back as far as the 1960s and 1970s (e.g., Boddington, 2023; Coeckelbergh, 2020). However, there has been a lack of philosophical research that situates AI in teacher discourses and practices, specifically in technology education (e.g., Wieczorek, 2025).

3 METHODOLOGY

This study is philosophical but grounded in empirical examples as vignettes to illuminate teachers' arguments on how they reason about AI in technology education. These vignettes were based on empirical interview data collected through semi-structured interviews with three technology teachers in lower secondary education in Sweden, as outlined in Lundberg et al. (2025). In this study, philosophical inquiry is co-constructed with teachers' reflections and philosophers' concepts through an iterative, reflective dialogue concerning how AI mediates human intentions, judgment, and responsibility. Philosophical analysis is therefore understood here as a dialogical process (Hansson, 2008).

The philosophical analysis was carried out on arguments and views that were prominent in the interviews, as illustrated by the vignettes, but mainly pertained central philosophical concepts and concerns as they have been discussed by prominent philosophers of technology, in line with established philosophical methods such as interpretation/hermeneutics and argumentation. The degree of stringency of the philosophical analysis ultimately decided the validity of the method (e.g., Dusek, 2006). Finally, the results of the philosophical analysis were fed back to the technology education domain to inform implications for teaching, thus fulfilling the methodological role of the philosophy of technology in this paper as a dialogue partner (Dohn, 2011, p. 431-432).

The authors have not employed AI in the analysis or writing of the paper.

4 PRACTITIONER REFLECTIONS FROM A PHILOSOPHICAL STANDPOINT

The teachers express three different perspectives on the role of AI in technology education. These three perspectives, of which we will showcase one example of each from the data in form of vignettes, also reflect three different philosophical standpoints. Here, we label the teachers' perspectives as: (1) AI technology as potential; (2) AI technology as disruption; and (3) AI technology with awareness. We thus anchor the data in the philosophical literature, both to show how AI makes up a pertinent example of technology relevant for technology education and how it reflects broader issues concerning technology that have been around for a long time, even before there was something called AI. As such, the teachers' views of and relationships with AI reflect broader themes that can stimulate discussion of and reflection on AI in the technology classroom.

4.1 *AI technology as potential*

This perspective explores AI as an evolving technology in educational contexts. The analysis focuses on how technological openness raises questions about basic understanding and educational responsibility in relation to future developments of AI.

Teacher A describes AI as a technology with significant potential and argues that students need a solid technical and conceptual foundation early in their encounters with AI in order to participate meaningfully in a rapidly shifting technological environment. While acknowledging that AI may develop in many different directions and be applied across various domains both in school and outside of school, Teacher A maintains that technology education offers a crucial starting point. By understanding how AI systems work, how they are designed, and how these design choices influence outcomes fed back into social practices, students gain a framework to use when engaging with future AI developments.

An influential ontological voice in thinking about the potential of technology is Gilbert Simondon, who emphasizes the importance of understanding the genesis and evolution of technical objects (Dakers, 2019). Simondon highlights the need to cultivate a technological understanding as '*things*' (in the broad sense, encompassing all forms of being in the world) are never fully stable, but always subject to transformation. Rather than viewing technological objects as alien intrusions into human life, Simondon describes them as metastable and relational. For example, in a system atoms can exist in a metastable equilibrium where a potential for reorganization within the system is present. When the atoms are disturbed, say through changes in temperature or pressure, they can reorganize into a different structure. What kind of structure is thus dependent on how the system is disturbed, and this process, metaphorically applied to technology, Simondon defines as *individuation* (Simondon, 1958/2020).

According to Teacher A, students' understanding of AI likewise has the potential to evolve differently depending on how they are exposed to and use AI in school. What appears as a gradual growth in students' understanding can be seen as the actualization of different potentials depending on different classroom engagements. The teacher raises the idea that knowledge about AI is shaped differently depending on the subject-specific setting and emphasizes technology education as a site for developing an understanding of both technical and conceptual knowledge. Strengthening the students' understanding through technology education is therefore articulated as an opportunity to support their further engagement with AI. Analytically, this resonates with Simondon's account on how this process occurs through human intervention, and is shaped through individuation, thus the human subject and technology co-develop in relation to their milieu (Simondon, 1958/2020). That is, to understand technology, Simondon emphasizes that one must engage with its internal logic and genesis, not merely its function (cf., Arthur, 2009). While the teacher's reflection resonates with Simondon's emphasis on development of technology, it simultaneously introduces an insistence on technology education as a starting point. This account suggests that although the development is open-ended, it nevertheless requires a structured introduction.

The teacher's perspective resonates with long-lasting promises of technology in education but also philosophical strands about technology and its role in human life. It invites us to consider

the ontogeny of technical objects as technologies evolve and converge through processes of individuation, where each technical object carries within it a history of transformations as well as potential for future development (Simondon, 1958/1980; cf., Briggs & Burke, 2009). The teacher suggests that AI in education cannot be understood through its design, or its intended functions, alone. Instead, AI is to be approached as a technology laden with potential, where the teacher guides the process of individuation through pedagogical strategies, and where the result of using AI is neither predetermined nor fixed. In this light, AI can be considered as an offshoot of a longer trajectory of evolution in technology education, one that calls for a different way to meet technical competence (use of AI) and education capable of fostering meaningful participation in technological becoming (understanding AI). Consequently, the individuation of AI carries on as students participate in and contribute to the ongoing shaping of AI not only within technology education but also in broader contexts.

4.2 *AI technology as disruption*

This perspective addresses how AI is understood as a technology that challenges our engagement with practices and responsibilities. The analysis focuses on reflections on consequences and disruptions that accompany AI use when the technology itself is still emerging.

Teacher B approaches AI as a technology that unsettles established ways of acting responsible with digital tools. While recognizing the benefits and efficiencies AI may offer, the teacher raises concerns about how its consequences may remain invisible to users and only become clear when practices have already adapted to them. Furthermore, the teacher emphasizes an educational responsibility to make visible the values, assumptions, and limitations built into AI systems, and to address these problems before they become normalized and embedded in systems and practices. For Teacher B, engaging with AI in the classroom is therefore not primarily about adopting a new tool, but about responding to a disruption that is still unfolding and whose implications are not yet fully known.

Political philosopher Langdon Winner argues that technologies are not mere instruments to be used by humans, nor can they be controlled without understanding of and reflection on their impact. Embedded in their intended use is an implicit assumption that the developed technology represents an improvement of human life, an assumption that influences behavior and traditions related to how tasks are carried out. According to Winner, this notion of improvement is seldom questioned or subjected to critical evaluation. Nevertheless, he sees how technology carries specific assumptions and political values and as such, they affect society and therefore cannot be considered neutral technical tools (Winner, 1986, 2007).

While Winner underscores critical engagement with existing technology, the teacher's reflection is situated in an ongoing development where both use and consequences are still emerging and debated. The teacher raises a concern about the problems we might build into the system understood as the unintended consequences only become visible once the results of our actions unfold. Thus, teacher B approaches AI not as a static or neutral technology, or even a stabilized technology, but as one shaped within and outside of educational practice and carrying consequences – advantages as well as disadvantages – that extend beyond the classroom, and where education about AI makes this dynamic evolution explicit and visible.

The question raised by the teacher and revoiced through Winner is thus not simply how AI can improve society, but rather what kind of society we want AI to help us build (cf., Axell, 2019). Viewing AI as a tool to be used without concern therefore becomes problematic, and Winner argues that the discussion must shift from technical efficiency to political and moral reflection (Winner, 1986). The teacher highlights the need for caution and responsibility in relation to human influence, and how education about AI must make human participation visible in shaping both problems and possibilities that become actualized. This view concerns not only active users of AI, but also those who are excluded from using it and how technology can become controlling and disrupting for those who do not understand it, and underscores the need to move beyond a purely instrumental view of technology and reflect on its premises and implications (cf., Ropohl, 1997), and how questions regarding the social and ethical implications can be brought into pedagogical practice (Winner, 1986).

4.3 *AI technology with awareness*

This perspective introduces AI as a technology that mediates experience and perception. The analysis highlights reflections on the importance of cultivating awareness of how AI shapes what decisions are prioritized in educational contexts.

Teacher C describes AI as a technology that shapes how the world is perceived and acted upon. AI is described as a tool that can make tasks easier and more efficient, but at the same time something that risks pushing certain aspects of experience to the background. For this reason, the teacher sees teaching about AI as an opportunity to draw attention to how technologies mediate understanding and decision-making. The teacher emphasizes the importance of helping students recognize both what AI enables and what may become less visible through its use. In this sense, the classroom becomes a space where students can critically engage with how AI participates in shaping their ways of seeing and responding to the world.

The post-phenomenologist Don Ihde argues that technology should not be seen as isolated or autonomous, but rather as something that exists in relation to humans and their lifeworlds, presented as different types of human-technology relations. Technologies enable certain relations, which then change our perception, and can be understood in a positive sense as an expansion of human capacities. This allows us to see aspects of the world that would otherwise remain hidden, for example, using spectacles or a hearing aid make visible or audible what was previously inaccessible (Ihde, 1990). Instruments such as the electron microscope even create entirely new ways of perceiving reality (Ihde, 2011). These technologies therefore do not simply add more detail to what we already know but they enrich and transform our relation to the world itself which will appear differently depending on the technology we use (Keirl, 2019; Mitcham, 1994). AI technology is thus an example of such a technology that is experienced differently depending on its application and uses, shaping how the user acts and perceives the world (Ihde, 1990, 2002). The teacher highlights how technologies mediate experience and emphasize the importance of making this visible in education about AI. In this sense, the teacher foregrounds the educational need in how to critically engage with AI, illustrating the role in how AI is realized in education, and by extension what students learn about AI and society.

Ihde reminds us that no extension comes without transformation. Just as a microscope allows us to see what is otherwise hidden but narrows our field of vision, AI brings some things into sharp focus while pushing others to the periphery (Ihde, 1990; Keirl, 2019; Mitcham, 1994). As we adapt to what AI makes easy or visible, we may gradually unlearn what slips beyond our sight. The risk is thus not only that we overlook what AI cannot see or grasp, but that our own ways of seeing changes in the process. Although the teacher acknowledges the risks inherent in technological mediation, a call to reject AI is not implied. Rather, the reflection is situated at a critical juncture where ethical and democratic responsibility arises as teaching about AI not only concerns the technology that already exists, but also how educators and students engage with emerging applications of AI. Ihde sees the relationship between human, instrument and the world as central, and calls for active participation. Thus, we are called not only to perceive and critique but to respond to, and shape, new technology (Ihde, 1990), including AI (cf., Feenberg, 2017). Similar to the teacher's account, learning about or with technology is never a neutral process according to Ihde, and he emphasizes that it becomes important to discuss how technology shapes learning and not merely what is learned (Keirl, 2019). Accordingly, the premises of education are subject to change and need to be evaluated when we teach through AI, in technology education as well as in other subjects.

Teacher C reflects on the impossible task of predicting how AI will be used in the future. While the thought itself can be daunting, the teacher insists that part of the process is that the students must understand what already exists, and what is possible to do with AI, where strategies for using AI become central, even when the future remains unpredictable. AI takes shape through interaction and intervention from both teachers and students, and from this standpoint, the role of the teacher is to develop and exemplify strategies for how AI can be used. Feenberg (2017) builds on this by introducing the idea of democratic intervention, highlighting that citizens actively can influence and shape technology rather than simply adapt to it. In this way, students will acquire knowledge needed to navigate AI both critically and competently. Teacher C highlights that with the teacher as a guide comes an awareness of responsibility: their interventions shape how AI is introduced, how it is understood by students, and ultimately how students engage with AI and the world unfold.

5 CONCLUSIONS AND IMPLICATIONS FOR TECHNOLOGY EDUCATION

AI in education is frequently discussed in terms of tools, uses, or outcomes. When AI is reduced to the input and output of education, there is a risk of obscuring how technology education is shaped through teachers' choices, how these decisions influence what is learned, and what consequences are actualized through the use of AI. In this paper we have used philosophical dialogue between teachers and philosophers as a method with the idea that they both are to be understood as "equal partners with distinct voices who have equal rights to call the views of each other into question" (Dohn, 2011, p.448). Therefore, in the dialogue, teachers and philosophers both bring perspectives on AI to strengthen and problematize AI in technology education together, thus actively shaping the meaning and direction of the educational significance of AI. By doing so, this paper demonstrates three ways in how AI can take form in technology education.

First, AI technology is discussed as potential that will continue to develop in different directions depending on use. While this openness of direction is not discussed as good or bad, a foundational understanding of AI provides students with the possibility to engage with future AI developments in informed and reflective ways, and where educational research may benefit from recognizing technology teachers already existing orientations regarding conceptual and technical knowledge. Here, students and teachers both participate in and contribute to the ongoing shaping of what AI will evolve into.

Second, AI technology is framed as a disruption, and there is an emphasized need to address how emerging technologies reshape practices and responsibilities, and how consequences of its use affect us. That makes it insufficient to focus solely on technical functionality in AI. Teaching about AI is thus to be found in a situation where it becomes important to address the embedded assumptions on technological development of AI before AI technology becomes stabilized.

Third, AI technology needs to be taught with awareness. Teaching about AI involves students understanding the consequences of their use, but also how their own design choices, values, and assumptions become embedded in the systems as they develop. This allows the students to actively take part in the shaping of AI technology rather than merely adopting or adjusting to it. Therefore, teaching about AI also includes how technologies shape our perception and understanding.

Together these perspectives present AI not as carrying finished technological functions or with a fixed meaning, but as shaped by its internal structures and in relation to the users and society, for good or bad. AI can thus be recognized as a technology with an ongoing evolutionary trajectory, where teaching about AI must include establishing the conditions under which it can be understood to support a reflective use beyond educational settings. Engaging with philosophers' and practitioners' arguments encourages a reorientation of philosophical reflection toward the educational practices through which AI is enacted in technology education, and perhaps also to understand how AI shapes and is shaped in broader educational contexts. Therefore, teachers' interpretations and decisions are decisive in shaping how AI takes form in education.

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Decoding Design Thinking: Deepening the Lens on Values and Capabilities

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Abstract

Design thinking is widely recognised as a fundamental aspect of technology education, yet its meaning remains inconsistently applied across research, policy, and classroom practice. The term has been used to describe a broad spectrum of activities, dispositions, and cognitive processes, and these interpretations often vary substantially between contexts. As a result, the field lacks a well-defined and commonly accepted framework that can support meaningful connections between design thinking and the broader aims of technology education. Previous research has attempted to address this issue by identifying common trends in the use of design thinking and by grouping its characteristics into a set of components. From this work, eleven components have been proposed, organised across two levels: technical components, which relate to processes and actions involved in designing, and value- and capability-focused components, which capture underlying attitudes, dispositions, and ways of engaging with complex design problems. Due to the nature of the previous study being a rapid review, only a surface level identification of components was developed. This paper extends the earlier research which only provided a broad overview by providing a deeper and more nuanced exploration of the value- and capability-focused components. Drawing on a review of the literature, this paper analyses these components and examines the ways in which they manifest within common practices in technology education. In doing so, the paper highlights how value- and capability-based aspects of design thinking support authentic engagement in technological problem-solving and strengthen alignment with curricular priorities. Ultimately, the paper seeks to clarify the nature and significance of the value- and capability-focused components of design thinking, providing insights that can inform future research, support pedagogical practice, and contribute to the development of a more coherent and commonly understood framework for design thinking in technology education.

Key Words: Design Thinking, Values, Literature Review

1 INTRODUCTION

Design has long been seen as a core part of technology education (Baynes, 2006; Stables, 2008), and the term design thinking has become a prominent feature of contemporary technology education discourse, which can be seen reflected in the title of the subject in certain countries (Design and Technology in the UK) as well as in the title of leading journals in the area (*International Journal of Technology and Design Education*, *Design and Technology Education: An International Journal*). This is especially true in the Irish secondary level educational system (NCCA, 2019a, 2019b). It is often argued as a core means through which learners engage with technological problem-solving, innovation, and creative practice. Across literature and curricula, design thinking is used to describe a wide range of activities, processes, and viewpoints, from structured and iterative cycles to broader ways of thinking about users, systems, and contexts. In practice, design processes generally focus on the development of technological systems or artefacts. While this wide array of uses reflects the perceived value of design thinking within technology education, it has also contributed to increasing uncertainty around what the term actually represents.

This lack of clarity poses challenges for both research and practice. When design thinking definitions vary, it can become difficult to develop commonalities of learning goals, to design appropriate pedagogical approaches, or to assess learning outcomes validly. In technology education in particular, design thinking is sometimes reduced to a sequence of steps, emphasising the completion of design tasks over a deeper engagement with the values and capabilities that underpin authentic design. Such a procedural viewpoint risks hindering the educational purpose of design thinking and limiting its potential to support complex, real-world problem-solving.

Previous research has aimed to address this issue by analysing how design thinking is described and applied across the literature, resulting in the identification of eleven commonly occurring components (Maquet et al., 2025). These components were organised into two categories: technical components, which relate to the procedural actions involved in designing, and value- and capability components, which capture underlying values, attitudes, and ways of dealing with complexity. While this initial identification of components provided a useful starting point, the rapid review methodology employed limited the depth of analysis that could be conducted. Building on this earlier work, this paper seeks to expand the understanding of design thinking by exploring selected value- and capability-focused components in greater detail. By conducting a review of the earlier-identified literature, the paper examines how these components are currently framed and how they may manifest within technology education. In doing so, it argues that the value- and capability-based aspects of design thinking play a critical role in supporting authentic technological problem-solving and in aligning design learning with broader curricular priorities. This paper seeks to strengthen the understanding of design thinking components and their potential utility at secondary level, such that future research regarding its implementation may have a clearer methodological starting point. In practice, it is vital that educators are provided with clear frameworks to guide teaching and learning, such that implementation and assessment of these methods may be clear to both learners and teachers, this paper offers an initial step in this important clarification.

2 METHODS

This paper presents a narrative literature review based on the analysis of a dataset previously compiled through a rapid review of design thinking models. The original rapid review (Grant & Booth, 2009), conducted by Maquet et al. (2025), initially retrieved 1929 records, which through screening then reduced to 124, using the following search strings:

SCOPUS: TITLE (("design*" OR "creativ*") AND ("Think*" OR "capabil*" OR "competenc*" OR "abil*" OR "liter*") AND ("framework" OR "model*" OR "tool" OR "structure" OR "paradigm*" OR "method*" OR "process*" OR "component*" OR "element*" OR "dimension*" OR "stage*" OR "phase*" OR "review")) AND PUBYEAR > 2020 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")).

Web of Science, with the same limitations as above included: TI=("design*" OR "creativ*") AND TI=("Think*" OR "capabil*" OR "competenc*" OR "abil*" OR "liter*") AND TI=("framework" OR "model*" OR "tool" OR "structure" OR "paradigm*" OR "method*" OR "process*" OR "component*" OR "element*" OR "dimension*" OR "stage*" OR "phase*" OR "review").

The PRISMA guidelines were adhered to for the literature search (Moher et al., 2009), which was conducted on 28/5/2025. Full information on the literature search can be found in the original paper.

These 124 articles described design thinking models either conceptually or in use.

The included articles were analysed through a narrative thematic analysis using an inductive approach. Full texts were read to identify the models used, and each term used in these models was extracted. After all terms were extracted, these were examined and grouped into emerging interpretive themes. During this, attention was given to similarities, differences, and contradictions. These patterns informed the development of the overarching themes. From the eleven design thinking components identified in the rapid review, this paper focuses on the subset of five value- and capability-focused components. These components were selected due to their relevance to educational aims in technology education and due to their lack of exploration in the previous paper. Descriptions were developed to explain how value- and capability-focused components were framed, named, and enacted within the various models. Attention was given to the terminology used to describe these components, the purposes they served in the model, and the ways in which designers (learners) engaged with them. As a narrative review, this analysis does not seek to provide an exhaustive account of all design thinking literature. Rather, it aims to generate a deeper insight into selected components by examining patterns across studies. GenAI was used only for the purpose of copyediting the paper before submission.

3 VALUE AND CAPABILITY COMPONENTS

3.1 *Understanding Users and Perspectives*

During the initial rapid review process, a range of terms were collated into the component of ‘understanding users and perspectives’, including *empathise* and *empathy* (both of which were quite prominently observed), *create alter egos*, *perspective discovering*, *point of view*, and *user-centredness*. A clear and recurring theme emerged around understanding users within design thinking, which was a prominent feature across most examples reviewed. The human-centred nature of design thinking places empathising with users as a component of central importance (He et al., 2023). The dominant terms of *empathise* and *empathy* were consistently associated with developing “a deep understanding of the needs of the users involved in the solution that has been developed, as well as of their environment” (Yedra & Aguilar, 2022, p. 6), with researchers emphasising that “being able to understand how people feel is critically important” (Montero, 2023, p. 157). Core processes of developing empathy include interviews, questioning, conversations, and observations in order to understand the users’ experiences and needs (Castiblanco Jimenez et al., 2021; Moffett & Cassidy, 2023; Pondelíková, 2023). While the lesser-used terms varied in wording, they remained conceptually consistent. For example, *create alter egos* referred to the generation of personas and scenarios in order to guide the design activity by providing a concrete user focus (Arvanitakis et al., 2025). *Perspective discovering* was quite unique in its application to teachers, offering opportunities to tailor the design thinking process to learners’ needs, while still emphasising user understanding (Elwood & Jordan, 2022). The term *point of view* described the synthesis of gathered information to form an understanding of user needs (Orliv et al., 2021; Yang & Man, 2021). Finally, *user-centredness* was framed not as a discrete stage, but as an overarching practice and underpinning principle of design thinking (Cai et al., 2023). Although at times structured tasks were utilised, it is important to note that the purpose of these tasks was to develop empathy as a capability within the learners, rather than to complete a task on empathy.

3.2 *Collaborative Engagement*

While reviewing the literature another clear component began to develop, that of collaborative engagement. Collaboration and engagement, with others, were seen to be core elements of design thinking, from the perspective of epistemic development. Worapun and Nuangchalerm (2024), while using the term *explanation*, discuss the importance of collaboration for the sharing of knowledge, and promotion of critical thinking. Similarly, Van Uffelen et al. (2024) discuss the importance of gaining a wide range of perspectives under the terms *interdisciplinary teams and knowledge*, and *active participation of multiple stakeholders*. Gaining differing viewpoints from a wide range of stakeholders is important not only for representation purposes, but to “capture and integrate divergent perspectives and inspirations into a holistic viewpoint to generate creative ideas and solutions” (Cai et al., 2023, p. 4). This is captured by Cai et al. under the term *embracing diversity* (Cai et al., 2023). Collaborative engagement is seen to be an important element at all stages of a design process from the initial steps of *collective problem solving* (Ozsoy & Mengüç, 2024) and *brainstorm and share ideas* (Xi et al., 2024), to the later step of *co-creation* (Jarrett et al., 2022). The use of collaborative approaches within design is fundamental to developing ideas

as it provides an opportunity to develop one's ability to engage in design decision-making and design judgement, supporting both collective design outcomes and individual design judgement.

3.3 *Reflecting and Reframing*

Reflection as a part of iteration can also be seen in existing design thinking models. Aris et al. (2025, p. 5) discuss the use of reflection to allow the designers (learners) opportunities to examine “the entire design process, including challenges, successes, and areas for improvement”. The term *reflective reframing* has also been used to describe this process, with the importance being highlighted for both teachers and learners. This entails a designer “thoughtfully drawing from previous stages” (Elwood & Jordan, 2022, p. 1801). Reflecting and reframing is an integral part of design thinking, as it provides opportunities for the designer to critically examine what it is they have done, and how well it achieves the goal of the design. This in turn facilitates redefinition of design problems and supports authentic engagement in an iterative process characteristic of technological practice.

3.4 *Developing Social Consciousness and Ethical Awareness*

Another core component of design thinking is ‘developing social consciousness and ethical awareness’ (formerly referred to as ‘cultivating design values and awareness’), so that designers (learners) are developing their own values rather than just skills while engaging with design. Worapun and Nuangchalerm (2024) use the term *engagement* to describe how learners engage with real world, local, problems to encourage curiosity and creative thinking. In their model of design thinking, Högsdal & Grundmeier (2021) incorporate the *notice* phase, where learners were asked about their motivation for getting involved. This was done to acknowledge any beliefs that may have an impact on the process. The term *inspire* is used by Sadini et al. (2024), where they discuss the importance of inspiration on the design process so that designers can understand why they are engaging with the process. Arvanitakis et al. (2025, p. 470) use the term *sustainability* to explain the importance of developing learners’ awareness of global issues so that they can “understand and respond to complex challenges, such as climate change and responsible citizenship”. Together, these terms frame design thinking as a value-laden practice rather than a neutral problem-solving tool.

3.5 *Communicating and Sharing Design Work*

Many design thinking models incorporate an element of communication somewhere, as it provides a key opportunity for learners to receive critical feedback which may drive their designs forward. Fotaris and Mastoras (2022) use the term *brief* to discuss the need for communication at the beginning of a process, as a way to set goals and expectations. Blundell (2024) simply uses the term *communication* to describe the communication of findings or results at the end of a design thinking process. Park et al. (2022) similarly discusses the sharing of final ideas at the end of a process, by using the term *discourse* to describe this phase added on to the end of a traditional double-diamond model. Thammaariyasakun et al. (2025, p. 139) call this step *presentation* but echo the need for the communication of ideas, arguing that these “offer learners the opportunity to receive expert feedback for future improvements and developments”. Under the phrase *communicate and share the results* Xi et al. (2024, p. 2273) explain that “effective communication

of the final results is about telling the story of the project, including the challenges faced, the solutions developed, and the knowledge gained". The terms *document* (Fotaris & Mastoras, 2022), *share* (Högsdal & Grundmeier, 2021), and *design discussion* (Fu et al., 2024) are also used to highlight the need to share an explanation of final designs to others. Fotaris and Mastoras discuss the importance for this discussion, using the term *debrief*, to promote metacognition. It is vital that this communication is not a tick box exercise, but an authentic discussion of design progress so that meaningful learning can occur.

4 DISCUSSION

This paper set out to broaden the understanding of design thinking in technology education by looking at the components that extend beyond procedural aspects of design. The literature review highlights that although many different models of design thinking exist, there is a consistent thread within them that focusses on developing learners' capacities to understand users, collaborate, reflect, develop values, and communicate their work meaningfully. Together, these components place design thinking within technology education as a practice concerned not only with producing solutions, but with developing learners' capabilities, values, and capacity to engage with complex problems.

Within the literature, these components collectively move design thinking away from only being understood as a linear sequence of steps and towards a more interpretive practice impacted by many factors. Understanding users and perspectives emphasises empathy as a capability to develop rather than a task to complete, requiring learners to understand needs, contexts, and experiences in ways that will inform design decision-making. Collaborative engagement further supports this by placing knowledge development as a social act, where ideas are shaped through interaction and exposure to multiple viewpoints. Reflection and reframing extend this by providing learners an opportunity to critically evaluate their design actions, redefine problems, and respond to emerging insights. Together, these components reflect core characteristics of authentic technological practice, where uncertainty is central and adaptation of ideas is key.

The findings of this paper also highlight the value-laden nature of design thinking. Components linked with cultivating design values and awareness demonstrate that designing is not only procedural, but it is shaped by beliefs, values, knowledge of user needs, and broader concerns such as sustainability. When these aspects are actively employed, design thinking can support learners in developing awareness of why they design and what consequences these designs may have. This aligns strongly with curricular goals in technology education that emphasise ethical awareness, informed decision-making, and ability to engage in social and environmental contexts, rather than purely technical efficiency.

Communication and sharing of design work further reinforces the role of design thinking as a learning-centred practice. Within the literature, communication is discussed not only as the presentation of final outcomes, but as an opportunity for feedback, reflection, and metacognitive development. Authentic discussion of design progress, challenges encountered, and decisions made can support learners in articulating their reasoning and in shaping their ideas in response to

feedback. Communication, when engaged with correctly, becomes central to learning through design, rather than something that happens at the end of it.

This review suggests that uncertainty in design thinking terminology isn't problematic in itself, but challenges may arise when design thinking is understood as only procedural steps and disregards underlying values and capabilities. By clarifying how value- and capability-focused components are framed and enacted within the literature, this paper contributes to a more coherent understanding of design thinking that still allows for contextual nuance.

5 CONCLUSION

This paper aimed to expand on existing research on design thinking in technology education by moving beyond surface-level descriptions and providing a deeper examination of selected components. In response to uncertainty around the definition and enactment of design thinking, this paper highlights the importance of focusing not only on the procedural, but also on the values and ways of thinking about designing. These findings suggest that these components play an important role in enabling learners to navigate uncertainty, respond to real world information, and demonstrate autonomy within technological problem-solving tasks. By clarifying how these components are framed in the literature, this paper contributes to the development of a more coherent and commonly understood framework for design thinking. This clarity has implications for future research, particularly in relation to the implementation and assessment of design thinking, and likewise for pedagogical practice and teacher education. However, as this study is limited to a literature-based analysis, further empirical research is needed to explore how these components are enacted in diverse classroom contexts. Another limitation of this study is the short-term, yet broad, view as with the nature of the rapid review. Future work would benefit from being more comprehensive in nature (more than 5 years) and focused solely on technology education for greater clarity. Ultimately, strengthening the conceptual foundations of design thinking in technology education requires consistent attention to what both learners and educators do when engaging with design problems. By deepening the lens on values and capabilities, this paper offers a step towards more meaningful applications of design thinking within the field.

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‘You Are Just a Teacher’: A Researcher’s Insider Perspectives During a Collaboration with Teachers While Designing and Implementing a Student Renewable Energy Technology Project

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Abstract

This paper explores the notion of consultation, collegiality, and cooperation during researcher-teacher collaboration while conducting inside research. Insider researcher is given access more easily to the researched location and its culture compared to an outsider researcher. This is because the researcher normally works at the researched location and this may encounter unforeseen challenges, especially when collaborating with nonresearcher insiders. Moreover, how important decisions, defined as critical incidents, have been treated in the collaboration between an inside researcher and teachers are the scoop of this paper. Identifying potential pitfalls in a researcher-teacher collaboration in technology education are important to be aware of due to future similar collaborations. The collaboration studies in this paper was intended to improve educational practices where students were working on a student project regarding renewable energy technology from sustainable perspectives.

The study was based on design-based research, where a student project about renewable energy technology was developed and implemented in two iterations in collaboration with two colleagues. The empirical material consisted of teacher interviews where both teachers and researcher described and reflected upon the collaboration. This paper has utilised content analysis and focused on critical incidents in the collaboration when decisions and judgments about technology are made, which potentially can influence design-based research, and particularly the researcher-teacher collaboration.

The critical incidents can indicate that the teachers’ perception of the researcher as a researcher varies between outsider researcher and insider researcher or colleague. Factors, such as power relations and honesty, can be influenced, both positively and negatively, during collaboration between teachers and insider researcher due to strong collegiality and trust. Nevertheless, the research results can also indicate that inside research with features of outsideness is generally a positive endeavour but may contain elements of unfortunate episodes that can influence design-based research, the collaboration but also the student project.

1 INTRODUCTION

This paper will elaborate on some of the possibilities and challenges of conducting ‘insider’ research. Relatively little research has been done to uncover potential tensions and dilemmas that teachers meet in relation to their ‘insider-outsider’ positioning when they do research in their own school (Czerniawski, 2023). Inside research can be characterised as research conducted at a site where the researcher usually works and can therefore be given more access compared with an outsider (Mercer, 2007). Collaborations between university academics and K-12 teachers have increased and needs to be further researched due to power relations and other challenges that can be tackled through co-design (McMain et al., 2026). Design-based research (DBR) supports researcher-teacher collaborations because the collaboration focuses on design processes as a co-design partnership to improve educational practices (Getenet, 2019). Being a public PhD student conducting research at the school where I also teach on a regular basis makes me potentially to an inside researcher with outside perspectives or at least a researcher with extensive inside knowledge about the school, students, teachers, and the school culture.

The present research originally stems from design-based research (DBR), where collaboration between the researcher and teachers is one of several important features. Hence, I have been inspired to use some of the theoretical aspects of Goulet et al.’s (2003) notion of consultation, collegiality, and cooperation (Goulet et al., 2003), utilising these theoretical aspects as my analytical framework during content analysis. Furthermore, my paper focuses on critical incidents regarding decisions and judgments concerning technology that we had to make when we designed and implemented a student project regarding renewable energy technology from a sustainable perspective. This is because these decisions and judgments about technology may have had an impact on our collaboration and/or my DBR research.

The insider-outsider perspective may, for instance, have an impact on research design decisions (McNess et al., 2015). How I was positioned, or perceived by the teachers and students, during this research—either as an insider, outsider or ‘in-between’—may have changed dynamical throughout the researcher–teacher collaboration. I believe that Goulet’s framework is slightly lacking when it comes to elaborating on the collaborations between researchers and teachers in a dynamic insider–outsider continuum. I therefore pose the following research question:

How can the insider-outsider perspectives of the researcher in a researcher-teacher collaboration related to power relations influence the DBR and the collaboration?

2 THEORY

2.1 *Insider–outsider perspectives within research*

According to Nakata (2015), outsider educational research (OR) can be characterised as a person who comes from an outside community that is the subject of the investigation and, hence, initially knows little, if anything, about the social culture or the people who may contribute to the research (Nakata, 2015). The chances of missing out on tacit knowledge may also be enhanced by being an outsider researcher but can simultaneously offer the opportunity to critically examine insider ‘taken-for-granted knowledge’ (Hamdan, 2009, pp. 385-386).

Being an insider means that the researcher can be perceived by the interviewee as someone who understands and relates to the research object because of shared interests (Farahani, 2011). Additionally, it is generally presumed that an insider researcher is given access more easily than an outsider researcher (Mercer, 2007). According to Nakata (2015), insider educational research (IR) is characterised by a teacher who also functions as a researcher, and everybody involved is meant to benefit from IR research (Nakata, 2015).

Insider–outsider research is a continuum where the researcher continuously drifts somewhere in between (Hamdan, 2009). Factors such as time and place of the research, power relations between the researcher and researched, and personalities and topics are also dimensions of the insider–outsider continuum (Mercer, 2007). How the researcher is positioned within the insider–outsider continuum also depends on the researcher’s empathy towards the researched community (McNess et al., 2015).

2.2 *Important features of researcher-teacher collaboration*

Collaboration can be a researcher-teacher partnership collaboratively codesigning and shares the same goals (Juuti et al., 2021). Moreover, a collaboration necessitates a dialogue where researchers can recognize teacher worries (Wang & Hannafin, 2005). A researcher-teacher collaboration may also offer challenges, for instance, regarding who is going to decide what and who will take on the leading role in the collaboration, and this can be related to power relations (Bjønness & Johansen, 2014).

Goulet et al. (2003) suggested that collaboration in education is based on three fundamental aspects during the collaboration (Goulet et al., 2003). These aspects include consultation (i), collegiality (ii) and cooperation (iii), which are defined below.

- (i) Consultation is a type of conversation where sharing, talking and distributing knowledge (or the sharing of expertise) is central; listening is especially important in the ‘consultative process’ (Goulet et al., 2003). The meaning of having constructive talk and listening is related to building fruitful relations between those involved, which is founded on mutual trust and respect (Goulet et al., 2003). A problematic issue of a ‘consultative process’ regards knowledge. Factual, conceptual (‘know that’), procedural (‘know how’) knowledge are different types of knowledge that are mutually dependent

on each other and may develop symbiotically when managing technology (Barak, 2013). These knowledge types are important to distinguish because how technology is used will ‘stimulate’ each knowledge type differently, depending on what is to be accomplished.

- (ii) Collegiality is related to friendly, open and honest relationships between colleagues working together on a joint project. It implies collective responsibilities and dedications towards the work at hand (Goulet et al., 2003). Empathy and caring for others during the project are central aspects of collegiality. Honesty is related to power relations between people (Barends et al., 2019) and honesty, which ‘requires shared power’ (Goulet et al., 2003, p. 332). This sharing of power is important because it may impact the teachers’ opportunities to influence the research-teacher collaboration. Furthermore, a collaboration means that colleagues must trust each other (Tschannen-Moran, 2001).
- (iii) Cooperation means that all members of the collaborative group contribute with their unique set of knowledge and experiences and share these with one another to understand and/or to relate to each other’s knowledge base (Goulet et al., 2003). These collective understandings are important to have to work towards the fulfilment and realisation of shared and predefined goals within the project (Goulet et al., 2003). However, what happens if the involved parties disagree about the goals during researcher–teacher collaborations? (MacDonald, 2008). Disagreements should be handled and resolved through cooperation because cooperation will benefit both parties from collaborative action (Georgé et al., 2011).

3 THE STUDY

My research results originate from DBR, which requires a researcher-teacher collaboration and is flexible in terms of offering multiple iterations from the classroom to improve student projects concerning technology (Wang & Hannafin, 2005). I collaborated with two colleagues at my school. Teacher 1 (Anne) is a biologist and teaches natural science, geography and biology and has 20 years of teacher experience. Teacher 2 (Berit) is a physicist and teaches mathematics and physics and has 10 years of teacher experience.

Together with Anne and Berit, we have designed a student renewable energy technology project aiming to promote student argumentation and students’ ability to reach a joint consensus by listening, respecting and tolerate each other which supports their citizenship. Student materials and booklets were designed and further developed and improved due to multiple iterations with teacher-and student feedback. The county municipality gave the students a mission that invited the students to inquire the use of more renewable energy technology at their local upper secondary school. The students had to consider factors such as environmental, economic, political and social implications, along with consequences for their choices. They conducted small-scale experimentations on renewable energy technology and made theoretical large-scale systems

supplying the school with more ‘green’ energy. Finally, the students presented their technology systems to the local leadership, where they had to argue for their choices.

The empirical materials for this paper came from two teacher interviews (Anne from iteration 1 and Berit from iteration 2). The interview was semistructured accompanied by the use of an interview guide. The guide mainly contained questions about the design and implementation of the design regarding the use of different scaffolding procedures, such as technology and booklets, meant to support the students in their inquiries. The interviews were conducted only shortly after the classroom research. The interview with Anne lasted for one hour, and the interview with Berit lasted for half an hour and both interviews were fully transcribed. The teachers’ inputs and reflections will give insights into our collaboration during critical incidents.

Identifying critical incidents can reveal perspectives and practices while disclosing different meanings and several truths in a complex educational setting (Halquist & Musanti, 2010). Flanagan (1954) introduced critical incidents as an approach to examine and identify the critical conditions for success within several professions, including education and teaching (Spencer-Oatey, 2013). Critical incidents can identify features that are vital to certain important aspects of incidents or actions (Flanagan, 1954). Some researchers have used the term ‘significant’ instead of critical to better describe daily incidents (Keatinge, 2002). According to Flanagan (1954), a critical incident is defined as a behaviour, either ineffective or effective, regarding the achievement of a purpose of an action (Flanagan, 1954). Critical incidents are constructed by the way we observe a situation, which implies that it is our interpretations of a situation’s significance, for instance related to why and to whom, that makes an event into a critical incident in the classroom (Tripp, 2011). Additionally, identifying critical incidents is a constructive route to improve understanding of and control over professional judgments and practices (Tripp, 2011).

The data analysis is based on content analysis (Krippendorff, 2018) and involves interpretations of dialogue excerpts between the teachers and researcher. I have neither utilised Generative AI tools to generate texts or performed analysis nor utilised Generative AI as a supporting tool to form ideas or elaborate on ideas, translations, copy editing, develop my analysis etc. Initially, I deductively used Goulet et al.’s (2003) distinction for collaboration (consultation, collegiality and cooperation) as categories. During the analysis, I worked abductively to further strengthen Goulet et al.’s (2003) theory of collaboration. Moreover, some of the most significant critical incidents emerged in the transcripts when the teachers described and reflected upon decisions in the teacher-researcher collaboration of the design and implementation phases of the student project. I therefore regard critical incidents as a criterion of selection in my empirical material. These incidents were critical because they contained information that could be related to decisions regarding technology that involved professional judgments that we collaboratively had to make, which may have had an impact either on the student project or my DBR research or both.

4 RESULTS: CRITICAL INCIDENTS

4.1 *Excerpt 1: Implementation phase (iteration 1) of the original design with Anne:*

Anne described how the implementation took place and refers to the technological complexity and this can be related to the technological procedural knowledge required to maintain student progression that she had to teach. This is a critical incident because the teacher's notion of not possessing adequate technological knowledge required to teach during the implementation of renewable energy technology could influence (or deteriorate) both her teaching and/or my research.

- 1: Anne: Yes, and you were always present when you were supposed to, and you arranged the technical but at the same time you helped when it was needed.
- 2: Researcher: MmM.
- 3: Anne: And it [the help] was particularly eminent regarding couplings and the solar collector [laughs]. I just think, 'Oh my god, if I would have been alone with this equipment', that would never have worked out. Like, it was super important that you were there, and I felt we achieved an interaction when we talked with the student, too.
- 4: Researcher: MmM
- 5: Anne: It is like, you are not coming from distant outside. You are from here. And I believe that this has been good. You were not something artificial; you were like, ***you were just like a teacher!***

In line 1, Anne states that 'you were always present when you were supposed to' with the technological arrangement, and I assisted Anne when that was needed. I acknowledge Anne's statement by uttering, 'MmM' (line 2). She further explicates the reason for the importance of my presence in the classroom because of the difficulty of connecting solar cells and solar collectors (line 3). Moreover, she declares that being alone with the equipment is something she would not be able to manage, so it was important that I was present (line 3). This part of the excerpt (lines 1–3) indicates a consultation regarding Anne's perception of lacking technological knowledge. Her concerns worries were mostly related to the practical arrangements of the technology, indicating that her procedural knowledge shared in this consultation needed to be supported by my presence in the classroom.

Moreover, in line 1, she states, '... you were always present when you were supposed to, ..., you helped when it was needed', which may imply that she took me somewhat for granted during the implementation of the technology, even though we had beforehand decided that I would support her when necessary. Nevertheless, it was in both our interests that the implementation would 'work out,' and due to the cooperation and collegiality and my care for her it was not in my interest to observe Anne struggle. As a result, this decision to oversee the technological equipment and support Anne during implementation have been based on shared power during our cooperation but made me more an assistant teacher than an observing researcher. This became critical to me because my ability to observe the classroom "live" as a researcher was heavily deteriorated.

Anne's potential perception of me as an outsider drifts quite rapidly to an insider perception when declaring in line 5 "... you are not coming from distant outside. You are from here...". Furthermore, Anne states, in line 5, that '...you were just like a teacher!'. This could mean that she regarded me more as a colleague than as an outside/inside researcher because we shared power during the collaboration when we designed and implemented the student project together through co-design and joint action.

4.2 *Excerpt 2: The redesign phase of the original design with Berit:*

Berit and I talked about our joint decision to utilise instructional films. For instance, she showed the students two instructional films, given by me and not properly quality checked, about how to couple solar cells. In fact, these films were quite miserable due to incomprehensible sound, leading to misuse of student time. This excerpt may imply that the redesign phase of iteration 2 was not always a positive endeavour. Hence, the excerpt represents a critical incident because the collaboration led to unfortunate incidents in the classroom and a deterioration of my research.

- 1: Researcher: You had not quality checked the films? [laughing].
- 2: Berit: Correct! [laughing].
- 3: Researcher: So you trusted the researcher 100%?
- 4: Berit: Yes, I did. And I prepared before the project started by reading all the material [booklets] you sent me.
- 5: Researcher: We did have regular meetings each week for several weeks before.
- 6: Berit: Absolutely. I honestly must admit that there were issues, such as those instructional films; then, I just completely trusted ... eh, because the films were about coupling wires in series and parallel, was it not?
- 7: Researcher: Yes, and how much it helped the students is another matter!?
- 8: Berit: So then I fully trusted [relied on] you. I checked the duration of the films. It was the only thing I had done [concerning these films]. To be honest!

In line 1, I explicitly ask if Berit had not seen the films in advance while laughing. Berit replies that she had not by answering 'correct', also laughing (line 2). The laughing indicates that this was quite comical and perhaps a bit embarrassing. Furthermore, in line 3, I ask if Berit trusted the researcher by saying, 'So you trusted the researcher 100%?' She confirms the question by replying, 'Yes, I did' (line 4). Here, Berit appears a bit uncritical, perhaps due to collegial trust. Additionally, in line 4, Berit specifically utters that she prepared for our weekly meetings by reading all the material and booklets related to this project. Moreover, in line 5, I remind Berit of having regular weekly meetings preparing the project. Berit confirms, in line 6, by replying, 'absolutely'. Further, in line 6, Berit admits that she fully trusted us by stating, '... there were issues, such as those instructional films, then I just completely trusted ... eh, because the films were about coupling wires...'. In line 7, I confirm that the films were about couplings. These films are related to factual and procedural ('know how') knowledge concerning technology and were decided to be used during past consultations (regular weekly meetings). We did have a mutual understanding in the cooperation about using instructional films to support the students during the experimentation because we both had positive experiences with this kind of support.

Further, in line 7, I question the films' ability to assist the students, which may indicate that we had not cooperatively thought this thoroughly through, indicating a 'superficial' cooperation. However, despite having regular consultations, this excerpt may indicate that we, for instance, did not explicitly state the fulfilment and realisation of shared and predefined goals within parts of the project in advance. We did have constructive talks, but did we always listen to each other? As the researcher and co-designer of the student project together with Berit (and Anne) I cannot recall that we explicitly shared other goals than those related to teaching. If this is the case, the critical incident shown in this excerpt may therefore just be symptomatic due to an uncritical cooperation and ineffective 'consultative processes' where didactical choices, decisions and judgments about technology have not been thoroughly discussed in advance during the design of the student project. Even more, Berit's perception of my role as a researcher can have been downplayed because of me drifting from a semi-outside research position in the beginning of our collaboration to an insider research position due to strong collegiality and trust. Moreover, my own perception of me as a researcher can have been potentially (and unintentionally) forgotten (or suppressed) by the teacher within me due to collegiality and this is critical and problematic from a research point of view. Furthermore, in line 8, the teacher repeats that she trusted the researcher and admits that the only thing she checked was the duration of the films. This trust may be related to the collegiality between us. However, this can have led us both to be uncritical towards one another, neglecting our collective responsibilities towards the student project. Even more, this excerpt can indicate that the teacher perceives the insider researcher more as a colleague both during design (preparation) and implementation compared to a "stranger" from the outside that would potentially make the teacher more critical towards the researcher and the researcher's agendas and goals. Berit has also admitted to this after research where she has explained to me that she would have been far more "sceptical" towards outsiders because she does not know them.

5 DISCUSSION AND CONCLUSION

Consultations are based on mutual trust and respect (Goulet et al., 2003). A well-anchored professional relationship between me and the teachers was already established a long time before the research commenced. This solid foundation gave us the opportunity to be honest and rely on each other, hence making it easy to reveal 'truths' and flaws as we knew and experienced them regarding technological knowledge and the utilisation of technology (excerpts 1 and 2). For instance, both me and the teachers partially shared the same goals—enhanced student learning (excerpt 2)—but I was also interested in other factors related to research and outside the teachers' scope regarding their interests or competence, which can lead to potential disagreements (MacDonald, 2008), such as the researchers role in the classroom during student project implementation (excerpt 1). Teachers are meant to benefit from IR research and, therefore, can become a motivating factor for participating (Nakata, 2015). Nevertheless, teachers collaborating with an IR may hinder teachers' critical reflections concerning their own teaching practices and goals (Juuti et al., 2021). A teacher's goal can be to 'selfishly' influence the student project design to obtain a feeling of comfort due to practices of technology (excerpt 1).

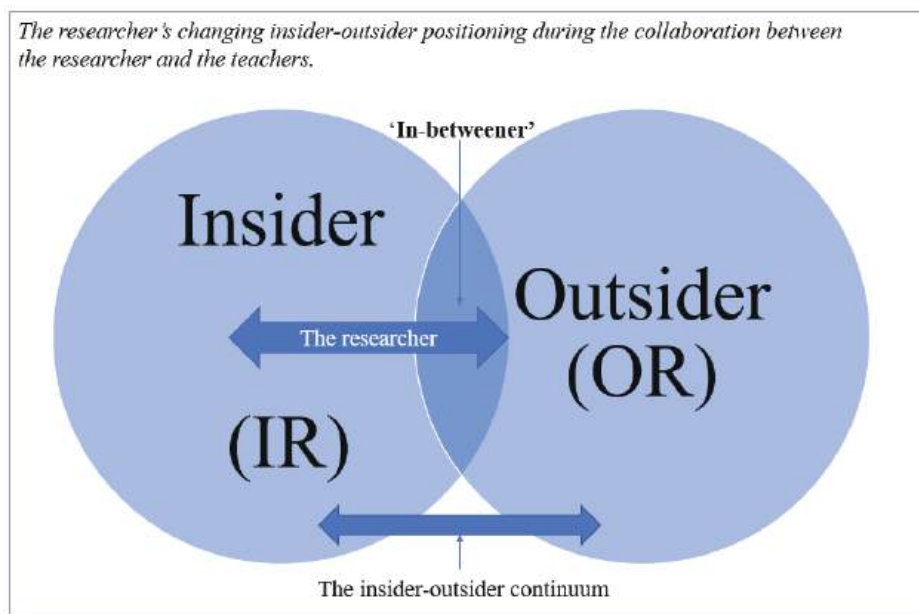
‘Taken-for-granted’ knowledge due to shared culture may influence both insider and OR (Hamdan, 2009). Collegial trust (Tschannen-Moran, 2001), may lead to episodes in which teachers ‘take for granted’ a researcher’s disposition to assist them during the collaboration. For instance, teachers may take for granted that the researcher will support them during implementations while the researcher should conduct research (excerpt 1). Or teachers may uncritically implement scaffolding which they not necessarily have quality-checked for themselves (excerpt 2). This may be related to a researcher being perceived by the teachers as an IR or perhaps just a colleague with large amount of insider knowledge.

IR provides exclusive access (Mercer, 2007). However, an insider position may make it more difficult not to assist one’s colleagues (McNess et al., 2015). Even though I was first and foremost a researcher, I was also the teachers’ colleague, which gave me special access to the research facilities. Nevertheless, special access may have hindered me in keeping a necessary researcher–teacher distance to focus on the observation of educational practices. Furthermore, lacking distance became even more obvious in the redesigning phase with Berit (excerpt 2), where our collegiality might have blurred our ability to critically scrutinise the decided technological scaffolding. This can be a result of a teacher perceiving the researcher as an insider (colleague), not necessarily as an IR. Moreover, power relation is an unavoidable dimension in an inside–outside continuum (Mercer, 2007). Co-designing and joint action implies a sharing of power between the researcher and the teachers. Nevertheless, conducting research at my own school necessitated challenges because of the collegiality between me and the teachers. However, knowing the teachers but not the teachers’ students may have contributed to outside perspectives for me as the researcher (excerpt 1). Indeed, OR enables more critical scrutiny compared with IR (Hamdan, 2009). Nevertheless, our collegiality may have hindered us in asking critical and difficult questions generally during the collaboration because of strong collegial trust during the sharing of power when we co-designed and joint action. This may have led the teachers to perceive me more as a colleague and not as an outside researcher, or researcher at all. Furthermore, my perception of the teachers as research “objects” has probably also been influenced by our strong collegiality based on honesty and trust.

In conclusion, I was a researcher with massive inside knowledge conducting research in collaboration with my colleagues (IR) (excerpts 1–2). However, I was trained outside as a researcher (OR). My research contained features of outsideness, especially those related to the students in this research. Therefore, my DBR research in general and me particularly can be positioned as an ‘in-betweener’ during educational technology research. I have drawn a visualisation of my varying researcher perspectives within an insider–outsider continuum based on the discussion.

Figure 1

A figure illustrating my changing perspectives within the insider–outsider continuum during researcher-teacher collaboration. Different perspectives depended on which phase (design or implementation) the collaboration took place where features of OR were detectable throughout the researcher-teacher collaboration



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Teachers' Conceptualisations of Spatial Ability & Implications for STEM

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Abstract

Spatial ability is a key component of STEM education, shaping how learners visualise, manipulate, and reason about objects and relationships. Despite its importance, little is known about how teachers conceptualise spatial ability and how these beliefs influence classroom practices. This study investigates Irish post-primary teachers' conceptualisations of spatial competency, using online card-sorting and spatial self-efficacy tasks. In the card-sorting task, participants classified everyday activities, such as parallel parking, assembling flat-pack furniture, and taking notes, as 'spatial', 'somewhat spatial', or 'not spatial'. The self-efficacy task assessed confidence in performing spatially demanding activities, including puzzles, map reading, and interpreting working drawings. Results indicate that disciplinary background strongly shaped conceptualisations: Engineering and Graphics teachers consistently rated multiple tasks as fully spatial, while Mathematics, Science, Technology, and Materials Technology Wood teachers applied more distributed classifications. Biology and Physical Education teachers used the full range of categories, suggesting flexible understanding. Across disciplines, subtle or traditionally gendered tasks were often under-recognised as spatial, reflecting implicit norms. These findings highlight that teachers' spatial epistemologies are influenced by disciplinary culture and task experience, potentially affecting which skills are emphasised and how students develop spatially. The study underscores the need to broaden teachers' conceptualisations of spatial ability and integrate its development intentionally across STEM curricula.

Key Words: Spatial Ability, Conceptualisations, STEM, Gender, Student Engagement

1 INTRODUCTION

This study seeks to explore the multifaceted nature of spatial ability as understood by practicing Irish second-level teachers engaged in science, technology, engineering and mathematics (STEM) education. While spatial ability is particularly prominent within Technology Education, the study intentionally adopts a broader STEM perspective in order to explore the nature and meanings of spatial ability across multiple disciplinary contexts, rather than limiting it to a single subject

domain. By capturing teachers' understandings of what they perceive spatial ability to be, the study develops a picture of how spatial self-concept relates to educational experiences and professional identity. Including teachers from across STEM disciplines also supports a broader exploration of how spatial ability is conceptualised across subject areas, providing a richer contextual lens for considering its role within Technology Education. Given that spatial ability is malleable (Sorby 2009; Uttal et al. 2013), and that it provides a foundational knowledge for learners' engagement with design, modelling, and technological problem-solving in technology education (Lin *et al.* 2025), deeper insight into this construct is essential for strengthening teaching and learning. This study therefore focuses on four research questions:

- (i) How do teachers conceptualise spatial ability?
- (ii) How do gender, age and disciplinary background affect these conceptualisations?
- (iii) How do these conceptualisations relate to their own spatial self-efficacy?
- (iv) Where are the conceptual gaps between cognitive science models of spatial ability and teacher's conceptualisations?

2 LITERATURE REVIEW

2.1 *Teachers' Conceptualisations and Spatial Self-Efficacy*

Teachers' conceptualisations of spatial ability shape how they interpret spatially demanding tasks, how they support students' spatial reasoning, and the extent to which they recognise spatial thinking as part of everyday learning. These conceptualisations are influenced by a combination of self-beliefs, affective responses, task interpretations, and professional experience (Gagnier *et al.* 2022). A central factor is spatial self-efficacy, defined as an individual's belief in their ability to successfully perform spatial tasks (Ramful *et al.* 2017). Teachers with higher spatial self-efficacy tend to conceptualise spatial ability as accessible and teachable, leading them to incorporate spatial tools, visual representations, and spatial reasoning activities more readily (Gagnier *et al.* 2022). In contrast, lower spatial self-efficacy may lead teachers to view spatial reasoning as specialised or inherently difficult, reducing their use of spatial pedagogy. Burte *et al.* (2020) demonstrated that teachers differentiate tasks according to whether spatial thinking is required, optional, or negligible for solution. Teachers who believe they possess strong spatial skills are more likely to view spatial ability as malleable and relevant across grade levels. Experience and exposure also play important roles. Gagnier *et al.* (2022) found that many teachers perceive spatial skills as more important for older students; however, teachers with more years of experience tend to view spatial thinking as important across all year levels, including the early years.

Teacher-led spatial interventions have shown that when teachers engage with structured spatial tasks, they begin to treat spatial reasoning as a routine component of mathematical thinking rather than an isolated skill (Lowrie & Logan 2023). Gender, disciplinary background, and previous experiences have also been associated with differences in spatial performance and spatial self-efficacy (Linn & Petersen 1985; Reilly *et al.* 2017). However, studies examining how teachers'

self-efficacy beliefs relate to their conceptualisations of spatial ability remain limited. Understanding this relationship is essential, as self-efficacy may guide how teachers notice, value, and respond to spatial thinking in students.

2.2 Cognitive Science Models of Spatial Ability

Contemporary research conceptualises spatial ability as a family of related but distinct cognitive processes rather than a single unified skill. One of the most influential models is the 2x2 classification scheme proposed by Uttal *et al.* (2013) and Newcombe & Shipley (2015), which characterises spatial thinking along two dimensions: whether the spatial information concerns properties of a single object, or relationships among multiple objects, and whether that information is static or changing over time. Table 1 illustrates this typology using an everyday example involving a coffee mug.

Table 1

Everyday example of the 2x2 classification scheme

Intrinsic Static	Recognising the shape and features of the mug from your current viewpoint without imagining any rotation or change.
Intrinsic Dynamic	Mentally transforming the mug, such as rotating it in your mind or imagining a cross-section to see its internal structure.
Extrinsic Static	Knowing where the mug is in relation to other objects on the desk, such as to the right of your laptop, without any movement or perspective change.
Extrinsic Dynamic	Appreciating the position of the mug relative to other objects when perspectives change, either by actually moving around the desk or by imagining yourself moving and shifting viewpoint.

These four categories highlight the diversity of spatial processes and underscore the fact that individuals often demonstrate different strengths across task types (Newcombe & Shipley, 2015). However, research shows that educators frequently conceptualise spatial ability more narrowly, often equating it primarily with mental rotation or visualisation (Hegarty & Waller 2005).

3 METHODOLOGY

In September 2025, an online survey was conducted for which ethical approval was obtained from the University of Limerick, School of Engineering Ethics Committee under the reference number 2025_07_02_S&E. The project explores how Irish post-primary STEM teachers perceive and define spatial ability. The sample included 35 teachers (20 male, 14 female, 1 non-binary) aged 21 to 54 , with a mean age of ≈ 35.1 and median age of ≈ 30 . They taught subjects such as Science, Technology, Engineering, Mathematics, Materials Technology Wood (MTW), Construction

Studies, Design and Communication Graphics (DCG), Graphics, Biology, and Physical Education (PE). The survey comprised two core items along with demographic questions regarding age and subject area.

Firstly, a *card sorting* task, originally introduced by Hulin and Katz (1935), was employed in this study to investigate how participants naturally organise spatial tasks. In this method, individuals group cards containing terms, images, or scenarios in ways that make sense to them (Chen *et al.* 2020). They were not provided with any formal framework (e.g., 2 X 2 classification (Uttal *et al.* 2013)) to guide their decisions and instead relied on their own interpretations of what constitutes a spatial task. Following Miller’s working memory framework (1956), which suggests individuals can effectively process around seven items at once, the study used seven cards to avoid cognitive overload. Each card described a scenario representing one of the four categories of spatial ability (Uttal *et al.* 2013; Newcombe & Shipley, 2015). For example, packing a suitcase neatly and assembling flat-pack furniture both involve *intrinsic* spatial processing, meaning the focus is on the relationships between parts of the same object or set of objects. However, ‘packing a suitcase neatly’ is *intrinsic static* because it mainly requires organising items based on their size and shape without mentally transforming them. In contrast, assembling flat-pack furniture is *intrinsic dynamic* because it requires mentally rotating and manipulating parts to understand how they fit together during construction.

• Choosing a photo to post online	(<i>Intrinsic Static</i>)
• Packing a suitcase neatly	(<i>Intrinsic Static</i>)
• Assembling flat-pack furniture	(<i>Intrinsic Dynamic</i>)
• Taking notes during a lecture	(<i>Intrinsic Dynamic</i>)
• Putting on makeup or moisturiser	(<i>Intrinsic Dynamic</i>)
• Parallel parking a car	(<i>Extrinsic Dynamic</i>)
• Navigating a crowded space	(<i>Extrinsic Dynamic</i>)

Although all participants received the same scenarios, their order was randomised. Participants then sorted the cards into categories such as “very spatial,” “somewhat spatial,” and “not spatial,” allowing the study to capture how individuals perceive the spatial demands of everyday activities and how they personally conceptualise spatial ability. The card-sorting task was not analysed using internal consistency statistics, as it is an exploratory categorisation method rather than a psychometric scale. Instead, its construct validity was supported by its grounding in the spatial ability framework proposed by Uttal *et al.* (2013) and Newcombe & Shipley (2015). Reliability was assessed through patterns of agreement in participants’ sorting decisions. The *spatial self-efficacy scale*, adapted from the work of Arıkan & Çetin, (2024) (Cronbach’s $\alpha = 0.77$) was used secondly, to assess participants’ confidence in completing tasks involving spatial skills (e.g., puzzles, map reading, interpreting working drawings). Responses ranged from “I certainly cannot” to “I certainly can”. The scale also aligns with the same spatial ability framework that informed the card-sorting task (Uttal *et al.* 2013) ensuring conceptual coherence across both measures. Items were randomised and presented without explicit reference to spatial ability. As an additional procedural control, the items were randomised individually for each participant, and no two items belonging to the same spatial category appeared consecutively. The items used in this task are listed in Table 2.

Table 2

The spatial self-efficacy scale adapted from Arıkan & Çetin (2024)

Spatial Self-Efficacy Scale		I can certainly do it	I cannot do it	I can do it	I cannot do it
Intrinsic Static	I can spot the difference between two photos of the same object.				
	I can distinguish between shapes such as triangle, square, hexagon, prism, cube, sphere and trapezoid.				
	I can classify objects according to their geometric shapes.				
	I can sort objects of similar sizes from large to small.				
Intrinsic Dynamic	I can make models out of paper, such as ships and aeroplanes.				
	I can mentally visualise a three-dimensional object rotated 90° to the right (e.g., a pyramid, pencil case, etc.).				
	I can mentally visualise how to assemble a toy divided into five parts.				
	When two holes are punched in different places on a symmetrically folded piece of paper, I can accurately predict where the holes will be located on the paper once it is opened.				
Extrinsic Static	I can accurately predict which surfaces will face each other when a cardboard box with surfaces numbered is folded.				
	I can read a map by looking at the legend.				
	I can calculate the difference between the local time of two different locations marked on a map.				
Extrinsic Dynamic	I can draw a political map showing the borders of my country.				
	When I sit in the front row of the classroom, I can mentally visualise how someone sitting in the back row sees the teacher's desk.				
	After a short walk in a building (e.g., a shopping centre, hospital etc.) that I am visiting for the first time, I can mentally visualise in detail what is located where in that building.				
	Once I have asked for an address, I can keep the location described to me in mind until I reach my destination.				
	I can get to a place that I am visiting for the first time by walking with the help of a navigation application on my phone.				

4 RESULTS & DISCUSSION

4.1 Data Analysis

Responses from the card-sorting task were converted into numerical scores (0 = NOT SPATIAL, 1 = SOMEWHAT SPATIAL, and 2 = IS SPATIAL), allowing mean scores (M) to be calculated. A mean of higher value indicated stronger perceived spatial demand. Activities were then ranked, and descriptive subgroup analyses were conducted for gender, age, and disciplinary backgrounds.

Spatial self-efficacy responses were scored on a 0 to 3 scale, with higher values indicating greater confidence (0 = I certainly cannot, 1 = I cannot, 2 = I can, 3 = I certainly can). Means (M), medians and standard deviations were computed for each of the 16 items.

4.2 Card Sorting

Participants showed clear and consistent differences in how they classified the spatial demands of the seven everyday activities. Tasks that required moving through space or manipulating physical objects were overwhelmingly viewed as spatial. In particular, *parallel parking a car* (M = 1.91) *assembling flat-pack furniture* (M = 1.83), *packing a suitcase neatly* (M = 1.80) and *navigating a crowded space* (M = 1.77) were each classified as “IS SPATIAL” by the majority of participants. In contrast, activities that centred on visual judgement or cognitive organisation rather than physical interaction were typically viewed as non-spatial. *Choosing a photo to post online* (M = 0.40) or *taking notes during a lecture* (M = 0.49) were most often classified as “NOT SPATIAL”. One activity, *putting on makeup or moisturiser* (M = 1.09), consistently fell between these two extremes. Participants frequently placed it in the “SOMEWHAT SPATIAL” category, suggesting that while the task requires hand-face coordination and some awareness of spatial positioning, it does not demand substantial spatial planning or three-dimensional manipulation.

The median classification score across all activities was 1.77, closely aligning with the cluster of higher-scoring activities, reinforcing that participants’ default interpretation of *spatial* emphasised bodily movement, object manipulation, and navigation in physical environments. At the same time, the substantial gap between the lowest (0.40) and highest (1.91) mean ratings demonstrates clear differentiation in how participants conceptualised spatial demands. The intermediate classification of makeup application further suggests that participants recognised gradations of spatial effort rather than treating spatiality as a binary distinction.

Overall, the pattern of responses demonstrates that participants intuitively organised the activities along a spatial continuum. ‘Strong’ spatial tasks involved physical movement or manual handling, whereas ‘weak’ tasks relied more on visual preference or symbolic processing, and ‘intermediate’ tasks sat between these poles. The median value provides additional support for this continuum, showing that most activities were judged to involve at least some spatial thinking, even if the nature and intensity of those demands varied.

4.3 *Spatial Self-Efficacy*

Spatial self-efficacy was generally moderate to high, with scores ranging from 1.89 to 2.86. The strongest self-efficacy appeared in sorting objects by size ($M = 2.86$), navigating with a phone application ($M = 2.86$) and identifying geometric shapes ($M = 2.83$). These reflect strong confidence in perceptual and everyday navigation skills. The lowest self-efficacy was observed in map-based analytical tasks, including calculating time differences between locations ($M = 1.89$), retaining multi-step directions ($M = 1.94$), calculating distances on maps ($M = 2.06$). These tasks require spatial computation and topographic reasoning, for which participants reported lower confidence.

Standard deviations (0.35 - 0.90) indicated moderate variability, with greater disagreement for items involving mental transformation and map interpretation. The median self-efficacy score across all items was 2.34, indicating that the typical response fell within the moderate confidence range. Overall, confidence was higher for perceptual and navigation tasks than for abstract map-based tasks.

4.4 *Cross Task Alignment*

A clear conceptual mismatch emerged between what teachers *classify* as spatial and what they feel *confident* performing. Teachers rated their highest self-efficacy in perceptual tasks (e.g., distinguishing shapes), yet they tended not to classify parallel perceptual tasks (e.g., choosing photos, note layout) as spatial. Conversely, they strongly classified embodied, movement-based tasks as spatial, despite these being largely absent from the self-efficacy measure. These observations are based on descriptive analyses only; no statistical correlations between the card-sorting and self-efficacy measures were conducted.

Overall, teachers appear to hold a narrow, action-centred conception of spatial ability, emphasising physical manipulation while under-recognising cognitive, analytic, and visual-spatial skills that research identifies as critical for STEM learning (Wai *et al.* 2009).

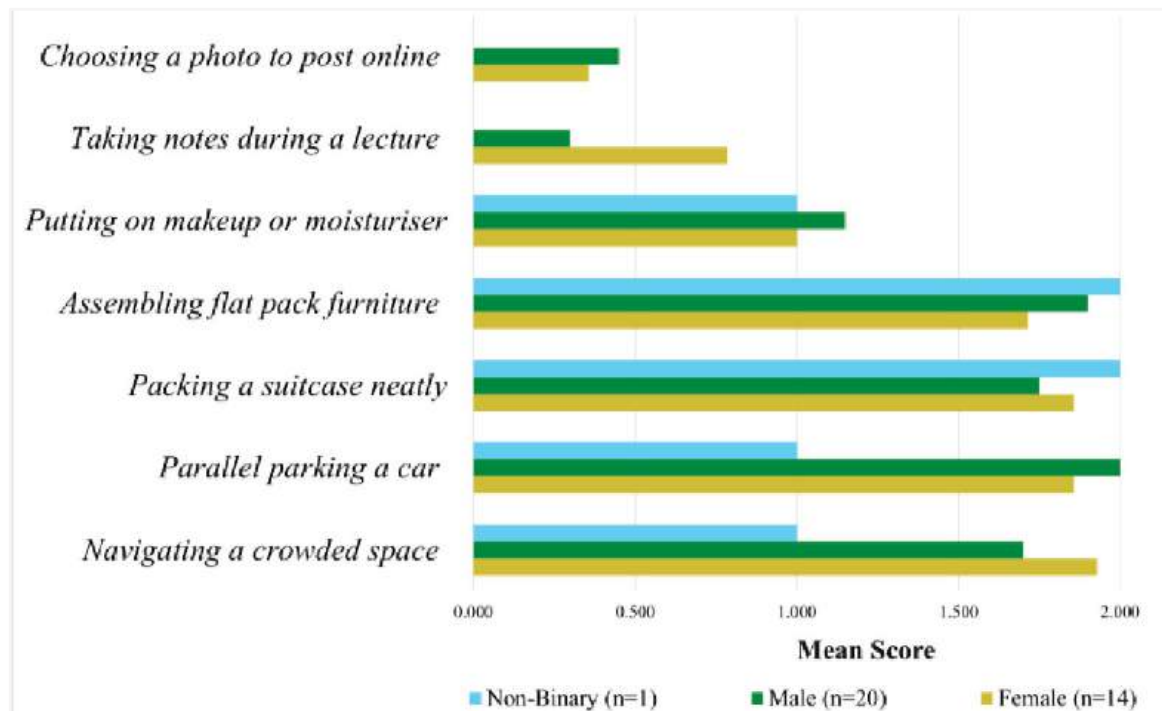
4.5 *Gender, Age and Disciplinary Background*

Patterns were broadly similar across genders, with all groups consistently classifying tasks involving physical movement or object manipulation as spatial, and perceptual or organisational tasks as non-spatial. Across the full sample ($N = 35$), parallel parking ($M = 1.91$), assembling flat-pack furniture ($M = 1.83$), packing a suitcase ($M = 1.80$), and navigating a crowded space ($M = 1.77$) were overwhelmingly rated as “IS SPATIAL”. In contrast, choosing a photo to post online ($M = 0.40$) and taking notes during a lecture ($M = 0.49$) were consistently classified as non-spatial. Modest gender-based differences reflected underlying conceptualisations of spatial ability. Male teachers ($N = 20$) rated object-based tasks most strongly, classifying parallel parking unanimously as spatial ($M = 2.00$) and assembling furniture highly ($M = 1.90$). Female teachers ($N = 14$) more readily identified socially embedded coordination tasks as spatial, with navigating a crowded space receiving their highest rating ($M = 1.93$) and showed greater recognition of

makeup/moisturiser application as spatial ($M = 1.00$). The non-binary participant's classifications aligned with these overall trends.

Figure 1

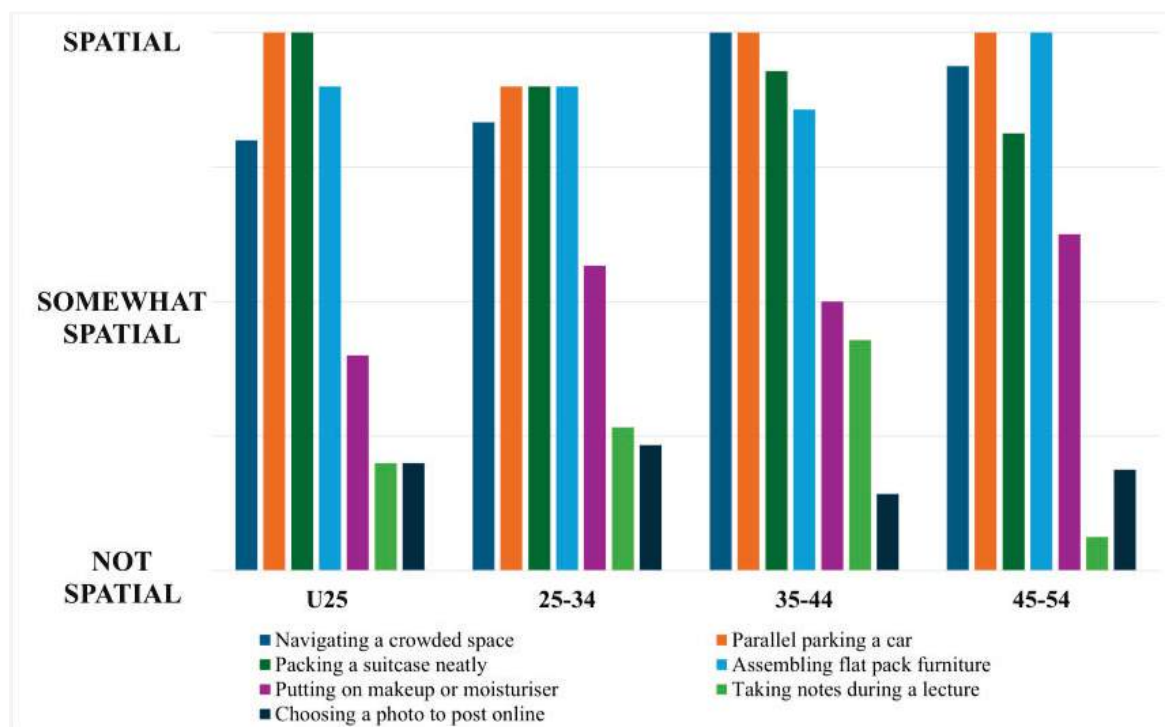
Card Sorting results organised by gender.



Descriptive analysis suggested potential age-related differences in spatial task ratings. Older teachers (35–54) made more categorical judgements, frequently assigning maximum spatial ratings to high-demand tasks (e.g. parallel parking, $M = 2.00$), whereas younger teachers (<25) relied more on the “SOMEWHAT SPATIAL” category, particularly for hybrid tasks.

Figure 2

Card Sorting results organised by age.

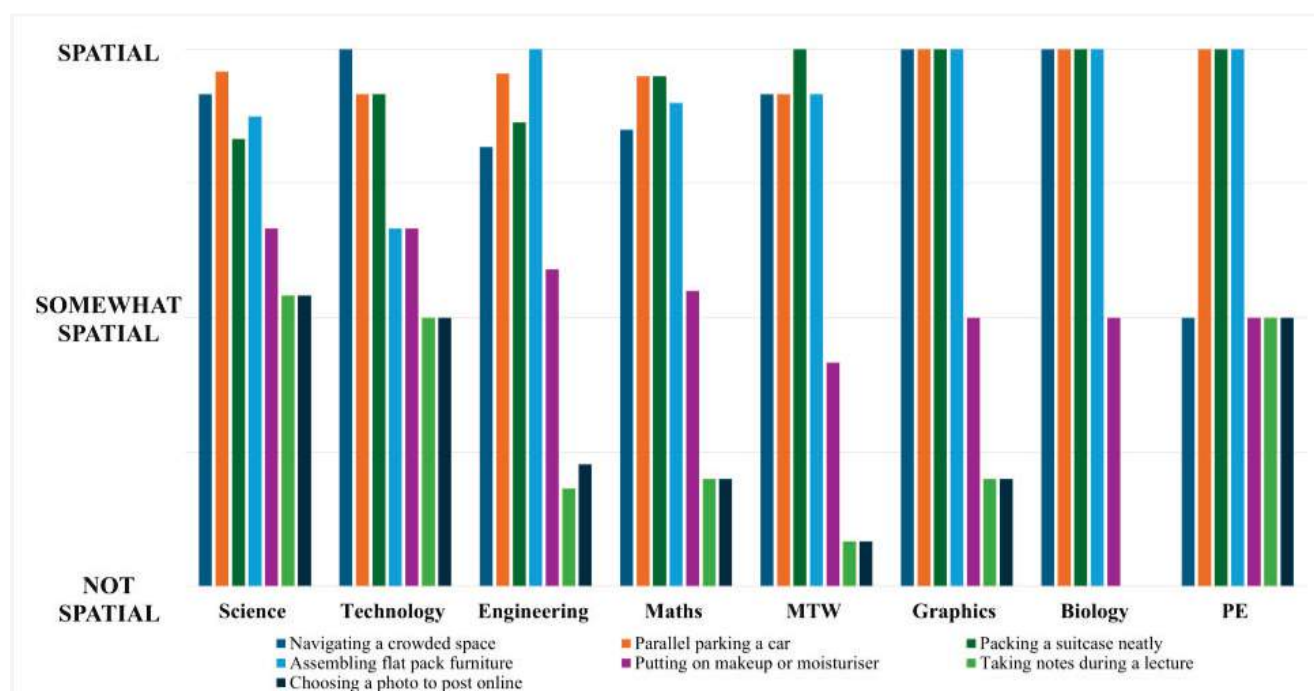


Disciplinary background exerted the most pronounced influence. Engineering and DCG/Graphics teachers rated multiple tasks as fully spatial (means frequently = 2.00), whereas mathematics, science, technology, and MTW teachers showed more distributed classifications. Biology and physical education teachers used the full range of categories, indicating more flexible spatial schemas.

However, given the relatively small sample size ($N = 35$), subgroup differences should be interpreted cautiously, as some variation may reflect sampling variability rather than meaningful differences.

Figure 3

Card Sorting results organised by discipline.



4.6 Perceived Gaps Between Research & Practice

A limitation of the card-sorting method used in this study is that categorising cards into only three groups may have constrained participants' ability to fully express the reasoning behind their choices. This approach offers limited insight into *why* teachers associated particular tasks with spatial ability, potentially oversimplifying complex conceptual understandings. Teachers in this study primarily associated spatial ability with overt physical movement and object manipulation. As a result, cognitive and analytic aspects of spatial reasoning received limited recognition. Tasks strongly linked to STEM achievement, such as visual comparison, map reasoning, and mental transformation, were rarely identified as spatial in the card-sorting task. These findings suggest a gap between research-based conceptualisations of abstract spatial skills and classroom recognition, highlighting the value of future interviews or qualitative methods to explore teachers' underlying reasoning and conceptual frameworks more deeply.

4.7 Implications for Practice

The results of this study suggest that teachers' understandings of spatial ability privilege physical manipulation and navigation, while abstract spatial processes such as visualisation, map reasoning, and diagram interpretation are less consistently recognised. Subtle differences related to gender, age, and disciplinary background further indicate that implicit norms shape which spatial skills are acknowledged in practice. These patterns have important implications for technology education. When abstract spatial demands are not explicitly identified, instruction

may place disproportionate emphasis on hands-on activities, limiting students' opportunities to develop representational and analytic spatial skills that are central to technological problem solving and STEM learning more broadly. Strengthening teacher education and curriculum design to broaden conceptions of spatial ability, and integrate perceptual, cognitive and representational spatial skills, can support more balanced learning opportunities and help ensure that diverse forms of spatial competence are recognised and valued.

5 CONCLUSION

This study shows that teachers tend to view spatial ability in terms of physical manipulation and navigation, while abstract skills such as map reasoning, diagram interpretation, and aspects of visualisation are less consistently recognised. Elements of mental rotation and other perceptual skills are generally acknowledged but not considered as central as embodied tasks. These conceptualisations, influenced by gender, age, and disciplinary background, create a mismatch between what teachers perceive as spatial and the skills they feel confident using. Including teachers from across STEM disciplines highlights how spatial ability is understood differently across subject areas, revealing diverse perspectives that can inform teaching practices. These differences have important implications for STEM education, as without recognition of abstract spatial skills, students may have limited opportunities to develop the full range of abilities critical for success. Enhancing teacher education and curriculum design by emphasising the multi-dimensional nature of spatial competency, integrating representational and abstract tasks, and using validated spatial activities that explicitly make students aware of the skills they are applying can help address these gaps. This approach fosters more diverse and effective learning experiences, supporting the development of spatial competency across all STEM disciplines.

6 DISCLOSURE STATEMENT

The title of this paper was generated with the assistance of ChatGPT. All other content is original and created without AI assistance.

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Exploring the Participation of Students with Additional Educational Needs in STEM Education: A Scoping Review

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Abstract

There is growing interest in supporting neurodiverse students and those with additional educational needs (AEN) through inclusive practices. While differentiated approaches are essential in the teaching, learning and assessment of all subjects, there is a scarcity of research targeted at how technology education can be adapted to meet the needs of students with AEN.

This paper is situated within a larger study which seeks to inform the pedagogical approaches to supporting the inclusion of students with AEN in technology education at second level. To achieve this there is a clear need to review the existing body of evidence investigating how students with AEN and STEM education are supported, with a particular focus on technology education. Much of the existing research suggests that there are limited studies highlighting research informed pedagogical strategies to cultivate the capability of students with AEN. In addition to this, although there is some evidence to suggest that students with AEN, in particular ASD (Autism Spectrum Disorder), have an aptitude towards creativity and high degrees of empathy, very few studies have explored the methods to support the development of these aptitudes. To address this gap in our understanding, this paper presents a scoping review to synthesise the existing research in the field, exploring the support of students with additional needs in STEM/Technology education. This paper aims to inform future research by highlighting current evidence of inclusive practices to make suggestions for the development of pedagogical practices to support students with AEN.

Key Words: Additional Educational Needs, Technology Education, STEM Education

1 INTRODUCTION AND LITERATURE REVIEW

Participation in technology education cultivates technologically capable students to develop competencies to support 21st century skills, the foundations built in STEM education can influence future progression (Fisher et al., 2021), developing skills applicable in wider society

and living (Sari et al., 2023). It should also be considered that students with additional educational needs (AEN) are capable learners, who can make academic and social progress alongside their peers, as capability is not limited by disability (Woolfson, 2025). Inclusion of students with AEN is considering that learners needs are met in a way that allows them to participate meaningfully, rather than to be marginalised (Rice et al., 2023), recognising the potential and capability of all learners, given the removal of barriers and implementation of suitable supports (Shevlin & Banks, 2021). When provided well planned learning experiences, AEN students can engage more deeply with STEM learning (Hutchison & Barnard-Brak, 2025), as students with AEN are capable contributors, not just passive participants.

Contemporary perspectives on students with AEN are evolving from viewing students through a deficit lens, emphasising limitations, towards a more positive, strengths-based recognition. Highlighting that students with AEN exhibit unique attributes that can hold much benefit to their enjoyment and success within STEM experiences (Kouo et al., 2021). There has been a growing interest in STEM education in recent times, due to the ever-increasing discourse within education and society (So et al., 2022). There are many benefits for students with AEN to gain from engaging with technology education, as often they are enabled the opportunity to develop their existing knowledge and skillsets through participation in active, open-ended challenges and hands on projects (Riccio & Martin, 2022). Skills gained in engineering, design and technology, such as problem solving, communication, and peer interaction, can translate to many other contexts, including real world application, both socially and behaviourally (Kouo et al., 2021; Riccio & Martin, 2022). Such that if students are provided with the appropriate educational environment, students with AEN can flourish (Bargerhuff, 2013).

Notably, attention must also be drawn to the gap in existing literature, as students with AEN remain underrepresented in literature on STEM and technology-based education (So et al., 2022). Although, there is a growing interest in supporting students with neurodivergent needs, and there are calls to support the inclusion of students with AEN in learning STEM content, there is minimal pedagogical guidance to support this endeavour, especially within technology education. There are limited studies that explore research-informed and evidence-based strategies to cultivate the development of students with AEN in technology education. To that extent, little is known about the potential of technology education environments and activities for students with AEN, highlighting the need for further investigation into inclusive practices that support AEN students in technology education classrooms, gathering such information holds the potential to drive changes to enhance AEN student experiences (So et al., 2022). This study aims to review and synthesise current literature addressing the inclusion of students with AEN in Technology education.

2 METHOD

A scoping literature review was conducted to gain an insight into existing literature to identify the current scope of research conducted into the inclusion of students with AEN within STEM education, with a focus on technology education. A scoping review was selected as this type of review is adopted when addressing an emerging field, with the intent to map available evidence and research conducted (Peters et al., 2020), leading to the identification of knowledge gaps. The

framework of Arksey and O'Malley (2005) was adopted to conduct this review, following the recommended five stage process 1) identifying the research question, 2) identifying relevant studies, 3) study selection, 4) charting the data, and 5) collating, summarising and reporting the results.

The eligibility criteria for this review were defined by the PCC (Population, Concept, Context) framework as illustrated in Table 1. The PCC framework is recommended by the Joanna Briggs institute (JBI), as it is suited to reviews with the aim of mapping rather than assessing effectiveness, providing a robust development of the review (Peters et al., 2020). The PCC framework supported the framing of the research question of this study, namely, *“What is the current state of research about the inclusion of students with additional educational needs (AEN) in STEM education?”*

Table 1

PCC Framework Search Terms

P (Population)	AND	C (Concept)	AND	C (Context)
Student*		SEN		"STEM"
Learner*		AEN		"STEM Education"
Pupil*		Neurodiv*		"STEM Subjects"
Teacher*		"Special Educational Need*"		"STEM Activity"
Educator*		"Special Need*"		"STEM Classroom"
		"Additional Need*"		"STEM Learning"
		Disabilit*		Design*based
		Disorder*		Project*based
				Problem*based

The databases ERIC (EBSCO), SCOPUS, and Web of Science were searched for relevant literature according to the search terms, which were combined and applied to suit each database. This process resulted in 869 total papers, which were uploaded into Rayyan for eligibility screening. 353 duplicates were removed from this cohort. The remaining articles were screened by title and abstract, yielding 98 articles to be screened at full text level. 31 papers remained for analysis. The inclusion and exclusion criteria were applied to the screening process of these articles. Figure 1 and Table 2 detail these criteria.

Figure 1

PRISMA flow diagram

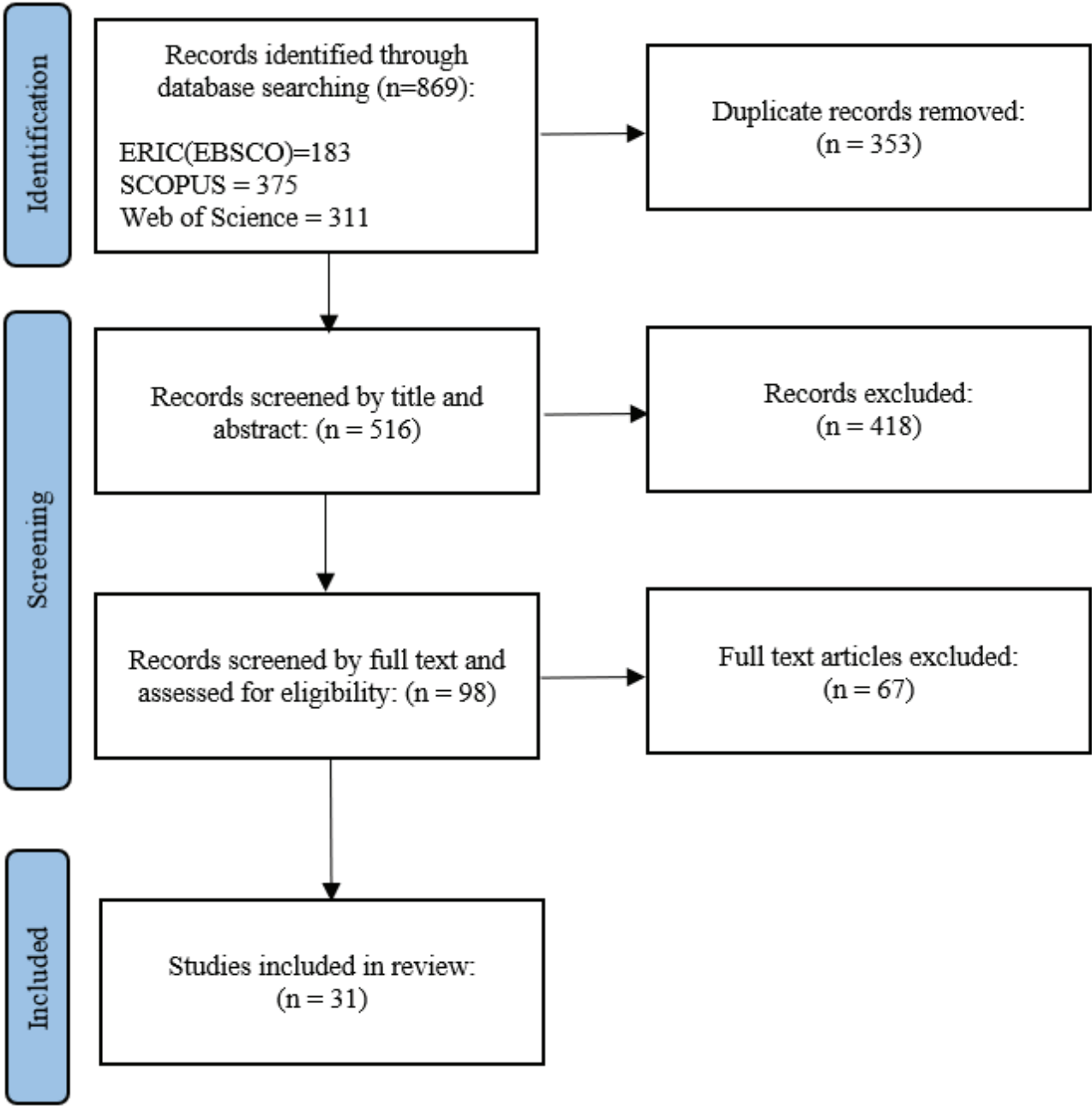


Table 2*Inclusion and Exclusion Criteria*

Inclusion Criteria	Exclusion Criteria
Written in English	Not written in English
Published after 2010	Published before 2010
Full text available	Full texts unavailable
Peer reviewed journal article	Non peer reviewed journal article
Empirical research	Non empirical research
Addressed students with additional educational needs	Does not address students with additional educational needs
Within the context of at least one STEM education discipline	Not within the context of STEM education
Within compulsory education	Not within compulsory education (e.g.: Tertiary education)

3 FINDINGS AND DISCUSSION

For the purpose of this paper, we report on key qualitative themes that came from this review, which can be broadly categorised by student and teacher. Other significant themes are beyond the scope of this paper. These findings are discussed by student level factors; student engagement outcomes, student engagement challenges and enhancing student participation. Followed by teacher level factors; teacher credentialing and perspectives, pedagogical and instructional practices.

3.1 *Student level factors***3.1.1 *Student engagement outcomes***

Research indicates that STEM based education offers meaningful benefits for AEN students, when the teaching and learning experiences are carefully and appropriately designed (So et al., 2022). This is particularly evident when the learning is orientated towards hands-on learning, as some STEM domains, including technology education, often involve engagement with tools and materials that combine experiential learning, creativity, and exploration. These experiences can afford students the opportunity to link abstract ideas to real world experiences or contexts (Sari et al., 2023). Hutchison and Barnard-Brak (2025) reported that students with AEN, including those with Autism Spectrum Disorder (ASD), respond particularly well to hands-on learning. These students demonstrated higher levels of interest and engagement through the physical

manipulation of robots, by being able to direct and adjust their actions. Students with ASD described these activities as enjoyable and motivating, and it was indicated that the students acquired basic robotic and coding skills ‘rapidly’ (Wright et al., 2019). Teacher guidance plays a key role in these learning experiences, as So et al. (2022) reported on teacher guidance through the four phases of engaging, exploring, engineering, and explaining, where students’ engagement seemed to be heightened. Hutchison & Barnard-Brak (2025) echoed these findings, stating that coding related tasks developed a sense of student empowerment, leading to deeper understanding and participation.

3.1.2 *Student engagement challenges*

Despite the recognised benefits of STEM education, students with AEN continue to be faced with barriers to full participation. They can often face academic and social exclusion, such as difficulty focusing and reduced executive functioning barriers, which may hinder their engagement and participation in STEM learning (Fisher et al., 2021). Although it is recognised that collaboration and communication are key competencies required within and developed through STEM education domains, these can prove to be problematic for AEN students. Past negative experiences, limited skill development, low confidence and ongoing fear can contribute to students’ reluctance to participating in these settings (Brecl et al., 2024). These social reservations can affect participation, particularly in learning environments that adopt largely collaborative approaches, such as problem-based or project-based learning which are often utilised in technology education. Hindered engagement can also be a result of student’s difficulties with attention, executive functioning and abstract thinking, which can be particularly evident in technology and engineering where planning, problem solving and critical thinking come to the fore (Fisher et al., 2021).

Abstract thinking can present as a significant limitation for students with AEN, including students with ASD who may be considered high functioning, experiencing difficulty within learning environments where their neurotypical peers may comfortably participate (Hutchison & Barnard-Brak, 2025). Similar experiences can be identified through the challenges some students faced in the comprehension of coding concepts and application as revealed by Hutchison & Barnard-Brak’s (2025) study, where some students found it difficult to understand abstract coding or adapt when outcomes vary from expectations. In circumstances like this, when activities become overwhelming, or when students believe they have made a ‘mistake’, So et al. (2022) reported that students can disengage when they perceive a task to be too difficult, resulting in avoidance behaviour. Planning of inclusive practices must also consider that students with multiple disabilities required constant support to continue their engagement (So et al., 2022).

Considering the range of challenges that students may face, along with the diversity of their needs, the gap between conceptual understanding and practical execution is emerging as a key challenge (Hutchison & Barnard-Brak, 2025), which is particularly prominent in technology and engineering classrooms. Instructional approaches can play a role in reducing or reinforcing these obstacles. Inquiry-based learning holds potential for students with additional needs when addressing problem solving (So et al., 2022), however without appropriate scaffolding, inquiry can fall in the boundaries of being overwhelming. Knight et al. (2019) highlights the importance of exposure to STEM related learning for students with ASD, as without opportunity, STEM

interest will not grow where they may develop personal gains through hobbies, connection with peers and post-secondary growth.

3.1.3 Enhancing student participation

Innovation in engineering and technology learning environments is especially important for students with AEN. It facilitates the meeting of student's individual needs through personalised learning opportunities including new technologies, teaching approaches and flexible methods (Brecl et al., 2024). Digital technology is gaining importance in today's society, and within our classrooms. It has the potential to enhance learning experiences, when adopted to meet the pedagogical goals and is accessible by students (So et al., 2022), as it has shown to play an active role in student enthusiasm, for all students, including those with AEN. Students with AEN report that modern teaching aids can be more interesting to engage with during class time (Brecl et al., 2024), which heightens student motivation and participation. Although digital technology is widely prevalent, there still exists some access related barriers, for AEN students, including students' self-determination, a lack of meaningful instructional strategies, and inconsistent frequency of use, which can inevitably restrict learning opportunities (So et al., 2022). Knight et al. (2019) reports that many students with ASD hold an aptitude for engaging with and effectively using digital technologies, showing potential as valuable learning tools. Knight et al. (2019) further suggests a correlation between digital technology and reduced social and communication pressure.

Game based learning (GBL) is growing in uptake as a form of digital technology, GBL supports the development of both collaboration and communication which are at the core of STEM, whilst also including aspects of competition. These elements encourage the development of emotional intelligence, decision making and heightened understanding of concepts (Brecl et al., 2024). Further to these competencies, Brecl et al. (2024) indicated that visual and graphic elements of GBL, supports students in understanding abstract concepts. Digital technology and GBL can be powerful tools in creating flexible, personalised and interactive learning environments for students with AEN.

3.2 Teacher level factors

3.2.1 Teacher credentialing and perspectives

Many studies refer to the role of teacher expertise and the impact of professional development on the successful inclusion of students with AEN in STEM education. Williams et al. (2018) poses the question about cross credentialing, suggesting that there exists a misalignment between STEM disciplinary teachers and special education teachers. STEM teachers feel unprepared to adapt to the range of diverse learners while special education teachers lack disciplinary depth or STEM content knowledge (Williams et al., 2018). The results from Williams et al. (2018) study underscores the importance of collaborative practice, as partnership between STEM and special education teachers can successfully meet the curricular goals and individual goals of students with AEN (Klimaitis & Mullen, 2021), rather than educators working in isolation. So et al. (2021) provides some evidence to validate the effectiveness of peer coaching to address these

‘confidence’ gaps between STEM educators and special educators, proving to be a key tool for professional development. Effective peer coaching suggested here moves beyond sole “in-class” observations but rather in conjunction with “out-of class” forms of peer coaching, such as co-planning (So et al., 2021). Revealing that teachers gained clarity and a greater awareness of the diverse abilities of students with AEN in the context of STEM teaching and learning environments.

Collaboration and reflection as part of professional development, can be associated with more sustained changes in practice. Along with enhancing inclusive practice, it can also shift teacher perceptions. O’Sullivan et al. (2020) noted that teacher perceptions changed after student participation with the STEM-21CLD activities, as it revealed higher levels of capacity than expected or evidenced previously by students. Students who were perceived as ‘less academic’ proved to be more capable and confident, in turn evolving teachers outlook about the competence of these students (O’Sullivan et al., 2020). Emphasising the importance of providing inclusive educational opportunities, as inquiry-based learning can support AEN students with their learning and development (Wood et al., 2024). Through these experiences, teachers expressed a sense of growth in their own motivation to develop more inclusion STEM classrooms, due to seeing such success (O’Sullivan et al., 2020). Professional development influences mindset, along with skill development.

3.2.2 *Pedagogical and instructional practices*

Approaches that rely on lecture style delivery methods, those considered to be textbook learning, are often ineffective for many students with AEN in classroom settings. The challenges associated with these methods is due to the heavy cognitive demands experienced, leading to reduced engagement with the learning experience (Taylor et al., 2018). Education is moving away from rote-learning, memorisation and test taking methods, towards innovative approaches that better support students, to promote greater engagement, participation and motivation. Innovation in teaching and learning is particularly valuable for students with AEN, as it can increase student engagement through alternative and flexible teaching approaches, heightening the quality of education received (Brecl et al., 2024).

Such practices place the students at the centre of classroom experiences, Knight et al. (2019) reported the role this had in reducing challenging student behaviour exhibited by students who are displaying a reluctance to engage. Taylor et al. (2018) echoes this sentiment in science education, as inquiry-based learning is recognised as a preferred approach. Technology education environments can too encourage students to promote deeper engagement and active learning, through a constructivist pedagogy which was evidenced through engagement with robotics (Hutchison & Barnard-Brak, 2025). Through this lens, project-based, problem-based, research-based or games-based learning may be adopted strategies, however to be effective students must be supported in their development of collaboration and communication (Brecl et al., 2024), through effective instruction, particularly for students with ASD (Knight et al., 2019). As emphasised by Taylor et al. (2018), the adoption of inquiry-based learning methods does not come without challenges, however it holds promise to enable educators to differentiate, individualise and personalise (Brecl et al., 2024), by adapting teaching and learning methods and materials.

3.3 *Insights for technology education*

The body of research in this realm is expanding with studies drawing inferences about the strength's students with AEN hold towards creativity, problem solving and empathy along with engaging more enthusiastically in activities that enable them to pursue their interests (Martin et al., 2020). Suggesting the potential of technology education experiences for students with AEN, when appropriately designed. Despite this growing recognition, obstacles remain. Such barriers can be pronounced for students with ASD, who have often been marginalised due to low expectations and ineffective instructional practices (Knight et al., 2019). However, when educators hold the understanding of student's needs and are equipped with the skills to cater for such, they are better positioned to address existing barriers and provide appropriate support (Williams et al., 2018). Mere access to educational STEM opportunities does not automatically lead to success, evidence-based techniques must be adopted to ensure long term outcomes for individuals (Michalek et al., 2020).

There remains a paucity in available research that demonstrates evidence-based models and pedagogical strategies to support the inclusion of students with AEN, in particular ASD, within technology education. Knight et al. (2019) noted that experimental studies about teaching engineering skills to students with ASD are significantly lacking, with limited research delving into engineering and design experiences for students with mild learning disabilities (Wood et al., 2024). While existing studies highlight the potential benefits of STEM experiences for students with AEN, further research is needed to explore the impact of technology education for AEN students, to address the barriers and necessary supports for meaningful participation and long-term success in technology education.

To conclude, these emerging findings suggest that while rich, hands-on technology education environments can powerfully engage students with AEN, the gains for students are reliant on intentional design that bridges the gap between conceptual understanding and practical execution. This highlights a pressing need to move beyond simply providing access to these contexts, towards the developments of robust evidence based pedagogical models that directly respond to the profiles of AEN students, to translate student strengths into sustained engagement and long-term success within technology education.

The authors did not use generative AI tools in the preparation of this work, all content is the sole responsibility of the human authors.

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Investigating the Progression of Students' Designerly Capability in Technology Education through a Grounded Theory Project

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Abstract

Technology education strives to foster active citizens who have an appreciation and understanding of the made world and the impact of the use, modification and manipulation of technology towards positive change. Being designerly has been identified as a central attribute to this shared goal, where possessing designerly capabilities will enable active participation and engagement in society. Design holds a significant position within technology education internationally and this recognition is evident in curricula and research activity, although there still exists a lack of consensus towards a shared understanding of what it means to be a designer that designs, how designing unfolds, and how designerly capabilities can be fostered.

This paper presents a point during the second phase of a grounded theory project where the central research objective is to investigate the complexities of learning through designing with the following research question: what does the progression of designerly capability look like for students in technology education? Two technology education academics with experience in design and one design education academic were theoretically selected. Unstructured interviews were conducted and analysed according to the principles of classical grounded theory, where both open coding was utilised for this initial analysis. In this paper, key findings identify the transferability of designers, the assessment barrier and the future of design education. These insights provide further focus for future data collection of this phase, to investigate the progression of students' designerly capability.

Key Words: Classical Grounded Theory, Technology Education, Design, Designerly Capability, Higher Education

1 INTRODUCTION

Design and the act of designing can be described as an essential element to technology education internationally, through growing research agendas (McDyer et al., 2022), curriculum developments, and the view that design is essential for the achievement of an innovative society (Williams et al., 2013). The purpose of technology education is rooted in exploring the impact of the use, modification and manipulation of technology (de Vries, 2016) to foster active citizens to understand and equip them to engage in positive change in the made world. At the heart of these purposes is allowing students to foster and elicit designerly capabilities through the engagement in design activities (Baynes, 2006; Stables, 2008). However, there exists uncertainties and ambiguity surrounding a consensus of how design and designing is defined, what design should look like in practice, and how it should be taught (Atkinson, 2017). This ambiguity and the intricacies of design(ing) and researching design (McDyer et al., 2023) coupled with the broad and open ended spectrum of research into design (McDyer et al., 2022) calls for further investigation into the complexity of design. Design has been a prominent topic of inquiry from 2000-2018 (Williams, 2016; Xu et al., 2020), which still continues to be today, and will continue to be a fundamental and common area of inquiry in technology education (Williams, 2017). Ritz & Martin (2013) identified that in order for the progression of the field of technology education, one of the necessary research agendas is how should design activities with intentions for concept learning be taught by teachers. However, adding further complexity to this need, one must be considerate of the varying descriptions of design as a noun and as a verb, the designer, and the act of designing, while also being conscious of the differentiation between design in a professional capacity and design within technology education (Spendlove, 2015). This ambiguity, uncertainty and ultimately complexity of design in technology education encapsulates the essence of design. Design prepares students for the future, which of course nobody can define, but through design and designing the future can look free and open to indefinite manipulation (Mitcham, 2001), making further investigation into design(ing) a prominent need for technology education.

This paper presents findings from an on-going classical grounded theory (CGT) project where the main research question is to investigate the complexities of design in technology education. The first phase of this project identified how design is enacted in practice within Irish technology education, and demonstrated that design is complex, intricate and that teachers more strongly value supporting students engaging in design activities compared to strictly teaching about design theory and design processes (McDyer et al., 2024). The results from the first phase led to the identification of a core category ('designer') for further focused investigation in this current phase presented in this paper. The iterative relationship between data collection and data analysis within a CGT methodology (Walker & Myrick, 2006) allows this paper to present an insight into initial findings during this phase. This phase focuses on the following research question, 'what does the progression of designerly capability look like for students in technology education?'.

2 METHODS

The methodology chosen for this research is classical grounded theory, founded by Glaser and Strauss (1967). This methodology utilises an iterative approach whereby data collection and

analysis takes place simultaneously and merges the qualities of quantitative research's rigor with the depth and richness of qualitative research (Walker & Myrick, 2006).

2.1 *Participant Selection*

Theoretical sampling was employed to identify participants that had potential to be included in the data collection, allowing this stage of data collection to be in-line with the initial concept and theory discovery that has taken place from the first phase (Glaser & Strauss, 2017). The identified group for inclusion in sampling were academics within the field of technology education or design education, that have a research focus within the remit of design or designing. Attaining a broad international perspective was also part of the inclusion criteria, where participants were included from various countries around the world. At this current stage of the project, only three participants' data have been included in this paper as this is an on-going study.

Participants included in this paper were two academics within technology education (one male from the United Kingdom and one female from Sweden) and one male academic from design education (from the United Kingdom). They had a varying range of experiences within research and as educators, with varying undergraduate degree backgrounds.

2.2 *Data collection*

Online unstructured interviews were conducted on Microsoft Teams by the principal investigator and ranged from 35 minutes to 64 minutes in duration. The unstructured nature of the interviews was to limit researcher bias and to allow for open directional influence of the participants' experience on the data collected. However, this phase of the project was directed to explore the core category identified within the previous phase with more focus, which is the category of 'designer' (McDyer et al., 2024).

2.3 *Researcher Positionality and Ethical Considerations*

Full ethical approval was granted by the supporting university, and anonymity has been ensured through providing each participant with a pseudonym and storing data in a password protected storage system. Only the principal investigator conducted the interviews for this study and has an undergraduate degree in technology education and is currently a PhD student in this field, which supported the development of a positive rapport with the participants from a similar background. The unstructured interview design allowed for a conversational style approach between researcher and participant, which supported the gathering of insightful data. It was made clear that the participant could withdraw at any stage of the interview or remove their data up until 2 weeks post interview. The frequency of codes identified within the data is not used as an indicator of validity or importance, compared to less frequent codes. Finally, the researcher's bias and preconceptions were managed through memoing, reflexivity, and a recognition of the influence this could have on the data collected.

2.4 *Data Analysis*

Data analysis was aligned with the classical grounded theory methodology, where open coding was conducted for this stage of the project, as described by (Kenny & Fourie, 2015). The software NVivo was used to support coding. Biases and preconceptions of the researcher were identified and separated from the study particularly during data collection and analysis. Memo writing and reflexive journaling (Steltenpohl et al., 2024) were implemented before and after interviews, and during the data analysis stage to support this, and to ensure accurate interpretation within data analysis, and to note any key insights that provide rich data for consideration. Constant comparison has been used between the data collection and open coding processes to compare and contrast with each interview's data. After each interview, the associated transcript is openly coded to allow the researcher to become familiar with the data, the codes being generated and the emergence of the core category.

3 FINDINGS

As this data collection is still on-going, the findings section only presents the open codes that have been identified from the transcripts and are not grouped conceptually or categorised. The codes offer insight into the complexities of design, designing and designer. Direct quotes have been taken from the transcripts and the name in brackets refers to the participant's assigned pseudonym to ensure anonymity.

Despite 'designer' being identified as the core category during the analysis of phase 1, there was a lot of discussion regarding design and designing as well as the activity of the designer during interviews. Therefore, from initial analysis all codes presented below do not fall into the core category of 'designer' but are valuable findings worth describing within this paper.

3.1 *Design is not formulaic... but it can be*

This is a combination of 2 codes that have been identified within the data. The first code labelled 'design isn't formulaic' refers to the nature of design being free from structure, procedural steps and methods, whereby the person engaging in design will go through their own interpreted process, as best they see it to come towards a final design solution, independent and free from a formulated procedural design process.

"But also reflecting that the things that we're showing on the slides, like the double diamond, are not real processes. They're kind of a suggested... in an idealized world, if you look a bit squinty eyed, fuzz things up, you will get some kind of process like this overall, but really the important bit is the going out and coming back in and going out and coming back in and doing that multiple times" (Hugh).

Secondly 'design can be formulaic' is a code from the data that refers to the possibility of design being formulaic, through following curated steps, a specific process to design or by allowing the assessment criterion to determine the process. Participants refer to the formulisation being

through assessment driven approaches and the challenges of implementing design in classroom practice,

“it [designing] has become more formalized, it tends to be being led by assessment” (Frank).

3.2 *Assessment can be a barrier to design*

The assessment approaches, the use of visible criterion and grading rubrics have been identified as placing a limiting factor on true designing. The fluid, free moving and personal expression of students’ designs and design processes can be prescribed and formulated into a procedural set of steps based on the criterion that their work will be assessed on. Often referring to the design portfolio being a polished structure of designing, although with the intent to capture each students’ design processes, it can ultimately be used as a deductive design process. However, the awareness of the assessment barrier to design is supported by the difficulty and ambiguity as to what are the most beneficial assessment approaches to be used, that do not take away from true design.

“How the design process is experienced is the assessment criteria, particularly when you think about upper secondary and post 16 where they're working towards an examination. And quite often you find that the design process is framed by the assessment” (Frank).

3.3 *Where does optimal learning take place?*

This code presented asks the question about where the optimal learning point along a design process is. Participants talk about the need for self-reflection along a design process to fully understand the intricacies of design, and others identify the use of design theory to build a body of awareness of the complexities of the variable processes in designing. Participants identified a pivot away from the finalised design product being the encapsulation of learning, towards a focus on the ‘why’ or the meaning of the process towards the outcome.

“I discuss that a lot with my students too, how to make the technology education meaningful and not put all the focus on the making” (Grace).

3.4 *Future of Design Education*

Key data that formulated this code identifies the need for supporting the implementation of open and creative design tasks for students in classroom practice. The current constraints to this are through the necessity of curriculum development, time allocation and teacher professional development, among others. These implementation challenges can often discourage intentionally open and ill-defined design tasks to become closed, prescribed and formulaic to allow engagement and realisation in the classroom. The complexities of allowing the students to be autonomous and to be engaging in uncertain or ill-defined design tasks require a deeper investigation into design theory and processes, and pedagogical approaches to support this.

“I think that's one part that I wish I could put more time on, to teach them how to be creative” (Grace).

3.5 *Design is to be comfortable in uncertainty*

A common trend across interviews was that of the need for students to be comfortable within uncertainty and to be confident in their own self-belief. It is discussed how engaging in design tasks bring different hurdles, challenges and unknowns which amount to uncertainty, so it is identified that students must develop their comfort in being uncomfortable in these moments.

“To give them as much kind of confidence to tackle the other areas which are more uncertain” (Hugo).

3.6 *Transferability of Designers*

It is frequently discussed that design within different contexts and disciplines such as product design, engineering design and artistic design are vastly different due to the context specific skills, knowledge and experience that is required to successfully design within the associated context. What this code refers to however, are the elements of the designer that are transferable to any discipline and any context. A range of cognitive skills, meta skills, being a design thinker and the necessity of representational skills are some elements of a designer and have been identified as being transferable across disciplines and contexts.

“Many of the cognitive processes and like coordination processes are the same, the kind of responding to contexts, engaging with humans, engaging with technology. There are many parallels” (Hugo).

3.7 *Design is teachable and learnable*

A consistent element across the data is that it is possible to teach and learn to design. Students can have varying starting points in relation to their skills and abilities but there is no identification of unlearnable traits of a designer. A frequent identified element within the data is that creativity is learnable and teachable, that there are tools to support creativity, and the development of this skill. There exist differentiating levels of creativity that students can engage in, dependent on the uncertainty of the design activity, the guidance from the educator and the use of supporting tools and methods.

“I would say that all students can design but, we have to assess them, grade them. So there is some difference and some students or humans are better at finding solution(s), but I think you can train that ability as well” (Grace).

3.8 *Development of Meta Skills*

Discussed in this code is the necessity and intent of current design practices to develop and foster meta skills to enable lifelong learning. A frequent skill identified is the ability to reflect, ultimately developing towards a reflective practitioner which enables the student to understand the ‘why’ of a design process and activity in order to apply this to other scenarios and contexts never experienced before. The uncertain nature of design demands that students can be confident in

their ability to engage in never seen before scenarios through the development and fostering of meta skills. It is frequently identified, how engagement in a design process can support the fostering of said skills for lifelong learning.

“So my focus is really on like meta skills” (Hugo).

3.9 *Developing understanding of design*

The participants shared the journey that their understanding of design, designing and the implementation of design activities and tasks have developed throughout their career. This code refers to the progression of the field of design research and the impact that it has on academics within the area. Insights to this code include, participants sharing the progression of their understanding of design as they developed as academics and their journey to become experts within their field.

“I've got a more nuanced and a more theoretical understanding of design now as an academic” (Frank).

3.10 *Trapped in a process*

This code refers to the participants describing how students can become trapped within a design process, particularly when the students perceive that there is a predetermined process to consider. The entrapment is described as the result of engaging students in design activities that follow a particular design process or processes, and so the moment that the student gets fixated on a design, struggles within a certain element, they find it very difficult to overcome this to design a successful solution to the task.

“when I was younger, I suppose I felt more trapped by, well, there's the double diamond and then there's stage gate and then there's agile and then there's design thinking... I'm much more confident to look at the more like underlying mechanisms and that essentially all of these models are specific embodiments of underlying ideas” (Hugo).

4 CONCLUSION

A limitation to this paper is the small participant sample size, therefore the associated findings are not representative of the potential findings of this project. They represent a point in the process of the on-going project, to consider the initial findings and also to illustrate the iterative relationship between data collection and analysis that takes place simultaneously through this methodology. It must also be recognised that there are a multitude of codes presented in the findings that is indicative of this stage of this phase, but during the final stages of data analysis these codes and future ones will be grouped conceptually to a greater level of abstraction that will support the identification of an emerging theory.

From these initial conversations with experts within the field, confidence is seen within the remit of design being teachable and learnable, where being able to successfully design can be enhanced and fostered, and that there exist transferable skills across design contexts, ultimately fostering a whole designer, independent of time or place. Recognition towards the possibility of enhancing all students' design capabilities in technology education elicits a positive bright future for design education, ultimately making our field which sees design as a main contributor, being accessible to everyone. However, with the identified need to further enhance current pedagogical practices and make applicable the expert, tacit knowledge, top-down understanding of design theory to a more open and available level.

It is clear there is a wide-ranging complexity to design, designing and designer identified from these initial findings. Ensuring design's true nature of being free, autonomous and uncertain can provide difficulties and challenges for implementation into curricula and classroom practice. The potential of design becoming formulaic may result in students becoming trapped in a design process, not being equipped with dealing with uncertainty in design and limiting their transferability across disciplines and contexts. Williams (2000) described there to be no simple generalizable process to designing or how to teach it, which is consistent with the key findings discussed within this paper. However, what is also consistent from these findings and existing research (Hennessy & McCormick, 1994; Williams, 2000) is the problematic relationship between design and its appropriate assessment approaches. When design activity is valued to be uncertain and ill-defined but is still described to be manipulated to become defined, prescribed and closed within current assessment approaches, raises the concern as to what has progressed to reduce or resolve this issue over the past two decades. The complexity of this issue is evidently significant, but it is not unknown. One avenue of investigation uses adaptive comparative judgement which points positively towards a resolution (Buckley et al., 2020; Seery et al., 2012), however it is not yet widely adopted in practice. Will assessing design always provide core challenges to preserving design, and will this and other complexities of design always induce strain on the involvement of true design in technology education?

As this is an on-going study utilising the principles of a classical grounded theory methodology, there is a limited reference to literature and theoretical relationships to previous research conducted. Continuation of data collection and analysis using constant comparison, selective and theoretical coding, and the engagement of participants from a range of varied experiences and geographical contexts, will support the investigation of progressing designerly capability in technology education and ultimately the complexity of design.

Disclosure statement: Please note that there was no use of generative artificial intelligence (AI) tools to conduct this research or write this paper presented.

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Technologies in Scotland's Curriculum for Excellence 2011-2025: From "Time for Change" to "Time for Action!"

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Abstract

Scotland stands at a pivotal moment for Technological education. Fifteen years after the introduction of Curriculum for Excellence (CfE), and McLaren's musings in *Time for Change?* (2011), Scottish Technological education, particularly Craft, Design, Engineering and Graphics (CDEG), is experiencing persistent decline in uptake, workforce capacity and disciplinary visibility. This paper argues that these trends reflect not curricular irrelevance, but systemic neglect: a prolonged absence of curriculum stewardship, misalignment between assessment and practice-based learning, and erosion of professional and research infrastructure.

Drawing on Scottish policy developments, national reviews and sector analyses since 2011, the paper examines why CfE's promise of transformational change in technological education has remained largely unrealised. It situates current reform efforts, the Curriculum Improvement Cycle (CIC) and the Education (Scotland) Act 2025, as an unprecedented opportunity to address these long-standing weaknesses. The analysis identifies three interrelated insights: that CDEG's decline is systemic rather than pedagogical; that the current reform creates genuine opportunity for renewal; and that meaningful progress depends on workforce stability, coherent qualification design and the rebuilding of subject voice and research capacity.

The paper positions Scotland as a case study in the limits of curriculum reform without sustained professional infrastructure and invites the PATT community to engage critically with this reform moment as an opportunity for Technological education internationally to ensure that Technological education's "time for change" has come and now we must see a "time for action".

Key Words: Curriculum for Excellence, Design and Technology, Scotland, Transformational Change

1 INTRODUCTION

When McLaren wrote *Technologies in Scotland's Curriculum for Excellence: Time for Change?* (2011) she captured a moment of profound uncertainty within Technology departments across Scotland. Curriculum for Excellence (CfE), newly introduced at the time, was heralded as a potential vehicle for “transformational change” (Priestley, 2010, p. 25), yet teachers expressed deep concern about what this transformation would mean in practice. More than 15 years later, those concerns remain unresolved and are once again brought to the surface with the current Curriculum Improvement Cycle (CIC).

This paper argues that Scottish Technological education did not experience “transformational change” but, instead, stagnated. Crucially, the findings suggest this failure was not attributable to curricular irrelevance or pedagogical weakness, but to systemic conditions which constrained implementation: the absence of sustained curriculum stewardship, erosion of workforce capacity in terms of numbers and professional learning and the diminishing presence of a subject voice and research culture. These factors have limited the realisation of CfE’s ambitions despite continued policy affirmation of the importance of Technological education.

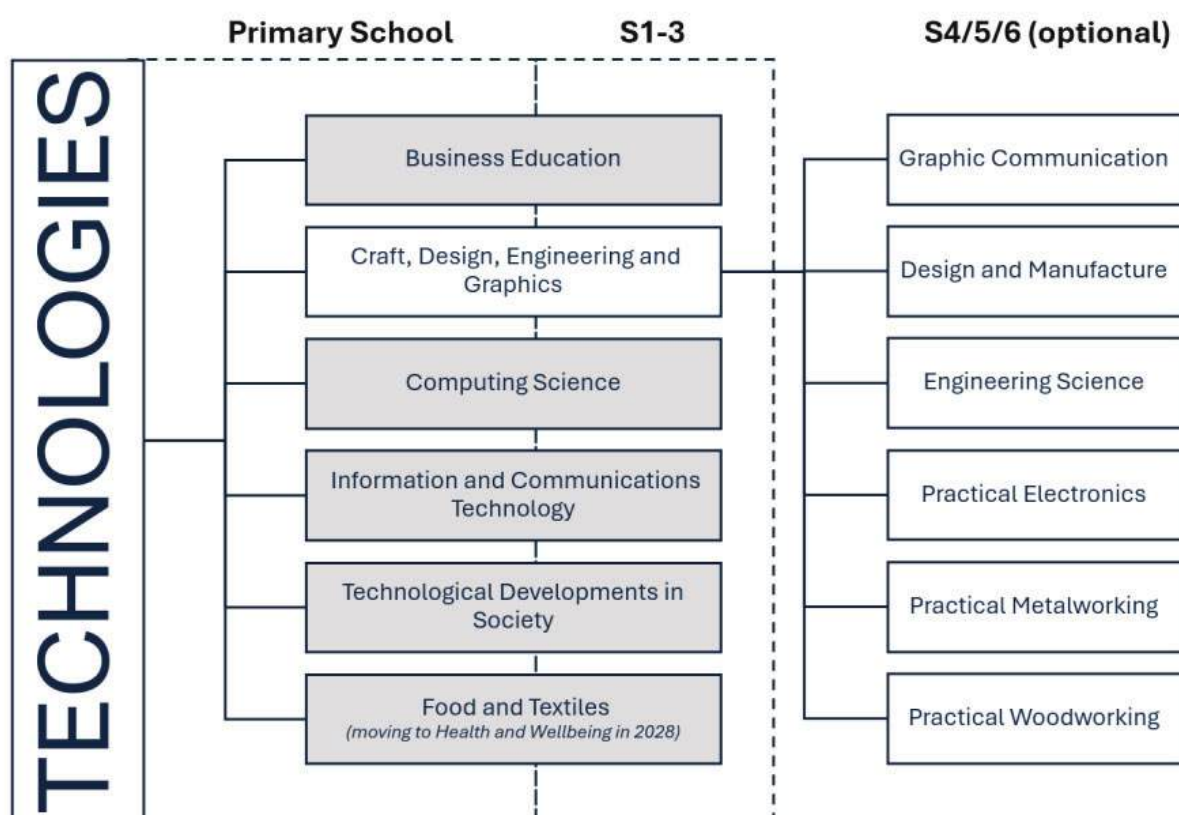
This paper is situated within the current reform context shaped by the CIC - the most significant restructuring of Scotland’s curriculum since CfE’s inception and creates an institutional mechanism capable of addressing the long-standing structural weaknesses identified in earlier critiques. The central question this paper addresses is therefore not simply whether CfE’s aspirations were unrealistic, but what lessons can be learned to seize the opportunity offered by the CIC to move from unrealised ambition to sustained improvement within Technological education.

2 CRAFT, DESIGN, ENGINEERING AND GRAPHICS (CDEG) IN SCOTLAND

Scottish schooling is organised into two major phases: the Broad General Education (BGE), spanning approximately ages 3 to 15, and the Senior Phase (15-18), where learning is largely structured through National Qualifications (Figure 1). The BGE phase spans the entirety of Primary school, where learners experience eight curricular areas with specialisation beginning upon transition to secondary school, around age 11, where learners continue their BGE, albeit with teachers registered as subject specialists. At this stage the Technologies area separates into distinct subject areas which includes Computing Science and Technological Education, often referred in documentation as Craft, Design, Engineering and Graphics (CDEG).

Figure 1

An illustrative overview of CDEG education in primary and secondary school in Scotland



Within the BGE, CDEG provision is developed locally by departments and aspires to introduce learners to a range of technological concepts, skills and knowledge, however many schools “... fall far short of delivering children’s full entitlement to Technologies” (Education Scotland, 2014, p. 10). In contrast, the Senior Phase frames learning primarily through the Scottish Qualifications Authority (SQA)’s national courses, with no mandatory courses of study.

CDEG is a pedagogically rich but structurally fragile subject area. Its learning relies on iterative design processes, material practice and the development of tacit knowledge, all of which require specialist expertise, appropriate workshop facilities and sustained technical support and professional development. This dependence on skilled staff and school infrastructure makes CDEG particularly vulnerable to fluctuations in workforce capacity and resourcing. Recognising this inherent fragility is essential for understanding the subsequent debates regarding recruitment, curriculum coherence and the extent to which current reforms, including the CIC, can address the longstanding systemic conditions that have constrained technological education in Scotland.

3 METHODOLOGY

This paper adopts a narrative review methodology, drawing on policy documents, national reviews, workforce statistics and published research to identify and examine the systemic conditions shaping CDEG education in Scotland between 2011 and 2025 and to suggest areas of focus which would support the current reform from continuing the inertia CDEG appears to have experienced. Narrative reviews allow for the integration of heterogeneous evidence sources and support interpretive analysis of complex policy environments, which, given the marked contraction in scholarly representation in Scotland, renders this approach appropriate. The extent of this scarcity was illustrated when targeted searches for peer-reviewed research on Scottish CDEG were conducted across major academic databases using combinations of terms related to technology education, curriculum and secondary schooling in Scotland for the period 2015–2025. Whilst such searches cannot capture all forms of professional knowledge production, they provide a reasonable indication of the visibility of peer-reviewed research within the field. Within these constraints, the results are striking: Since McLaren’s final published contribution in 2015, only one peer-reviewed journal article was identified that focused explicitly *on* Scottish secondary CDEG education (Hart-Anderson & Holme, 2023) although there is research emerging *from* Scotland re: Technological education (see Morrison-Love).

Given the limited volume of peer-reviewed research specific to Scottish CDEG, the review also incorporates reputable media reports where appropriate to provide timely evidence on workforce trends, recruitment pressures and professional discourse.

No artificial intelligence tools were employed at any stage of the research. All data collection, interpretation, drafting and editing was conducted solely by the author.

4 FINDINGS

This paper does not consider qualification and assessment reform, which sits outwith the CIC and is the subject of substantial ongoing work in response to the recently passed Education (Scotland) Act 2025. It would be remiss not to acknowledge its importance in light of evidence demonstrating a 60% reduction in the number of entries for Technological subjects since the introduction of CfE (Shapira et al., 2023) however the scale of this influence warrants a separate paper. The findings below focus on the structural conditions which are not already the focus of explicit interventions.

4.1 *Workforce Capacity: Recruitment, Retention and Initial Teacher Education*

Teacher recruitment and retention have emerged as defining challenges within Scottish secondary education, with recent surveys showing that over half of the respondents stated that Primary teachers were now being employed to fill gaps (SSTA, 2025). The shortage of secondary specialists is particularly acute within CDEG. Over the past decade, workforce shortages in Technological education have shifted from episodic difficulties to chronic scarcity. These shortages now represent the principal limiting factor on subject viability.

Recent evidence points to a sustained decline in specialist capacity. In 2024, over one fifth of Scottish secondary schools reported at least one vacancy in a CDEG subject (TES, 2024), with some posts advertised repeatedly across successive terms (Press and Journal, 2023). While the proportion might seem modest, it is important to recognise that vacancies are often subsumed within other curricular areas, meaning the reported figures likely underestimate the actual staffing pressures. Indeed, a survey undertaken by School Leaders Scotland found that nearly a quarter (24.5%) of responding schools were forced to reduce their CDEG provision by over 50% due to recruitment issues, with some schools removing their provision altogether (SLS Scotland, 2025). Additionally, nearly half of respondents revealed that they were teaching classes they had no specialism in, including certificated classes (SSTA, 2025) and in some cases there was no CDEG specialist at all (Press and Journal, 2023). Table 1 shows that whilst efforts to improve teacher numbers saw an increase overall by 9%, over the same period, the number of Technological Education teachers fell by approximately 6.5%, from 1,237 to 1,157 (Scottish Government, 2025).

Table 1

Teachers in Scotland census 2015-2025

Year	Total number of teachers in secondary teacher in Scotland	Registered CDEG teachers
2015	21,590	1,237
2016	21,528	1,237
2017	21,707	1,245
2018	21,861	1,225
2019	22,057	1,212
2020	22,623	1,223
2021	23,318	1,239
2022	23,383	1,228
2023	23,526	1,192
2024	23,436	1,165
2025	23,516	1,157
Difference	+ 1,846 (+ 9%)	-80 (- 6.5%)

CDEG is particularly exposed to recruitment pressures for several reasons. Entry to teaching competes directly with employment in engineering, design and construction industries that offer

higher salaries, clearer progression pathways and fewer workload-related demands. Within schools, the resource-intensive nature of CDEG, specialist workshops, consumables, health-and-safety compliance and technical support, further amplifies workload and responsibility for teachers. These conditions disproportionately impact early-career staff and deter mid-career entrants, particularly in rural and island authorities where geographic isolation reduces access to experienced peers and national professional learning, typically concentrated in the central belt.

Policy responses have sought to mitigate these pressures through financial incentives and recruitment campaigns. The Scottish Government's STEM bursary scheme, offers up to £20,000 to career-changers entering shortage subjects, including Technological Education (Scottish Government, 2021). National campaigns such as *Teaching Makes People* (Scottish Government, 2026) have attempted to reposition teaching as an attractive option for industry professionals, while some local authorities have experimented with relocation incentives (Moray Council, 2015) and retraining schemes (University of Aberdeen, 2015). Whilst these initiatives have generated modest localised gains, evaluations suggest they have not altered the underlying trajectory. Bursaries have attracted entrants, but retention remains fragile, with workload, resource scarcity and professional isolation frequently cited as reasons for early exit (Scottish Government, 2018).

These dynamics place increasing pressure on Initial Teacher Education (ITE) as both a gatekeeper and potential amplifier of workforce decline. The following section therefore examines the capacity, structure and recent evolution of ITE routes and considers their implications for the long-term sustainability of CDEG within Scotland's reform agenda.

ITE occupies a pivotal position in the sustainability of CDEG, yet at a time of heightened reform expectations, it is itself operating under significant strain. As McLaren (2011) noted, entry to secondary Technological education teaching in Scotland has traditionally been available through two routes via a number of universities in Scotland: a one-year Professional Graduate Diploma in Education (PGDE) for graduates of related disciplines, and a four- or five-year undergraduate programme (B.Tech.Ed. /M.Tech.Ed.). Over the past decade, however, this landscape has narrowed significantly. The withdrawal of the undergraduate course at the University of Edinburgh in 2011 left the University of Glasgow as the sole undergraduate provider whose recent decision to pause M.Tech.Ed. admissions for 2026–27 in response to sustained low uptake, temporarily removes that mode of entry. These institutional decisions should not be read as isolated anomalies, but as indicators of systemic pressure within a shrinking recruitment pipeline.

That being said, a recent innovation, the Education and Curricular Studies with Teaching Qualification (B.Sc. (Hons)) at the University of Strathclyde, offers an alternative entry point and has attracted significant interest as it offers entry with a relevant Higher National Diploma (HND), directly into the third year of a degree programme. Whilst such a development is encouraging, it still operates within a broader context of declining demand. In 2024, the Scottish Government aimed to recruit 81 into Technological Education ITE (although this includes 15 places at the University of Stirling which does not have Technological Education route) however only 26 were filled (Scottish Government, 2024), continuing a declining trend in recruitment as shown in Table 2. Demand continues to outstrip supply at a national level at a similar scale: schools requested 117 newly qualified CDEG teachers for the 24/25 session, however only 39 of these requests were

filled (TES, 2024). These figures highlight the significant scale of the deficit between workforce demand and ITE capability.

Table 2

Initial Teacher Education intake target and places filled numbers 2021-2024

Year	Target intake	Places filled
2024	81	26
2023	81	26
2022	85	34
2021	85	53

Beyond recruitment volume, CDEG presents a distinctive challenge for ITE in terms of disciplinary breadth. Unlike most secondary subjects, where teachers specialise, at least initially, in a single certificated domain, CDEG teachers are expected to deliver across multiple qualifications spanning design, engineering, practical workshop skills and graphic communication. This breadth places significant demands on ITE programmes, which must develop sufficient competence across diverse technical domains within limited timeframes. Research has long noted the resulting tensions between depth and coverage (Canavan & Doherty, 2003; Morrison-Love, 2018), with implications for teacher confidence, subject choice and curriculum enactment.

The importance of technical support staff is often overlooked in policy discussions, yet their decline represents a significant structural constraint. Recent data indicate that the number of secondary school technicians in Scotland has fallen by more than half over two decades, from 1,431 in 2005 to 648 in 2025 (TES, 2025). As technician numbers fall, teachers report delays in preparation, reduced maintenance capacity and increasing simplification of practical activities. These pressures directly affect curriculum enactment, narrowing the scope of learning experiences and amplifying workload for an already stretched workforce.

These dynamics suggest that ITE cannot be treated simply as a pipeline issue to be expanded or incentivised. It is a structural component of curriculum reform whose capacity, design and resourcing must be aligned with the ambitions placed upon it. Whilst recent innovations offer grounds for cautious optimism, they do not yet resolve the fundamental disparity between the breadth of CDEG provision expected in schools and the conditions under which teachers are prepared. Addressing this mismatch is essential if the CIC is to translate policy coherence into sustained pedagogical change.

4.2 Professional and research infrastructure

The aforementioned difficulty of assembling a contemporary Scottish literature base should be understood not as a limitation of this paper, but as a finding in its own right. Whilst the limited research output in Scottish CDEG could reflect factors such as workload, a lack of institutional support for practitioner enquiry, or the difficulties in Higher Educational establish, as discussed in the previous section. Its persistence over more than a decade is reflected not only in reduced publication volume but also in the loss of continuity, visibility and a sustained scholarly conversation capable of supporting disciplinary renewal.

The implications of this decline extend beyond academic representation. In technological education, research culture functions as a form of professional infrastructure: it articulates the epistemic foundations of the subject, supports critical engagement with policy, and provides a mechanism through which practice is examined, challenged and renewed. Without current Scottish research and active research community in which to engage with it, curriculum reform risks becoming reactive or externally driven, rather than grounded in field-specific knowledge and sustained professional dialogue.

A further complicating factor is the absence of a stable, widely recognised subject identity. Despite the official designation of CDEG, secondary school departments continue to employ a wide range of alternative labels, such as: Design and Technology; Craft, Design and Technology; Design, Manufacture and Graphics to list but a few (Canavan & Doherty, 2003). This terminological fragmentation is not merely semantic; it reflects deeper uncertainty about disciplinary boundaries, purpose and status. The lack of a coherent subject narrative has implications for curriculum design, professional learning, research visibility and policy engagement, weakening CDEG's collective voice within the education system.

This “crisis of identity” (McFarlane, 2021) is further reinforced with the General Teaching Council for Scotland (GTCS) registration category of *Technological Education* an umbrella term forcing CDEG teachers to be interdisciplinary rather than allowing them to pursue the craft-based, design-led or engineering-orientated backgrounds or interests they may have.

An additional indicator of the weakened subject voice in Scotland is the absence of a visible, functioning subject association capable of representing CDEG at national level. Subject associations play a critical role in sustaining professional identity, supporting curriculum interpretation, disseminating resources and acting as intermediaries between practitioners, researchers and policymakers. In fields undergoing reform, they often function as informal but influential sites of curriculum sense-making and professional learning.

In Scotland, the Scottish Technology Teachers Association (TTA) exists nominally as a representative body for CDEG education. Established in 1955, its recent activity was sporadic and appears to have halted completely as of November 2024. Public-facing indicators of an active association, such as an accessible digital presence, curated professional resources, regular communications, or transparent governance, are largely absent. Whilst the association has previously supported an annual one-day professional learning conference, there is little evidence

of sustained engagement beyond this event, and membership composition and representation remain unclear. This contrasts sharply with other Technologies associations in other systems, most notably the Design and Technology Association (DATA) in England which maintains a highly visible presence, published research, plays an active role in policy consultation and professional resource creation.

The absence of a comparable organisational infrastructure for CDEG in Scotland has significant implications. Without a recognised professional body to articulate subject-specific concerns, technological education lacks a collective mechanism through which expertise can be mobilised, research disseminated, or reform interrogated from within the field. This the profession's capacity to influence curriculum development and contributes to the fragmentation of subject identity observed elsewhere in this paper.

Viewed alongside the contraction of research output, the limited visibility of a subject association should be understood not as an isolated organisational failure, but prolonged absence of curriculum and professional stewardship. In this context, the difficulty of identifying a coherent, contemporary CDEG voice in Scotland is itself indicative of systemic fragility. If the CIC is to support meaningful renewal rather than procedural compliance, rebuilding mechanisms for subject representation, alongside workforce and assessment reform, will be essential.

5 CURRICULUM IMPROVEMENT CYCLE (CIC)

The Curriculum Improvement Cycle (CIC) represents Scotland's most significant shift in curriculum governance since the introduction of CfE. It establishes a planned, recurring national process for reviewing and evolving the curriculum to ensure its continued relevance, coherence and responsiveness to system needs. Adopting a four-stage model designed to embed curriculum review within an iterative cycle rather than episodic reform events, the CIC is operationalised through a layered organisational structure each with defined responsibilities for evidence synthesis, curriculum design, quality assurance and constructive challenge. These processes are supported by a strong emphasis on co-design, with a stated aim of having teachers form the majority of groups involved in shaping curriculum developments, led by a National Advisor – a recent classroom teacher. Critically, the CIC also identifies interdependencies with policy, qualifications, inspection and digital strategy, signalling a shift toward a more integrated reform model that acknowledges curriculum improvement cannot occur in isolation.

Whilst the CIC does not, in itself, resolve the challenges facing technological education, it provides an institutional context in which long-standing issues, misalignment between curriculum and assessment, workforce fragility, and weakened subject infrastructure, can be highlighted and potentially addressed more systematically than was previously possible. This paper therefore treats the CIC not as a solution, but as a framing condition: its significance lies in the extent to which it enables sustained engagement with the structural constraints identified in the preceding sections.

6 CONCLUSION

This research aimed to identify and examine the systemic conditions shaping CDEG education in Scotland between 2011 and 2025 and suggest areas focus to support the current reform activity. Based on the synthesis of findings, the following recommendations are proposed:

- (i) re-establish a robust and representative subject association;
- (ii) rebuild and strengthen research capacity in Scottish Technological education;
- (iii) undertake systematic research to generate robust, quantifiable evidence on workforce challenges;
- (iv) strengthen workforce capacity to protect the breadth and quality of subject provision;
- (v) enhance the capacity and coherence of ITE

Fifteen years after McLaren questioned whether CfE signalled a “time for change,” it is now clear that its ambitions for Technological education were never matched by the structural conditions needed for realisation. Evidence across the past decade suggests that the stagnation of CDEG reflects not curricular weakness, but persistent systemic constraints which were never adequately addressed.

This review has shown how a lack of stewardship spanning chronic recruitment difficulties, declining workforce capacity and the contraction of ITE has collectively limited subject provision and undermined stability within the profession. At the same time, the erosion of research activity and the absence of a visible, functioning subject association have weakened CDEG’s collective voice and its ability to shape reform or sustain disciplinary renewal.

Despite consistent policy endorsement, “transformational change” has remained elusive because reforms have proceeded without the necessary professional, infrastructural and organisational supports. Ambition without infrastructure has produced inertia rather than improvement.

The introduction of the CIC alters the governance context by creating a mechanism for sustained alignment across the Scottish education system. However, its impact will depend on whether the system invests in the structural foundations, capacity, coherence and professional infrastructure, that CDEG requires, and the recommendations made herein, which may be the catalyst required to kickstart the process. The imperative is no longer to articulate the need for *Time for Change?*, but to commit to the systemic action required to enable it.

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From Handwork to Human Capital: A Discourse Analysis of Design and Technology Education Policy in England, 1900 to the Present

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Abstract

This paper offers a critical discourse analysis informed discussion of UK policy texts that have shaped design and technology (D&T) education in England from the early twentieth century to the present, drawing exclusively on the provided annotated corpus of Acts, statutory orders, curriculum documents, and white papers. Treating these texts as discursive artefacts, the analysis traces how D&T has been problem-framed, how learners and teachers have been constructed, and which policy levers (statutory status, accountability measures, and assessment architectures) have materialised these framings in schools. Five eras are identified: (i) handwork for character and citizenship (1904–1918); (ii) post-war technical modernity (1944–1949); (iii) the invention of D&T as design capability within the national curriculum for England (1988–1999); (iv) standards, choice, and accountability with the marginalisation of non-English Baccalaureate subjects (2002–2016); and (v) skills/productivity and technical pathways (2016–present). The corpus also evidences the consolidation of statutory frameworks (1996), primary-phase turbulence (2009), and the reconfiguration of vocational pathways (2011). A sustained policy contradiction is visible: economic and skills strategies valorise design and technical capability, while accountability regimes simultaneously decentre D&T at Key Stage 4. A coherent national settlement requires realigning performance measures or restoring statutory guarantees, so school-level incentives match national ambitions.

Key Words: Accountability, Curriculum Policy, Design and Technology, Discourse Analysis, England, National Curriculum, Policymaking

1 INTRODUCTION

Design and technology (D&T) education in England has been repeatedly reconfigured through policy across the past century, moving from early conceptions of handwork linked to character and citizenship towards contemporary framings emphasising technological capability, skills, and productivity. These shifts have been enacted not only through curriculum language but through

statutory frameworks, national curriculum (NC) orders, and accountability arrangements that structure what schools are required and incentivised to provide.

This paper examines how official policy texts have problem framed D&T, constructed learners and teachers, and mobilised policy levers over time. Drawing exclusively on a purposively defined corpus of Acts of Parliament, statutory curriculum orders, national curriculum documents, white papers, and official reports from 1900 to the present, the analysis treats these texts as discursive artefacts through which educational purposes and priorities are articulated and operationalised.

Particular attention is paid to how statutory status and accountability measures have functioned as governing instruments. While the introduction of the NC in the late 1980s established D&T as a statutory entitlement and articulated it as a form of design capability, later reforms selectively relaxed curricular obligation (most notably at upper secondary) without equivalent changes to performance metrics. This has produced a persistent tension between policy rhetoric that valorises design and technical capability and accountability regimes that marginalise D&T within schools' curricular decision making.

Adopting a critical discourse analysis (CDA)–informed approach, the paper identifies five analytically constructed policy eras from 1904 to the present, capturing dominant and recurring configurations of purpose, subject identity, and governance. By tracing these discursive shifts, the paper highlights a long-standing policy contradiction between national ambitions for skills and productivity and the incentive structures through which school curricula are steered, providing a basis for discussing the implications for the status and future of D&T in England.

2 LITERATURE REVIEW

Research on D&T education in England highlights the subject's development as shaped by a dynamic interplay of economic, technological, and social drivers, mediated through curriculum policy and statutory reform. Across the twentieth and early twenty first centuries, D&T has been repeatedly reframed in response to changing national priorities, producing ongoing tensions around its curricular status, purpose, and value.

Economic rationales have been particularly influential in shaping D&T policy (Table 1). Early policy conceptions aligned practical education with industrial production and workforce preparation, while late twentieth century reforms increasingly positioned D&T as a means of developing technological capability and human capital for a knowledge-based economy (Atkinson, 2019; Wilson & Harris, 2004). The introduction of D&T as a statutory subject within the national curriculum in 1989 represented a significant attempt to codify these ambitions, framing design activity as a cognitive, creative, and problem-solving discipline rather than as a collection of vocational crafts. However, research suggests that, despite successive curriculum revisions, English policy has not consistently articulated or sustained this economic rationale, particularly when compared with international counterparts (Atkinson, 2019).

Table 1*Economic Drivers in D&T Policy Response*

Period	Economic Drivers	Policy Response	Evidence/Impact
1900–1950	Industrialisation, skills for manufacturing	Vocational training, technical schools	Emphasis on practical skills for industry
1980s–1990s	Deindustrialisation, knowledge economy	Introduction of D&T in national curriculum (1989)	Aimed to develop technological capability and human capital
2000–2025	Global competitiveness, digital economy	Curriculum reviews, focus on STEM, optional D&T post-14	Mixed evidence of economic impact; calls for stronger alignment with industry needs

Technological change has also driven periodic curriculum reform (Table 2). The expansion of materials technologies, the digital revolution, and the growth of computational and automated systems have all prompted calls for greater responsiveness within D&T frameworks (Hardy, 2018; McLain et al., 2019). While curriculum documents have progressively incorporated digital design, systems thinking, and sustainability, analyses indicate uneven integration across phases and frequent lag between technological change and policy enactment. This has contributed to concerns that D&T policy rhetoric often outpaces what is structurally supported in schools.

Table 2*Technological Drivers and Policy Response*

Drivers	Policy Response	Evidence/Impact
New materials (post-1960s)	Expansion of D&T content to include materials science	Recognition of broader technological base
Digital revolution (1980s–present)	Inclusion of ICT, digital design, robotics, AI in curriculum	Ongoing curriculum updates; need for further integration
Sustainability, circular economy (2000s–present)	Emphasis on eco-innovation, systems thinking	Growing but uneven integration in D&T

Social and cultural motivations further complicate the policy landscape. D&T has been advocated as a means of promoting equity, countering academic stratification, and providing all learners with access to forms of practical and creative knowledge traditionally associated with vocational tracks (Bell et al., 2017; McLain et al., 2019). At the same time, the subject's hybrid identity (positioned between academic and vocational domains) has rendered it vulnerable to marginalisation within competitive, performance driven curriculum systems. Persistent gender disparities and contested perceptions of status signal unresolved tensions within both policy and practice (Bell et al., 2017).

Legislative frameworks (**Fel! Hittar inte referenskölla.**) have translated these economic, technological, and social motivations (**Fel! Hittar inte referenskölla.**) into binding or permissive policy arrangements. The statutory inclusion of D&T in the national curriculum marked a high point in terms of entitlement and visibility, while subsequent reforms have altered schools' incentive structures; particularly the relaxation of Key Stage 4 compulsion and the prioritisation of selected academic subjects within accountability measures (Atkinson, 2019; Wilson & Harris, 2004). As a result, research highlights a growing disjunction between policy narratives that emphasise skills, innovation, and productivity and the governance mechanisms that shape subject provision on the ground.

Table 3

Key Legislative and Policy Milestones

Year	Policy, Report, or Act	Motivation and Driver(s)	Impact on D&T Curriculum
1989	National curriculum (D&T statutory)	Economic (skills), social (equity)	Universal entitlement to D&T
2002	Green Paper 14–19	Flexibility, economic, curriculum crowding	D&T no longer compulsory post-14
2010s & 2020s	Curriculum reviews, STEM focus	Global competitiveness, technological change	Emphasis on STEM, optionality of D&T

Table 4*Social Drivers and Policy Response*

Drivers	Policy Response	Evidence/Impact
Social justice, equity	Inclusion of D&T for all students, not just vocational tracks	Aimed to address cultural reproduction and low expectations
Gender equity	Efforts to increase female participation in D&T	Ongoing challenge: some progress noted
Changing societal needs	Curriculum updates to reflect real-world problems, user-centred design	Emphasis on design for social change, inclusion

Overall, the literature suggests that D&T policy in England cannot be understood through individual curriculum documents alone. Rather, its development reflects shifting configurations of economic ambition, technological change, social purpose, and legislative control. These intersecting forces have produced recurring cycles of elevation and marginalisation, providing the context for the policy discourse analysis that follows. Having set the scene, the following sections will focus on policy documents from the start of the twentieth century to the present day, exploring the policy discourse through legislation and statutory guidance.

3 METHODOLOGICAL NOTE: A CDA-INFORMED APPROACH TO POLICY TEXTS

This study adopts a critical discourse analysis (CDA)–informed approach to historical education policy documents, drawing primarily on Fairclough’s (1995, 2010) conception of discourse as social practice, in which language both reflects and constitutes institutional power, social relations, and material effects. Policy texts are treated as discursive artefacts that: (i) problem-frame educational purposes and social need; (ii) construct subject positions for learners, teachers, and disciplinary knowledge; and (iii) mobilise policy instruments (such as statutory status, curriculum orders, and accountability measures) to materialise preferred educational futures (Ball, 1993; Fairclough, 2003).

The corpus comprises a purposively delimited set of Acts of Parliament, statutory curriculum orders, national curriculum documents, white papers, and official reports relating to D&T education (and its curriculum predecessors) in England from 1900 to the present. Texts were selected on the basis of their legal force, system-wide policy reach, and recurring citation within the English education policy record, consistent with approaches to historical and policy-focused discourse analysis (Apple, 2018; Ozga, 2000).

Analysis proceeded through iterative close reading and comparative historical analysis, rather than formal coding, reflecting established CDA practices in policy research (Fairclough, 2003; Wodak & Meyer, 2015). Attention was paid to recurring lexical choices (for example handwork, capability, standards, skills), shifts in how D&T is justified and valued, intertextual relationships between education policy and wider industrial or skills policy, and changes in the authority of policy levers over time (Ball, Maguire & Braun, 2011). Through repeated comparison across periods, clusters of relatively stable problem framings, subject constructions, and governing instruments were identified. These clusters were synthesised into five analytically constructed policy eras, understood not as discrete or exhaustive historical phases but as dominant discursive configurations that capture continuity, rupture, and contradiction in policy meaning-making (Fairclough, 2013; Wodak & Meyer, 2015).

This CDA-informed, historically sensitive approach prioritises analytic transparency and explanatory power, enabling the identification of long-term tensions between curricular intent and accountability regimes (the system of performance measures, inspections, and reporting mechanisms through which schools' effectiveness is evaluated) in English D&T education policy (Ball, 1993; Ozga, 2000).

4 ERA I (1904–1918): HANDWORK FOR CHARACTER AND CITIZENSHIP

The Board of Education's Regulations for Secondary Schools (1904) formalised a broad curriculum that included manual instruction, explicitly tying practical work to character development within a liberal conception of education (Board of Education, 1904). The Acland Report (1913) reinforced handwork as cognitively and morally valuable for all, not merely pre-vocational (Board of Education, 1913). Structural legislation underpinned these ideals: the Education (Administrative Provisions) Act 1907 expanded system capacity and welfare supports, while the Education Act 1918 raised the leaving age and instituted continuation schools including technical instruction (Education [Administrative Provisions] Act, 1907; Education Act, 1918). Collectively, these texts construct practical education as a universal entitlement for civic formation rather than a narrow occupational pipeline.

5 ERA II (1944–1949): TECHNICAL MODERNITY AND THE POST-WAR SETTLEMENT

The Education Act 1944 codified the tripartite system (grammar, technical, and secondary modern) legitimating technical education as a distinct pathway aligned with national reconstruction (Education Act, 1944). The Registered Designs Act 1949 extended legal protection to industrial designs, signalling state recognition of design as an economic asset and strengthening the case for design education's role in productivity and innovation (Registered Designs Act, 1949). The imagined learner is re-cast from rounded citizen to technician/designer serving post-war modernity.

6 ERA III (1988–1999): INVENTING ‘DESIGN AND TECHNOLOGY’ AND THE CAPABILITY DISCOURSE

A decisive policy turn arrives with the Education Reform Act 1988, introducing the NC and creating conditions for D&T’s statutory status (Education Reform Act, 1988). The D&T Working Group’s interim report (1988) and the Secretary of State’s proposals (1989) define D&T as design thinking, problem-solving, creativity, and technological understanding across Key Stages; an explicit move from craft-centric practice to design capability (DES & Welsh Office, 1988, 1989). The first D&T statutory Order (1990) operationalises this discourse through attainment targets and programmes of study (Department of Education & Science [DES], 1990). Subsequent reviews and orders manage scope without abandoning capability: the Dearing Review recommends slimming the curriculum (School Curriculum and Assessment Authority, 1994); the 1995 Order simplifies assessment (Department for Education [DfE], 1995); and the 1999 Order clarifies iterative design, user-centred approaches, and ICT integration (Department for Education & Employment [DfEE], 1999). The Education Act 1996 consolidates the statutory framework, reaffirming D&T’s curricular status within the overall legal architecture (Education Act, 1996).

7 ERA IV (2002–2016): ACCOUNTABILITY, CHOICE, AND THE MARGINALISATION OF NON-ENGLISH BACCALAUREATE SUBJECTS

The Education Act 2002 reconfigures the KS4 settlement: from 2004, D&T is no longer compulsory at Key Stage 4 (KS4); instead, schools must offer at least one subject from each entitlement area, including D&T (Education Act, 2002). KS4 refers to the final phase of compulsory secondary education in England (typically ages 14–16), culminating in external national qualifications such as general certificate of secondary education (GCSE) and serving as a major accountability checkpoint for schools (DfE, 2014). GCSEs are subject-based national qualifications typically taken by students at age 16 in England and serve as the primary outcome measure for secondary school accountability (Ofqual, 2015). The explanatory notes emphasise flexibility and innovation, and DfE guidance operationalises entitlement, but many schools reduce or merge D&T due to resource and timetable constraints (Education Act, 2002, Explanatory Notes; DfE, 2004). Meanwhile, the Education and Skills Act 2008 raises the participation age and underlines vocational and technical routes, without adjusting school-age accountability incentives (Education and Skills Act, 2008). The Rose Report (2009) reflects primary-phase policy turbulence, with proposals intersecting the wider curriculum context into which D&T must articulate (Rose, 2009). The Academies Act 2010 expands curriculum autonomy, increasing heterogeneity of provision (Academies Act, 2010). An academy is a publicly funded state school in England that operates outside local authority control and is not required to follow the NC, although it remains subject to national accountability measures. Most consequentially, the 2010 White Paper introduces the English Baccalaureate (EBacc) headline measure excluding D&T, and Progress 8 (2016) further codifies performance metrics that prioritise particular subject baskets (DfE, 2010; DfE, 2016). The Wolf Report (2011) reshapes the evaluation of vocational qualifications, influencing perceptions of practical and technical learning at KS4/16+ (Wolf, 2011). The *EBacc* is a school performance measure introduced in 2010 that assesses the proportion of students achieving good GCSE grades in a prescribed set of academic subjects,

from which D&T is excluded (DfE, 2010). *Progress 8* is a value-added secondary school accountability measure introduced in 2016 that calculates students' academic progress across eight subjects between ages 11 and 16, thereby strongly influencing schools' curriculum and subject offer (DfE, 2016). Together, these instruments produce a performativity regime in which D&T's *design-make-evaluate epistemics* are undervalued relative to measured academic cores.

8 ERA V (2016–PRESENT): SKILLS, PRODUCTIVITY, AND THE TECHNICAL PIPELINE; AMID ACCOUNTABILITY INERTIA

From 2016 onward, policy foregrounds skills and productivity through the Post-16 Skills Plan and the independent report on technical education, mapping clear technical routes and standards (DfE & Department for Business, Innovation & Skills [BIS], 2016). The Industrial Strategy (2017) and Skills for Jobs white paper (2021) emphasise STEM capacity, T Levels, and lifelong learning (HM Government, 2017; DfE, 2021). These texts presuppose a robust school-age pipeline that builds foundational design-technical literacies; competencies often cultivated in D&T (DfE, 2013). Yet EBacc and Progress 8 remain intact, leaving D&T outside the headline accountability basket (DfE, 2010; DfE, 2016). The Ofsted Research Review for D&T, noted as completed but unpublished in the corpus, signals a pending re-articulation of quality and curriculum intent but, absent lever change, cannot by itself alter subject status (Ofsted, n.d.).

9 CROSS-CUTTING SHIFTS AND TENSIONS

Formation to utility: Early texts position handwork as liberal and character-forming (Board of Education, 1904, 1913), whereas recent policy locates value in human capital, productivity, and technical pipelines (DfE & BIS, 2016; HM Government, 2017; DfE, 2021). Craft to capability to accountability: 1990s orders codify design capability and iterative problem-solving (DES, 1990; DfEE, 1999), later subordinated to EBacc/Progress 8 metrics (DfE, 2010; DfE, 2016). Statutory status and metrics as power devices: making D&T statutory (1988–1990) elevated the subject; removing KS4 compulsion (2004) and excluding D&T from EBacc lowered its priority (Education Reform Act, 1988; DES, 1990; Education Act, 2002; DfE, 2004; DfE, 2010). Intertextuality with industrial policy: the Registered Designs Act (1949) and the Industrial Strategy (2017) valorise design economically, while school metrics do not reflect this valuation (Registered Designs Act, 1949; HM Government, 2017). Consolidation and system architecture: the Education Act 1996 provides legal continuity that both enabled and constrained subsequent reforms, ensuring that changes like the 2002 Act and the 2013 Programmes of Study occur within a stable statutory frame (Education Act, 1996; DfE, 2013). Vocational re-evaluation: the Wolf Report (2011) and the 2008 Act reposition practical/technical routes, affecting how D&T articulates with 14–19 pathways (Education and Skills Act, 2008; Wolf, 2011). Primary-phase context: the Rose Report (2009) signals contested curriculum priorities that shape the feeder experience into secondary D&T (Rose, 2009).

10 DISCUSSION: RECONCILING CAPABILITY AND ACCOUNTABILITY

The corpus reveals a recurrent dynamic: curricular texts articulate rich, iterative visions of D&T while systemic levers reward narrow performance priorities. The removal of KS4 compulsion (Education Act, 2002; DfE, 2004), EBacc (DfE, 2010), and Progress 8 (DfE, 2016) have exerted greater influence on subject presence than any single programme-of-study revision (DfE, 2013). Meanwhile, industrial and skills policies assume a supply of design-technical literacies that D&T is structurally suited to develop (DfE & BIS, 2016; HM Government, 2017; DfE, 2021). Reconciling this contradiction requires metric realignment; recognising D&T's contributions within accountability baskets, or statutory reaffirmation of KS4 entitlement, restoring a baseline of provision (Education Act, 2002; DfE, 2010). The Education Act 1996 and subsequent orders demonstrate that legal architecture is an effective lever for sustaining subject identity (Education Act, 1996; DES, 1990).

11 IMPLICATIONS FOR POLICY AND PRACTICE

Policy: Align levers with aims by integrating D&T-relevant indicators into performance measures and/or reinstating KS4 entitlement (Education Act, 2002; DfE, 2010; DfE, 2016).

Leadership: Frame D&T as accountability-adjacent by evidencing contributions to whole-school outcomes and destinations that align with technical routes (DfE, 2013; DfE & BIS, 2016).

Curriculum and pedagogy: Maintain the design capability tradition (iterative, user-centred, knowledge-rich) explicit in the 1990, 1995, 1999 Orders and the 2013 Programmes of Study (DES, 1990; DfE, 1995; DfEE, 1999; DfE, 2013).

Pathways: Use the Wolf Report (2011) and the Education and Skills Act (2008) to articulate coherent 14–19 routes linking D&T learning to recognised technical qualifications (Education and Skills Act, 2008; Wolf, 2011).

12 CONCLUSION

Across more than a century, D&T in England has been repeatedly re-inscribed to meet shifting national priorities: from handwork as character formation (1904–1918), through technical modernity (1944–1949), to a statutory design capability curriculum (1988–1999), and into an accountability-dominated era (2002–2016) that coexists uneasily with skills/productivity ambitions (2016–present). The decisive forces are instrumental: statutory status and performance metrics. The corpus shows that removing KS4 compulsion and excluding D&T from EBacc/Progress 8 re-ordered school incentives, even as industrial and skills policies elevated design-technical capacity (Education Act, 2002; DfE, 2010; DfE & BIS, 2016; HM Government, 2017; DfE, 2021). To make policy rhetoric real, England must align levers with aims, either by metric reform, statutory guarantees, or both, so that D&T's distinctive *design-make-evaluate*

epistemics can flourish within the very system that claims to need them (DES, 1990; DfE, 2013; DfE, 2016).

13 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used to aid the identification of policy trends at the start of the study and to enhance clarity and structure of the written text at the end. Scholarly contributions, theoretical perspectives, and analyses were produced by the author.

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Mapping Subjective Perspectives in Technology, Engineering and/or Design Education: Part II of a Primer Series Outlining a Worked Example of Q Methodology in Practice

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Abstract

As technology, engineering, and design (TED) education continues to navigate competing priorities around sustainability, capability, curriculum purpose, and assessment, researchers increasingly require methodological approaches that illuminate (not flatten) diverse value positions. Q methodology provides a robust means of examining subjective perspectives by identifying coherent typologies of viewpoint rather than relying on consensus or averaged positions. Building on Part I of this primer series, which introduced the theoretical foundations of Q methodology, this Part II paper demonstrates its practical application through a fully worked example grounded in a TED-relevant context. Using a fictional but methodologically realistic study on stakeholder perspectives regarding sustainability in design education, the paper models each stage of the seven-stage Q methodology process, with particular emphasis on factor analysis and factor interpretation. The worked example is designed as a pedagogical resource, making analytical decisions transparent and accessible for researchers new to Q methodology. By situating the process within a TED education context, the paper illustrates how Q methodology can support researchers and practitioners in engaging rigorously and reflexively with the plurality of viewpoints that shape contemporary debates in TED education, offering methodological clarity alongside practical relevance for future research, curriculum development, and policy work.

Key Words: Educational Research, Factor Analysis, Plurality, Q Methodology, Pragmatism, Subjectivity, TED Education

1 INTRODUCTION

1.1 *From contested educational purposes to the need for pluralistic inquiry*

Technology, engineering, and design (TED) education is characterised by deeply contested value positions surrounding sustainability, capability, curriculum purpose, assessment practices, and the role of design judgement. These debates reflect substantive differences in educational priorities rather than technical disagreements, and they remain difficult to navigate through consensus-seeking or variable-centred research approaches alone. As a result, methods that foreground plurality and systematically engage with diverse ways of thinking are increasingly essential for understanding and improving TED education.

1.2 *Why Q methodology matters for TED education*

Q methodology (Watts & Stenner, 2012) offers a distinctive advantage in such contexts because it provides a structured means of examining subjective viewpoints while preserving their complexity. Rather than reducing perspectives to averaged positions, Q methodology identifies coherent typologies of viewpoint, showing *how* and *why* individuals and stakeholder groups differ in their assumptions, priorities, and values. This makes it particularly relevant for TED, where curriculum design, pedagogical practice, and policy formation are routinely shaped by competing interpretations of what education should do, for whom, and toward what purposes.

Examples from related fields such as environmental education, sustainability studies, health professions education, and curriculum reform have demonstrated Q methodology's capacity to illuminate value-laden debates and make stakeholder perspectives explicit. These applications underscore its potential to support TED researchers and practitioners in addressing similarly complex educational challenges.

1.3 *Positioning of this Part II paper*

Part I (McLain, 2025) of this primer series introduced the theoretical foundations of Q methodology and argued for its suitability within TED education research. However, many researchers (particularly those new to Q methodology) report difficulty translating theoretical process models into concrete analytical decisions. This Part II paper responds directly to that need. Its purpose is to operationalise the seven-stage Q methodology process through a fully worked, TED-relevant example, demonstrating how Q methodology can be applied rigorously and reflexively in practice.

The worked example presented here uses a fictional but methodologically realistic Q study on stakeholder perspectives regarding sustainability in design education. This fictional framing allows methodological decisions to be made transparent at each stage (from concourse construction through to factor analysis and interpretation) without the constraints associated with real participant data. The intention is to provide a pedagogical resource that supports methodological learning while maintaining direct relevance to TED education.

1.4 Contribution to TED education research practice

By modelling each stage of the Q process in a TED-specific context, this paper seeks to strengthen methodological capacity within the field, enhance transparency in analytical practice, and demonstrate the value of Q methodology for engaging with the plurality of viewpoints that characterise contemporary debates in TED education. Taken together, Parts I and II aim to support researchers in moving beyond procedural familiarity toward confident, contextually informed application of Q methodology in their own work.

2 METHODOLOGY

Q methodology is a pragmatic, mixed-methods research approach designed to systematically study human subjectivity, including opinions, beliefs, values, and viewpoints. Originating in psychology through the work of William Stephenson, Q methodology combines qualitative sensitivity with quantitative rigor to identify shared patterns of thinking, referred to as *factors*, across a group of participants. Rather than seeking a single consensus position, Q methodology explicitly preserves plurality, revealing distinct and internally coherent viewpoints held within a population.

Central to Q methodology is the assumption that subjectivity is *operant*: i.e., individuals actively construct meaning and can meaningfully express their perspectives when invited to do so in a structured manner. This is achieved through the Q-sort, in which participants rank a set of carefully selected statements relative to one another, making their subjective priorities visible and comparable. Statistical analysis is then used to identify groups of participants who have sorted the statements in similar ways, indicating shared perspectives.

Artificial Intelligence (AI) technologies were used to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the author.

3 THE SEVEN STAGES OF Q METHODOLOGY

Following the framework outlined in Part I of this primer (McLain, 2025) and in Watts and Stenner (2012), Q methodology proceeds through seven interrelated stages:

- (i) **Concourse construction:** The process begins with the development of a *concourse*—the full range of views, discourses, and opinions surrounding the topic of interest. Statements may be drawn from literature, policy documents, interviews, focus groups, or media sources, with the aim of capturing the breadth of debate rather than consensus.
- (ii) **Development of the Q-set:** A smaller, manageable subset of statements (the Q-set) is selected from the concourse. These statements are refined to ensure clarity, balance, and representativeness of contrasting positions. The Q-set typically reflects the conceptual diversity of the topic rather than its frequency of occurrence.

- (iii) **Selection of the P-set:** Participants (the P-set) are purposively selected based on their relevance to the research topic. Unlike survey research, Q methodology does not aim for statistical representativeness; instead, it seeks to include individuals likely to hold differing or competing viewpoints.
- (iv) **Q-sorting:** Participants rank-order the Q-set statements on a fixed, quasi-normal distribution grid, typically ranging from “most agree” to “most disagree.” This forced-choice process encourages comparative judgement, revealing participants’ subjective priorities and internal frames of reference.
- (v) **Post-sort interviews:** Qualitative data are gathered through interviews or written reflections to capture participants’ reasoning, particularly for statements placed at the extremes of the distribution. These data provide critical context for later interpretation.
- (vi) **Factor analysis:** Completed Q-sorts are subjected to by-person factor analysis, which identifies clusters of participants who have sorted the statements in similar ways. Each factor represents a shared viewpoint rather than a latent variable, distinguishing Q methodology from conventional R-method factor analysis.
- (vii) **Factor interpretation:** Finally, composite Q-sorts (factor arrays) are interpreted alongside post-sort qualitative data to construct rich, narrative accounts of each factor. These interpretations articulate distinct typologies of viewpoint, preserving both shared meaning and points of divergence across perspectives.

Taken together, the seven-stage Q methodology process provides a transparent and systematic means of mapping subjectivity, making it particularly well suited to educational research contexts characterised by competing values, diverse stakeholders, and contested purposes, such as TED education. The next section provides a worked example of Stages 6 (factor analysis) and 7 (factor interpretation) in the context of Q methodology.

4 WORKED EXAMPLE

In this section, we will explore a worked example of Q factor analysis using a training Q-Set of 10 items, derived from a full Q-Set of 60 items, which in turn was created from a concourse of 205 items extracted from three climate education policy relate documents within the context of England (Department for Education, 2025, 2023; Kitson, Phillips & Dillon, 2025). The supporting documents can be downloaded from <https://doi.org/10.5281/zenodo.19047497>. Subsection 5.1 provides an overview of factor analysis.

4.1 *An overview of factor analysis*

In Q methodology, factor analysis is a by-person statistical procedure used to identify groups of participants who have sorted a set of statements in similar ways, indicating shared viewpoints on the topic under study. Rather than analysing relationships between variables, as in conventional factor analysis, Q-based factor analysis correlates whole Q-sorts to reveal distinct, internally coherent patterns of subjective thinking. Each resulting factor represents a typology of perspective

(a shared way of understanding the issue) rather than an underlying latent trait or dimension. Factor analysis is commonly used to identify patterns of association within data, but *Q factor analysis* and *R factor analysis* differ fundamentally in what they analyse, what their results represent, and how their findings should be interpreted.

4.1.1 Unit of Analysis

The central distinction lies in the unit of analysis. *R factor analysis* correlates *variables* across a large sample of participants. Its purpose is to identify latent dimensions or constructs that explain patterns of association among measured variables (e.g. survey items).

By contrast, *Q factor analysis* correlates *people* (or more precisely, their complete Q-sorts) across a shared set of statements. The aim is to identify groups of individuals who have expressed similar patterns of judgement, indicating shared viewpoints. In simple terms, *R analysis* asks, “Which variables go together?”, whereas *Q analysis* asks, “Which people think alike?”.

4.1.2 Purpose and Outcomes

R factor analysis is typically used for measurement development, scale construction, or theory testing. The extracted factors are interpreted as latent constructs that are assumed to exist independently of the participants and to influence their responses (e.g. motivation, attitude, self-efficacy). *Q factor analysis* serves a different purpose: it is designed to map subjectivity. The resulting factors represent distinct, internally coherent perspectives on a topic, not underlying psychological traits. Each factor is interpreted as a *typology of viewpoint*, reflecting a shared way of seeing or understanding the issue under investigation.

4.1.3 Data Structure and Sample Size

R factor analysis generally requires large samples to ensure statistical stability and generalisability. The emphasis is on representativeness and the reliability of variable relationships. In contrast, *Q factor analysis* works with small, purposively selected samples, because the goal is not population inference but conceptual exploration. Participants are chosen for the diversity of their perspectives rather than their statistical representativeness. In Q methodology, fewer participants than variables is not a limitation but an expected feature.

4.1.4 Interpretation of Factors

Another key difference concerns interpretation. In *R analysis*, factors are interpreted based on variable loadings, with meaning inferred from clusters of items that load highly on a factor. These interpretations are often abstract and detached from individual respondents. In *Q analysis*, factors are interpreted using factor arrays: composite Q-sorts that represent how a hypothetical person with that viewpoint would rank all statements. Interpretation is grounded in concrete statements, supported by post-sort qualitative data, allowing factors to be described as rich, narrative accounts of shared meaning. **Table 1** summarises the comparison of Q and R factor analysis.

Table 1

Summary comparison of Q and R factor analysis

Aspect	R Factor Analysis	Q Factor Analysis
Unit of analysis	Variables (items)	People (Q-sorts)
Primary aim	Identify latent constructs	Identify shared viewpoints
Typical sample size	Large	Small, purposive
View of subjectivity	Measurement error to be controlled	Core phenomenon of interest
Nature of factors	Latent traits/dimensions	Typologies of perspective
Interpretation	Variable-centred	Person-centred and interpretive

4.1.5 In Methodological Terms

While both techniques rely on similar mathematical foundations, Q and R factor analysis answer different research questions and should not be treated as interchangeable. *R factor analysis* is appropriate when the aim is to measure, generalise, or model constructs. *Q factor analysis* is appropriate when the aim is to understand the structure of subjective viewpoints, particularly in contexts where multiple, competing perspectives coexist, such as education, policy, and socially contested fields.

4.2 Worked example of Q factor analysis

This section provides a step-by-step worked example of Q factor analysis using the simulated dataset introduced earlier in this paper. The purpose is not to demonstrate statistical sophistication, but to make the *process* of Q factor analysis transparent and replicable for researchers new to the method. All analysis steps described below were carried out using PQMethod (Schmolck, 2014), a freely available software package developed specifically for Q methodology. Refer to Table 2 in the Appendix for a glossary of technical terms.

The worked example uses 15 completed Q-sorts, each comprising rankings of the same 10 statements on a forced distribution ranging from -2 (most disagree) to $+2$ (most agree). The analysis follows the typical workflow recommended in the PQMethod manual and widely reported in published Q studies.

4.2.1 Step 1: Preparing and entering the data

The first step is to prepare the Q-sort data in a format that PQMethod can read. PQMethod requires a plain-text *.DAT* file containing:

- the number of Q-sorts (participants),
- the number of statements in the Q-set,
- the forced distribution shape, and
- each participant's completed Q-sort.

In this worked example, the dataset consists of:

- 15 Q-sorts (participants), and
- 10 statements (Q-set items).

Each Q-sort is entered as a single line of numbers representing the statement rankings from -2 to $+2$. Importantly, the order of the statements must be *identical for all participants*, as Q factor analysis compares the *patterns* of ranking across complete Q-sorts rather than individual item scores.

Once the data file is prepared, it is loaded into PQMethod and checked for errors using the programme's built-in validation tools.

4.2.2 Step 2: Correlating the Q-sorts

After the data are loaded, PQMethod generates a correlation matrix showing the degree of similarity between every pair of Q-sorts. Each value in the matrix represents how closely two participants ranked the statements relative to one another.

At this stage, no “viewpoints” have yet been identified. The correlation matrix simply answers the question: *Which participants sorted the statements in broadly similar ways, and which sorted them differently?* High positive correlations indicate shared patterns of judgement; low or negative correlations indicate divergent perspectives.

This correlation matrix forms the mathematical foundation for factor extraction.

4.2.3 Step 3: Extracting initial factors

The next step is factor extraction, which identifies clusters of Q-sorts that are sufficiently similar to be considered expressions of a shared viewpoint. In PQMethod, this is typically done using centroid factor extraction, although principal components analysis is also available.

For this worked example, centroid extraction is used because it aligns with the exploratory and interpretive aims of Q methodology and remains the most commonly reported approach in Q studies.

PQMethod automatically calculates:

- the number of extractable factors,
- the eigenvalues associated with each factor, and
- the percentage of variance explained.

At this point, several potential factor solutions are inspected (e.g. two-factor, three-factor, four-factor solutions). The aim is not to maximise explained variance, but to identify a solution that yields:

- interpretable factors,
- a meaningful number of defining Q-sorts on each factor, and
- theoretical coherence with the research topic.

For instructional clarity, this worked example proceeds with a three-factor solution, which balances analytic clarity with sufficient diversity of viewpoints.

4.2.4 *Step 4: Rotating the factor solution*

Once an initial factor structure has been extracted, the solution is rotated to improve clarity and interpretability. Rotation adjusts the factor axes to maximise the extent to which each Q-sort loads clearly onto one factor rather than weakly onto several.

In this example, Varimax rotation is applied. Varimax is an automatic rotation procedure that seeks a statistically cleaner solution and is commonly used when researchers are learning Q methodology or wish to minimise subjective decision-making at this stage.

After rotation, each participant's Q-sort receives a factor loading for each factor. These loadings indicate the strength and direction of the relationship between an individual Q-sort and a given factor.

4.2.5 *Step 5: Identifying defining Q-sorts*

The next step is to determine which participants *define* each factor. A Q-sort is considered defining if:

- its factor loading exceeds a statistically significant threshold, and
- it loads clearly on one factor rather than on multiple factors.

PQMethod automatically flags defining Q-sorts based on these criteria. Some participants may not define any factor (for example, if their viewpoints are idiosyncratic or straddle multiple factors). This is not treated as a methodological flaw, but as a substantive finding about the diversity of perspectives in the dataset.

At the end of this step, each retained factor is associated with a subset of participants whose Q-sorts exemplify that shared viewpoint.

4.2.6 *Step 6: Constructing factor arrays*

Once defining Q-sorts have been identified, PQMethod generates a factor array for each factor. A factor array is a composite Q-sort representing how a hypothetical participant with that viewpoint would have ranked all statements.

These arrays are calculated by weighting and averaging the rankings from the defining Q-sorts. The result is a complete -2 to $+2$ ranking for every statement, expressed from the perspective of each factor.

Factor arrays are central to interpretation because they translate statistical outputs back into the concrete language of the original statements.

4.2.7 *Step 7: Interpreting the factors*

The final step is factor interpretation, in which each factor array is examined as a coherent viewpoint. Interpretation focuses on:

- statements placed at the extremes ($+2$ and -2),
- statements ranked differently across factors, and
- any consensus statements ranked similarly by all factors.

In a full empirical study, this stage would draw heavily on post-sort interview data to ground interpretations in participant reasoning. In this worked example, interpretation is supported by the known characteristics of the simulated participant profiles and by the internal logic of the factor arrays themselves.

Each factor is ultimately presented as a narrative typology of perspective, rather than a statistical category, reflecting Q methodology's commitment to preserving subjectivity and plurality.

4.3 *Interpreting factor arrays*

Where factor analysis identifies *patterns* in the data, factor interpretation is the stage at which those patterns are translated into *meaningful accounts of viewpoint*. In Q methodology, the primary object of interpretation is not the factor loading or the eigenvalue, but the factor array; the composite Q-sort that represents a shared way of thinking about the topic under investigation.

This section outlines a structured and beginner-friendly approach to interpreting factor arrays generated in PQMethod, using the worked sustainability dataset introduced earlier. The aim is to show how factors are interpreted *systematically and reflexively*, rather than impressionistically.

4.3.1 *What a factor array represents*

A factor array is best understood as the Q-sort of a hypothetical participant who perfectly exemplifies that factor. It shows how that viewpoint ranks every statement in the Q-set, from strong disagreement (−2) to strong agreement (+2).

Crucially, a factor array is not an average opinion of the whole sample, nor is it a statistical abstraction detached from participants. Instead, it reflects the *shared subjective structure* of those participants whose Q-sorts define the factor.

Interpretation therefore proceeds by asking a simple but powerful question:

“What does the world look like from this point of view?”

4.3.2 *Step 1: Begin with the extremes*

Interpretation should always begin with the extreme statements in the factor array – those placed at +2 (most agree) and −2 (most disagree).

These statements are:

- the most salient to participants holding that viewpoint, and
- the strongest indicators of how the factor differs from others.

For each factor, the researcher should examine:

- which statements occupy the +2 positions,
- which statements occupy the −2 positions, and
- how these positions differ across factors.

At this stage, interpretation should remain *descriptive rather than evaluative*. The aim is simply to articulate what the factor strongly affirms and what it clearly rejects.

4.3.3 *Step 2: Identify the organising logic of the factor*

Once the extremes have been examined, the next step is to look for the organising logic that connects them. Factors rarely reflect random collections of preferences; rather, they tend to express a coherent orientation toward the issue.

In the sustainability example, organising logics might include:

- prioritisation of practical capability over ethical deliberation,
- emphasis on assessment and accountability, or
- commitment to learner agency and hopeful futures.

At this stage, factors should be given working labels (e.g. “*Sustainability as accountable practice*” or “*Skills-first pragmatism*”). These labels are provisional and should emerge inductively from the factor array rather than from preconceived categories.

4.3.4 Step 3: Examine distinguishing statements

Interpretation is deepened by identifying distinguishing statements – those ranked significantly differently in one factor compared to the others.

PQMethod flags these statistically, but their interpretive value lies in what they *do conceptually*: they show how one viewpoint diverges from competing perspectives on the *same issue*.

When interpreting distinguishing statements, researchers should ask:

- What issue does this statement represent in the debate?
- Why might this factor take a stronger or weaker position than others?
- What assumptions about teaching, learners, or curriculum does this position imply?

This step is particularly useful in educational research, where disagreements often centre not on *whether* something matters, but *how* and *in what way* it should matter.

4.3.5 Step 4: Attend to the middle ground

Although extremes attract most attention, the mid-range statements (−1, 0, +1) play an important interpretive role. These placements often indicate:

- accepted but unprioritised ideas,
- unresolved tensions, or
- issues perceived as context-dependent rather than central.

Beginners are often tempted to ignore these statements, but doing so risks flattening the nuance of the viewpoint. In many cases, it is the *combination* of strong commitments and cautious ambivalence that gives a factor its distinctive character.

4.3.6 *Step 5: Use qualitative data to strengthen interpretation*

In a full Q study, interpretation of factor arrays is strengthened through post-sort interviews or written reflections. These data help explain *why* participants placed certain statements where they did, particularly at the extremes.

Although the dataset used here is simulated, the same principle applies, factor arrays should never be interpreted in isolation from participant reasoning. Qualitative data:

- provide insight into underlying values and assumptions,
- guard against over-interpretation by the researcher, and
- help anchor factor narratives in participants' own language.

4.3.7 *Step 6: Write factors as narrative viewpoints*

The final stage of interpretation is to write each factor as a coherent narrative account. In Q methodology, factors are not described as dimensions or variables, but as typologies of viewpoint.

A well-constructed factor narrative typically:

- explains how the factor understands the core issue,
- describes what it prioritises and problematises, and
- situates the viewpoint relative to others in the study.

Importantly, factor narratives should avoid evaluative language (e.g. “better”, “more accurate”) and instead present each factor as a *legitimate and internally coherent perspective* within the broader plurality of views.

4.3.8 *Reflexivity and interpretive responsibility*

Interpreting factor arrays is an inherently interpretive act, and researchers must remain reflexive about their own assumptions, professional commitments, and theoretical orientations. Q methodology does not eliminate subjectivity from analysis; rather, it makes interpretive judgement transparent and accountable.

For this reason, good practice includes:

- documenting interpretive decisions,
- relating interpretations back to the factor arrays, and
- resisting the temptation to collapse multiple viewpoints into a single “take-home” message.

In the context of TED education, where debates about sustainability, skills, and curriculum purpose are value-laden and contested, this commitment to plural interpretation is a methodological strength rather than a limitation.

5 SUMMARY

Q methodology is uniquely well aligned with the *epistemic*, *pedagogical*, and *political* complexity of technology, engineering, and design (TED) education. As a field characterised by contested purposes, value-laden curricular choices, and competing priorities around sustainability, capability, assessment, and educational purpose, TED research requires approaches that can illuminate rather than obscure plurality. Q methodology meets this need by treating subjectivity not as noise or measurement error, but as the central object of inquiry. Through its focus on identifying shared patterns of thinking (typologies of viewpoint rather than averaged positions) it enables researchers to make visible the underlying assumptions that shape curriculum design, pedagogical decision-making, and policy formation.

This paper has demonstrated how Q methodology can be operationalised in a TED-relevant context through a fully worked, fictionalised example centred on sustainability in design education. By modelling each stage of the seven-stage Q process, with particular emphasis on factor analysis and factor interpretation, the paper has shown how analytical decisions can be made transparent, replicable, and pedagogically accessible. The fictional dataset enables researchers new to Q methodology to engage with the method without the constraints of real participant data, while keeping the example grounded in issues that are substantively important to contemporary TED debates.

The worked example illustrates the methodological clarity and interpretive richness that Q methodology can bring to TED education research. It demonstrates how competing viewpoints can be mapped systematically; how differences in priorities, assumptions, and values can be made explicit; and how these differences can be interpreted in ways that strengthen rather than flatten the plurality inherent in TED. Such mapping is especially valuable for areas such as sustainability transitions, curriculum reform, professional learning, and policy development, where contested values often underlie surface-level disagreements.

Taken together, Parts I and II of this primer series aim to build methodological capacity within the TED education research community, supporting researchers in moving beyond procedural familiarity toward confident, reflexive, and contextually informed application of Q methodology. By offering both theoretical grounding and a transparent, practice-oriented example, this series seeks to contribute to a more pluralistic, rigorous, and reflexive research culture within TED education, where diverse viewpoints are not only acknowledged but meaningfully engaged.

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7 APPENDIX

Table 2

Glossary of Terms

Term	Plain-language explanation
Factor	A shared pattern of thinking represented by a group of participants who have sorted the statements in similar ways. In Q methodology, a factor is interpreted as a viewpoint, not a variable or trait.
Q factor analysis	A by-person statistical technique that groups people (their complete Q-sorts) according to similarity, rather than grouping variables. Its purpose is to reveal shared subjective perspectives.
Factor array	A composite Q-sort that shows how a hypothetical participant representing a factor would rank all statements from most disagree to most agree. It forms the main basis for interpretation.
Factor loading	A numerical value indicating how strongly an individual participant's Q-sort is associated with a particular factor. Higher absolute loadings indicate stronger alignment with that viewpoint.
Centroid factor extraction	An exploratory method for identifying potential factors, commonly used in Q methodology because it supports interpretive flexibility rather than optimisation.
Rotation	A mathematical adjustment applied after factor extraction to improve the clarity of the factor solution by encouraging Q-sorts to load more clearly on one factor.
Varimax rotation	An automatic rotation procedure that maximises statistical simplicity by reducing cross-loadings, often used in introductory or instructional Q studies.
Defining Q-sort	A participant's Q-sort that loads significantly and uniquely on a single factor, meaning it clearly exemplifies that shared viewpoint.
Eigenvalue	A statistic indicating the relative strength of a factor in explaining variance among Q-sorts. In Q methodology, eigenvalues are used heuristically rather than as strict decision rules.
Correlation matrix	A table showing the degree of similarity between every pair of Q-sorts. It provides the basis for identifying which participants think alike.
Distinguishing statement	A statement ranked significantly differently in one factor compared to others, helping to clarify how that viewpoint differs from competing perspectives.
Consensus statement	A statement ranked similarly across all factors, indicating an area of broad agreement or shared assumption within the sample.
Factor interpretation	The analytic process of constructing meaningful narrative accounts of each factor by examining factor arrays alongside qualitative data and theoretical context.
Typology of viewpoint	The final interpretive product of Q methodology: a coherent description of a shared way of understanding the issue, represented by a factor.

The Rise and Fall (and Recovery?) of Design and Technology Examination Entries in England over Three Decades: A Statistical Analysis

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Abstract

This paper presents a longitudinal quantitative analysis of General Certificate of Secondary Education (GCSE) Design and Technology (D&T) examination entries in England from 1996 to 2025, examining long-term participation trends in relation to major curriculum and accountability reforms. National GCSE entry data were analysed using descriptive visualisation, percentage-share analysis, and epoch-based trend modelling. Three policy-relevant epochs were identified to compare patterns of uptake under contrasting policy conditions, including the removal of compulsory provision at Key Stage 4 (upper secondary), the introduction of the English Baccalaureate (EBacc) and Progress 8, and GCSE qualification reform. Logarithmic and linear trend analyses indicate a period of rapid growth followed by a sustained and accelerated decline, with the strongest and most consistent trend behaviour observed during the second epoch (2005–2018). Supplementary chi-square analysis was undertaken to explore associations between entry type and policy epoch, though results were constrained by low expected cell counts. While recent data suggest a slowing of decline, this is better characterised as tentative stabilisation rather than substantive recovery. The findings demonstrate a clear temporal alignment between education policy interventions and shifts in D&T participation. The paper contributes longitudinal empirical evidence to debates on curriculum policy, subject equity, and the strategic role of D&T in supporting national design, engineering, and manufacturing capacity.

Key Words: Design and Technology Education, England, Examination Entries, General Certificate of Secondary Education, Policy Reform

1 INTRODUCTION

Design and technology (D&T) has long been positioned as a distinctive component of general education, combining technical knowledge, creativity, problem solving, and critical engagement with the made world (Kimbell & Stables, 2007; Williams, 2012). In England, D&T achieved high levels of student participation following its inclusion as a compulsory national curriculum subject, particularly during the late 1990s and early 2000s. However, over the past two decades, concerns have intensified regarding sustained declines in general certificate of secondary education

(GCSE) D&T examination entries and the implications of this trend for technological capability, skills formation, and economic resilience (Education Policy Institute [EPI], 2022; McLain, 2025).

In England, the General Certificate of Secondary Education (GCSE) is the primary academic qualification taken by students aged 14–16 at the end of compulsory schooling. Almost all students undertake a suite of GCSE subjects, with choices shaped by school offerings, curriculum pathways, and accountability measures.

Previous research highlights the sensitivity of subject uptake to policy levers such as accountability measures, curriculum reform, and qualification design. The introduction of the English Baccalaureate and Progress 8 has been linked to curriculum narrowing and the marginalisation of creative and technical subjects, including D&T. Despite growing qualitative commentary, longitudinal quantitative analyses that align participation trends with discrete policy eras remain limited.

This paper addresses this gap by examining GCSE D&T entry patterns in England between 1996 and 2025, analysing long-term trends across three policy epochs to explore the relationship between systemic reform and subject participation.

2 METHODOLOGY

This study employs a longitudinal quantitative analysis of GCSE D&T entry data in England spanning the years 1996 to 2025. The dataset comprises annual records of total student entries, D&T entries, and non-D&T entries, expressed both in raw counts and as percentages of total entries. The data were sourced from publicly available national statistics and compiled into a structured dataset for analysis.

2.1 *Data Preparation*

The data was sourced from a combination of government data accessible via gov.uk and a freedom of information (FOI) request for details prior to the publicly available data. The dataset was cleaned and formatted in Microsoft Excel, with key variables including:

- Year: Academic year of entry.
- Total No. Students: Total GCSE entries.
- D&T Entries (n): Number of students entered for D&T.
- Percentage D&T Entries (%): Proportion of total entries attributed to D&T.
- Epoch: Categorical variable dividing the timeline into three policy-relevant periods:
 - Epoch 1: 1996–2004
 - Epoch 2: 2005–2018
 - Epoch 3: 2019–2025

2.2 *Analytical Approach*

A linear regression analysis was conducted to examine the overall trend in D&T entries over time. The dependent variable was % D&T Entries, and the independent variable was Year. To explore shifts in trend dynamics, separate regression models were fitted for each epoch. This allowed for comparison of slope coefficients and model fit across distinct policy and curriculum phases. The initial analysis was performed using generative artificial intelligence (GenAI) using Python (via `statsmodels` and `plotly` through Microsoft Copilot) and replicated manually in SPSS for validation. Key metrics such as R^2 , F-statistic, and p-values were used to assess model significance and explanatory power.

2.3 *Visualisation*

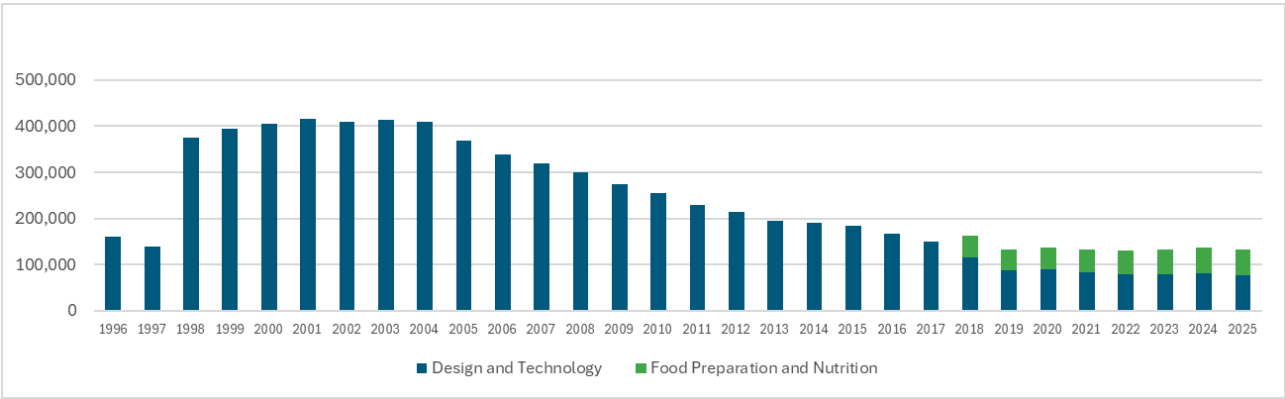
Trend lines were plotted to illustrate both the overall trajectory and epoch-specific patterns in D&T uptake. These visualisations support the statistical findings and highlight periods of significant change, particularly the sharp decline observed from 2005 onwards.

3 FINDINGS

Figure 1 graphically illustrates the numbers of GCSE D&T entries from 1996 to 2025. Prior to 2017, students could choose to study D&T through a range of specialist areas including (but not limited to) food, graphic products, resistant materials, textiles, and systems and control. However, under educational reforms from 2016 the option to study food preparation and nutrition (FP&N) as a non-D&T option. Furthermore, food was removed as a ‘material’ for students to work with in D&T from 2017, when the separate specialist areas were also removed; resulting in a singular GCSE D&T specification, where students were encouraged work in a more multimedia manner. Therefore, the examination results in Figure 1 include FP&N in green from 2018, when it was first examined (having been first studied from 2016). Due to the GCSE D&T specification being launched a year later (studied from 2017 and examined in 2019), in 2018 it was possible to study food through the D&T and FP&N specifications. This may explain why the total number of entries rose from 2017 to 2018, falling again in 2019. The inclusion of FP&N numbers provides a more comparable dataset pre- and post-2019.

Figure 1

Charting the GCSE Design & Technology Entries from 1996 to 2024 (Numbers of Students Entered), including GCSE Food Preparation and Nutrition from 2018



Alongside the rise and fall of GCSE D&T entries illustrated by Figure 1, Figure 2 provides a comparison of D&T (excluding FP&N) compared with non-D&T entries (i.e., the students who did not study D&T in each year). This shows a steady rise of non-D&T entries from the early 2000s against a fall in D&T entries that almost mirror one another.

Figure 2

Year-by-year breakdown of D&T vs Non-D&T GCSE entries from 1996 to 2025

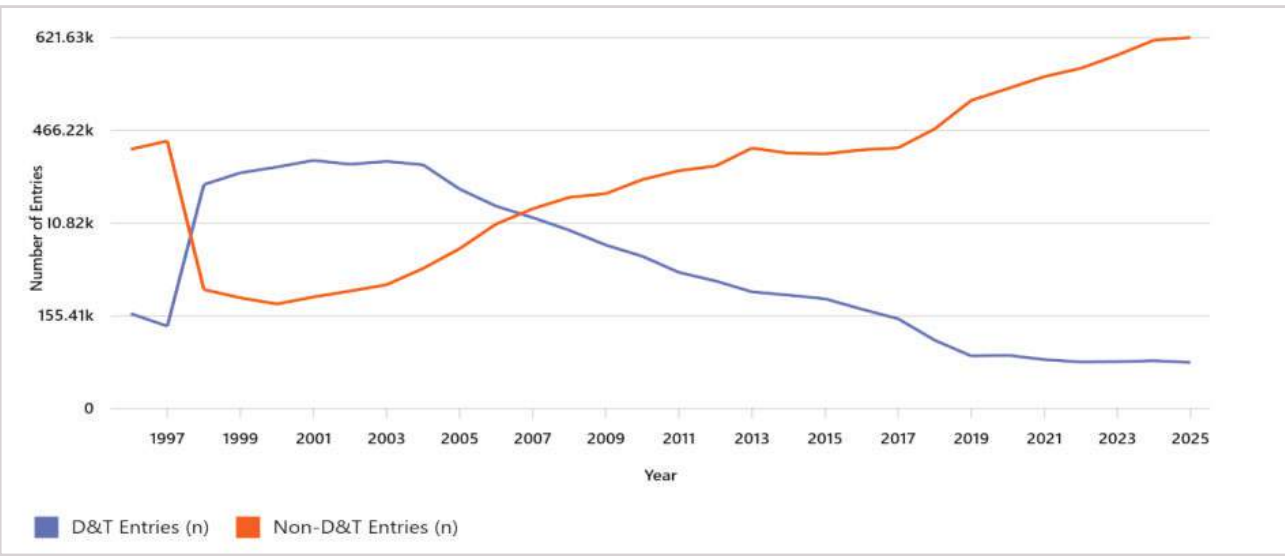


Figure 1Figure 2 compares the D&T with non-D&T GCSE entries over the past three-decade, year-by-year, illustrating the rapid rise to popularity in the late 1990s to the reversal of fortunes in the mid-2000s and expanding gap up to the present. In the late 1990s to early 2000s, D&T entries were strong, peaking around 2000–2002. By the mid-2000s to 2010s, a steady decline in D&T entries began, while Non-D&T entries remained stable or increased, coinciding with policy

changes around the subject becoming non-compulsory at KS4 (upper secondary). Post-2018, a sharp drop in D&T entries is evident, coinciding with policy and curriculum changes, while Non-D&T entries continued to rise. The lines do not mirror each other perfectly because total GCSE entries increase over time. As the cohort size grows, the rise in non-D&T entries is influenced both by the falling proportion of D&T uptake and by the expanding total number of GCSE entries. This results in similar but not mathematically identical patterns.

The data were divided into three ‘epochs’ with key policies marking the transition. Figure 3 illustrates the total number of GCSE D&T entries against the non-GCSE entries (i.e. the students in each year that did not take D&T). Epoch 1 (1996–2004), begins with the earliest data available from 1996 and ends with the policy change in 2004 where the subject was made non-compulsory for schools to offer at KS4. In this period, D&T entries were relatively high, forming a substantial portion of total entries. Epoch 2 (2005–2018) shows a noticeable decline in D&T entries, while Non-D&T entries increased. Epoch 3 (2019–2025) begins with the launch of the new GCSE specifications being first examined in 2019 D&T entries dropped significantly, with Non-D&T entries dominating. However, the epochs are not uniform in length, with Epoch 1 being 9 years, Epoch 2 being 14 years, and Epoch 3 being 7 years. Whilst there is similarity between Figure 3 and Figure 4, both are retained because it presents the raw entry numbers and the percentage shares. This allows clearer comparison of the magnitude of change (Figure 3) in absolute terms (particularly the widening gap between D&T and non-D&T entries) which complements Figure 4’s proportional analysis.

Figure 3

Visualization showing the trend of D&T vs Non-D&T GCSE entries across the three epochs

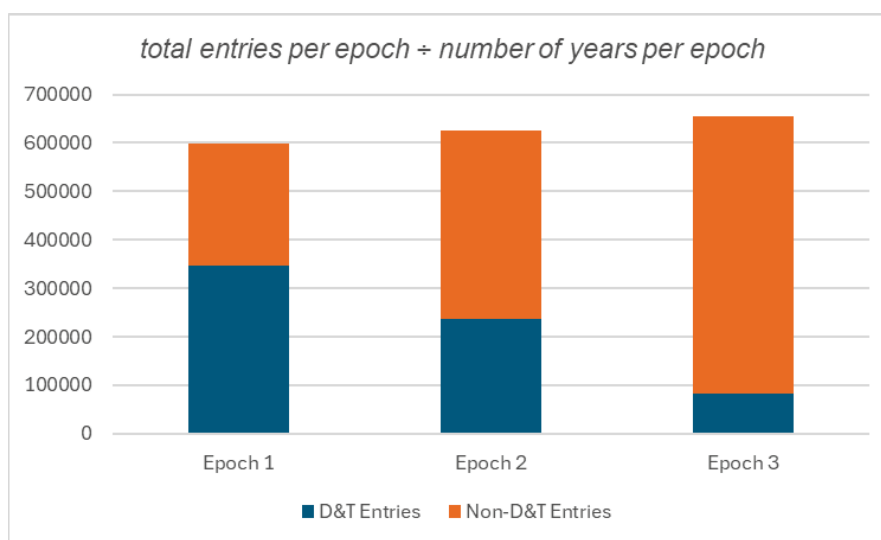


Figure 4 shows the same periods with the average percentage of D&T and non-D&T entries for the whole student population in each year, illustrating the drop in the ‘market share’ that D&T held in each epoch.

Figure 4

Visualization showing the average percentage for the total number of students for D&T vs Non-D&T GCSE entries across the three epochs

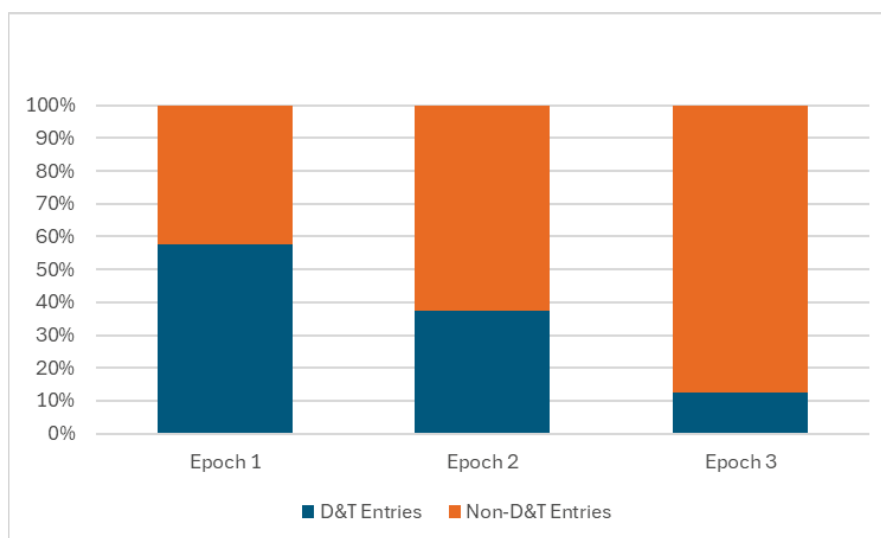


Figure 5, Figure 6 and Figure 7 chart the three epochs year-by-year, with logarithmic trendlines and R-Squared (R^2) values. The R^2 values (also known as the coefficient of determination) measures how well a trendline fits the data. When applied to a logarithmic trendline, it specifically indicates how well a logarithmic model explains the variation in the dependent variable. A logarithmic trendline assumes the relationship between variables follows the form:

$$y = a \cdot \ln(x) + b$$

This is useful when the rate of change decreases over time, common in saturation effects, diminishing returns, or decay patterns. If $R^2 = 1$, it indicates a perfect fit - the logarithmic model explains all variability in the data. If R^2 is close to 0, it indicates a poor fit, the model explains very little of the variability. Higher R^2 values suggest the logarithmic trendline is a good representation of the data's pattern.

The R^2 for logarithmic trendlines across the three epochs are:

- Epoch 1 (1996–2004): $R^2 = 0.7654$
- Epoch 2 (2005–2018): $R^2 = 0.9311$
- Epoch 3 (2019–2025): $R^2 = 0.7786$

The R^2 for Epoch 1 (0.7654) indicates a moderate-to-strong logarithmic relationship between year and D&T entries. Suggests that the early growth in D&T entries during this period followed a logarithmic pattern, possibly reflecting initial expansion followed by early signs of saturation or policy shifts (e.g., curriculum flexibility in KS4).

Epoch 2 (0.9311) is a very strong fit to a logarithmic model. The high R^2 suggests these factors had a predictable and compounding impact on uptake. This reflects a consistent and accelerating decline in D&T entries, likely driven by:

- Remove of compulsion for schools to offer D&T GCSE (2004).
- EBacc introduction (2010) excluding D&T.
- Progress 8 (2016) reinforcing EBacc focus.
- GCSE reform (2017) increasing delivery complexity.
- Teacher shortages and funding pressures.

Epoch 3 (0.7786) indicates a moderate fit, with some variability. The slightly lower R^2 may reflect uncertainty or emerging interventions. The decline continues but may be slowing or stabilising, possibly due to:

- GCSE reform (2017) acceptance by schools who continued to offer GCSE D&T.
- Vocational reforms (T Levels) shifting focus to post-16.
- Policy reviews and advocacy efforts (e.g., House of Lords report in 2023).

3.1 *Logarithmic Trendline Analysis*

The logarithmic trendline fits best in Epoch 2, where policy impacts were most pronounced and sustained. Epochs 1 and 3 show more variability, possibly due to transitional phases or mixed policy effects. Overall, the R^2 values support the interpretation that systemic policy changes have had a strong and measurable impact on D&T GCSE entries over time.

Figure 5

Epoch 1: GCSE D&T Entries by Number 1996 to 2004

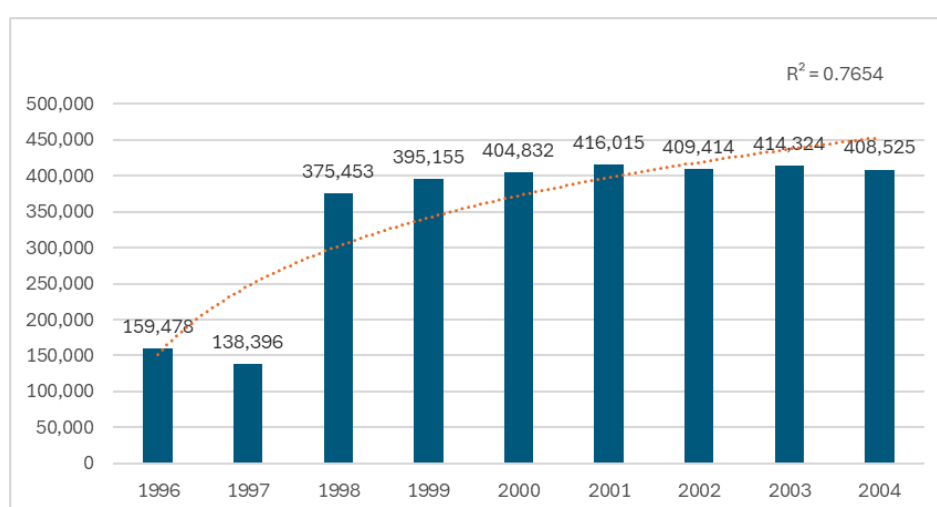


Figure 6

Epoch 2: GCSE D&T Entries by Number 2005 to 2018

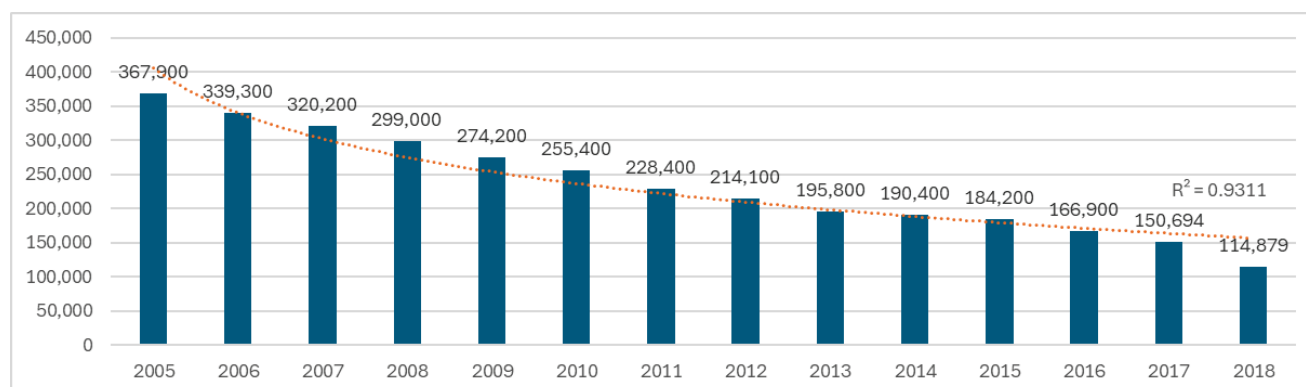
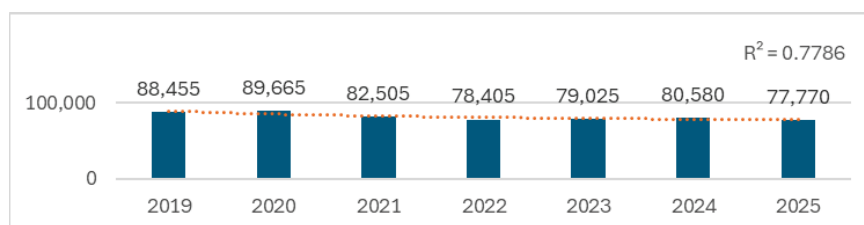


Figure 7

Epoch 3: GCSE D&T Entries by Number 2019 to 2024



3.2 Three-way Chi-Square Test

A three-way Chi-Square Test (Table 1) was conducted to test whether there is a statistically significant association between GCSE entry type (D&T vs Non-D&T) and policy epoch. The Pearson Chi-Square p-values for all epochs and the total dataset are > 0.05 (the asymptotic significance was 0.230 for Epoch 1, 0.234 for Epoch 2, and 0.227 for Epoch 3). It is likely that the ratio p-values are also non-significant (the asymptotic significance was 0.993 for Epoch 1, 1.000 for Epoch 2, and 0.853 for Epoch 23). No statistically significant association was found between entry type and epoch using this test. However, the test may be underpowered due to small sample sizes and many cells with expected counts < 5 (as noted in the footnotes). This limits the reliability of the chi-square results and suggests caution in interpreting them as definitive.

Table 1

Three-way Chi-Square tests of D&T and non-D&T GCSE entries, by policy epoch

GCSE D&T Epoch		Value	df	Asymptotic Sig. (2-sided)
Epoch 1 (1996-2004)	Pearson Chi-Square	72.000 ^b	64	0.230
	Likelihood Ratio	39.550	64	0.993
	No. of Valid Cases	9		
Epoch 2 (2005-2018)	Pearson Chi-Square	182.000 ^c	169	0.234
	Likelihood Ratio	73.894	169	1.000
	No. of Valid Cases	14		
Epoch 3 (2019-2025)	Pearson Chi-Square	42.000 ^d	36	0.227
	Likelihood Ratio	27.243	36	0.853
	No. of Valid Cases	7		
TOTAL	Pearson Chi-Square	870.000 ^a	841	0.237
	Likelihood Ratio	204.072	841	1.000
	No. of Valid Cases	30		

a. 900 cells (100.0%) have expected count less than 5. The minimum expected count is 0.03.

b. 81 cells (100.0%) have expected count less than 5. The minimum expected count is 0.11.

c. 196 cells (100.0%) have expected count less than 5. The minimum expected count is 0.07.

d. 49 cells (100.0%) have expected count less than 5. The minimum expected count is 0.14.

3.3 Regression Analysis

Regression analysis was conducted to assess how well Year predicts GCSE D&T entries using linear regression. Table 2 shows that the R^2 for Epoch 1 (0.597) has a moderate fit with some variability in early growth, Epoch 2 (0.981) has a very strong fit with consistent decline, and Epoch 3 (0.728) has a strong fit with decline continuing but with more variability.

Epoch 2 shows the strongest linear relationship, indicating a predictable and sustained decline in D&T entries. Epoch 1 reflects a period of growth but with more fluctuation. Whereas Epoch 3 suggests a possible stabilisation or slowing of the decline.

Table 2

Model Summary of Linear Regressions by Epoch

Model ^a	R ^b	R ²	Adjusted R ²	Std. Error
1	0.773	0.597	0.539	75573.910
2	0.990	0.981	0.979	10959.555
3	0.853	0.728	0.673	2775.746

a. Epoch 1 (1996-2004), Epoch 2 (2005-2018), Epoch 3 (2019-2025)

b. Predictors: (Constant), Year

Analysis of Variance (ANOVA) To test whether the regression models are statistically significant (Table 3). The key results are that for both Epochs 1 and 2 the F-statistic is 609.092, with $p < 0.001$ indicating high significance. For Epoch 3 the F-statistic is 13.369, with $p = 0.015$ indicating statistical significance. All three models are statistically significant, meaning Year is a valid predictor of D&T entries in each epoch. The very high F-values in Epochs 1 and 2 reflect strong model fit and low error variance.

Table 3

Analysis of Variance (ANOVA) by Epoch

Model ^a	Sum of Squares	df	Mean Square	F	Sig. ^b
1 Regression	73159135073.540	1	73159135073.540	609.092	<0.001
Residual	1441342265.675	12	120111855.473		
Total	74600477339.214	13			
2 Regression	73159135073.540	1	73159135073.540	609.092	<0.001
Residual	1441342265.675	12	120111855.473		
Total	74600477339.214	13			
3 Regression	103008108.036	1	103008108.036	13.369	0.015

Residual	38523827.679	5	7704765.536
Total	141531935.714	6	

a. Epoch 1 (1996-2004), Epoch 2 (2005-2018), Epoch 3 (2019-2025)

b. Predictors: (Constant), Year

Table 4 shows the coefficients by epoch to quantify the direction and magnitude of change in D&T entries over time. The Year coefficient for Epoch 1 is +31,879.233, confirming a positive slope, where entries increased over time. For Epoch 2, the Year coefficient (-17932.613), describes a strong negative slope indicating a sharp decline in entries. The Year coefficient for Epoch 3 (-1918.036) confirms a mild negative slope, indicating slower decline and possible stabilisation.

In summary, in Epoch 1 GCSE entries are in a rapid growth phase, possibly due to the introduction of D&T to the national curriculum, with expansion due to policy support as a compulsory subject in KS4 (upper secondary). In Epoch 2, entries go into a steep decline, aligned with major policy changes, including the removal of compulsion for schools to offer D&T at KS4, and later introduction of the EBacc and Progress 8 accountability measures. However, after the introduction of the reforms to GCSE D&T in 2017, first examined in 2019, Epoch 3 sees the decline continuing but at a reduced rate, possibly due to stabilisation efforts or vocational alternatives; despite the continuing policy disincentives for schools to offer the subject.

Table 4

Coefficients by Epoch

		Unstandardised Coefficients ^b			
Model ^a		B	Std. Error	t	Sig.
1	(Constant)	-63411623.111	19797135.006		-3.203
	Year	31879.233	9898.559	0.773	3.221
2	(Constant)	36307263.782	1461581.867		24.841
	Year	-17932.613	726.611	-0.990	-24.680
3	(Constant)	3960611.786	1060674.338		3.734
	Year	-1918.036	524.567	-0.853	-3.656

a. Epoch 1 (1996-2004), Epoch 2 (2005-2018), Epoch 3 (2019-2025)

The Chi-Square test was used to explore the categorical association between epochs and entry types but limited by small sample sizes. The regression and ANOVA test quantified and confirmed the strength and significance of trends over time, with the coefficients showing the direction and rate of change, helping to interpret policy impact.

3.4 Major Policy Impacts on GCSE Design and Technology Entries in England

The decline in GCSE D&T entries from 1996 to 2025 has been shaped by several key policy developments and systemic changes in England's education landscape.

The decline in GCSE D&T entries in England from the early 2000s to 2025 has been shaped by a series of significant policy changes and systemic challenges. These developments have influenced curriculum priorities, teacher supply, and school accountability frameworks. Referring to Department for Education (DfE) and EPI analyses, the following summaries outline the most impactful policy reforms.

3.4.1 English Baccalaureate (EBacc): Introduced in 2010

The EBacc performance measure prioritised academic subjects such as English, mathematics, sciences, humanities, and languages. D&T was excluded from this framework, leading many schools to reduce its curriculum time and resources (EPI, 2022).

3.4.2 Progress 8 Accountability Measure: Introduced in 2016

Progress 8 reinforced the focus on EBacc subjects by measuring student progress across eight qualifications. This further marginalised non-EBacc subjects like D&T, contributing to its declining uptake (EPI, 2022).

3.4.3 GCSE Qualification Reform: First Teaching from 2017

The reformed D&T GCSE introduced more rigorous content and assessment criteria. While intended to raise standards, the increased complexity and cost of delivery discouraged some schools from continuing the subject (DfE, 2015).

3.4.4 Teacher Workforce Decline: 2011 to 2020

Between 2011 and 2020, the number of D&T teachers halved from 14,800 to 7,300. Recruitment targets were consistently missed, and financial incentives for D&T teachers were limited compared to subjects like mathematics and physics (EPI, 2022).

3.4.5 *Funding and Infrastructure Challenges*

D&T is resource-intensive, requiring specialist equipment and dedicated teaching spaces. Schools facing capital constraints, particularly free schools and sponsored academies, often excluded D&T due to cost and infrastructure limitations (EPI, 2022).

3.4.6 *Vocational Education Reforms: Post-2018*

The government introduced T Levels, Institutes of Technology, and apprenticeship reforms to strengthen vocational pathways. However, these initiatives focused on post-16 education and did not reverse the decline in D&T uptake at GCSE level (EPI, 2022).

4 CONCLUSION

The pattern of decline presented in this paper strongly corresponds with specific policy moments: the subject's removal from compulsory status at KS4 (2004), EBacc prioritisation (2010), Progress 8 weighting (2016), and the reformed GCSE structure (2017–19). Each reform reduced curriculum space for D&T, incentivising schools to redirect resources to EBacc subjects; this structural shift is reflected in the accelerated decline observed during Epoch 2. GCSE D&T entries in England fell from 280,000 in 2009 to 136,000 in 2020, and further by 2025. An impact of this is that students who do not study D&T at GCSE are highly unlikely to pursue it post-16. Therefore, the decline poses risks to the UK's ambitions in engineering, manufacturing, and design skills development. The analysis indicates that the sustained decline in D&T entries is closely aligned with major systemic policy shifts. While the data show a modest slowing of decline in the third epoch, this should be interpreted as tentative stabilisation rather than recovery. Without changes to accountability structures or stronger curriculum incentives, the long-term viability of D&T remains uncertain. The removal of compulsory D&T provision at upper secondary (key stage 4, 14–16 years) reduced the subject's status within the curriculum, while the introduction of the EBacc from 2010 and Progress 8 from 2016 redirected school priorities toward headline accountability measures that exclude D&T; continuing its decline, albeit with limited statistically significant change in the rate during the period up to the launch of the new GCSE specifications. These policy pressures, combined with declining teacher recruitment, reduced specialist facilities, and increased delivery costs, contributed to a structural disincentive for schools to maintain D&T. The alignment between policy change and trend data therefore supports the interpretation that national reforms exerted a significant causal influence on participation rates.

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The Digital Shift and AI Integration in Undergraduate Education: Exploring Learning Experiences Across STEM and Non-STEM Disciplines

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Abstract

The rapid global digital shift, driven by artificial intelligence (AI) and digital technologies, is transforming higher education environments. This study examines how undergraduate students engage with these technologies and how such interactions are associated with personalized learning, student engagement, digital literacy, and adaptive learning across STEM and non-STEM disciplines. The research was conducted in Qatar as part of the Summer Internship Program at the Qatar University Young Scientists Center (QUYSC). A validated survey instrument was used to measure four key learning-related dimensions associated with students' interaction with these technologies. Quantitative analysis, including descriptive statistics, reliability testing, and correlation analysis, examined relationships among the constructs. The findings revealed strong positive associations across all dimensions, indicating that engagement with these technologies is associated with students' perceived learning readiness and digital competence. STEM students showed slightly higher levels of digital engagement, possibly reflecting differences in prior exposure to technological systems, while descriptive variations were observed across gender and nationality. From a technology and engineering education perspective, these findings suggest that students' engagement can be understood as interaction with technological systems through which technological awareness and interaction capabilities are developed. This study contributes to technology and engineering education by conceptualizing students' engagement with AI-enabled platforms as interaction with technological systems that support these capabilities.

Key Words: Digital Shift, Artificial Intelligence, Technological Systems, STEM and Non-STEM Education, Undergraduate Students

1 INTRODUCTION

The COVID-19 pandemic triggered an unprecedented disruption to education systems worldwide, affecting primary, secondary, and higher education. As institutions suspended face-to-face instruction, teaching and learning rapidly shifted to digitally mediated environments to ensure educational continuity. This shift accelerated digital transformation, fundamentally reshaping pedagogical practices, assessment models, institutional operations, and learner engagement across educational sectors. In the post-pandemic era, this large-scale digital shift was further intensified by rapid technological advancements, particularly in artificial intelligence (AI). Higher education institutions increasingly integrate digital technologies, including AI-enabled systems such as intelligent tutoring systems, adaptive learning platforms, learning analytics, automated assessment technologies, and generative AI applications such as ChatGPT. These systems do not merely support instructional delivery but reshape how students interact with digital information and technological infrastructures. They can be understood as technological systems with which students actively interact, interpret, and adapt during learning processes. From a technology and engineering education perspective, examining these interactions helps explain how learners develop technological awareness and interaction capabilities (Chen et al., 2020; Crompton & Burke, 2023; Zawacki-Richter et al., 2019).

Despite this increasing integration of technological systems, their educational impact remains contested. Empirical studies and systematic reviews report benefits such as improved academic performance, enhanced engagement, personalized learning pathways, and instructional efficiency (Kuleto et al., 2021; Zhou, 2023). However, parallel concerns have been raised regarding ethical use, digital dependency, uneven digital literacy, limited pedagogical integration, and insufficient evidence of deep learning gains (O'Dea & O'Dea, 2023; Zawacki-Richter et al., 2019). Recent reviews emphasize that while AI demonstrates transformative potential, robust empirical evidence on its long-term learning impact, particularly across diverse disciplines and educational contexts, remains limited.

Within this context, higher education students constitute a critical population for examining these dynamics, as they are preparing to enter an increasingly digital and AI-driven workforce. Their academic experiences during this period of accelerated technological transformation are likely to shape learning outcomes, engagement patterns, digital competencies, adaptability, and future career readiness. Understanding how students interact with these systems is essential for examining how they develop technological capabilities and learning experiences in digitally mediated environments (Chen et al., 2020; Crompton & Burke, 2023).

Within this evolving technological context, four interrelated dimensions are central to understanding students' learning experiences in digitally mediated higher education environments involving technological systems. Specifically, personalized learning captures students' self-reported improvements in understanding, skills, and academic performance (Zhou, 2023). Student engagement reflects learners' cognitive, behavioural, and emotional involvement in learning and has been consistently associated with how students interact with AI-enabled and digital technological systems, particularly through personalization and feedback processes (Crompton & Burke, 2023; Kuleto et al., 2021). Digital literacy refers to students' ability to use, evaluate, and adapt to digital and AI-based tools, functioning both as a prerequisite for and an

outcome of effective AI use (Zawacki-Richter et al., 2019; Ocaña-Fernández et al., 2019). Finally, adaptive learning denotes the personalization of content, pacing, and feedback through AI-enabled systems, which supports learning effectiveness across disciplines (Chen et al., 2020; Zhou, 2023).

Disciplinary orientation may further shape how students experience digitally mediated learning environments. Existing research indicates that AI applications in higher education have predominantly focused on STEM contexts, while learning experiences and outcomes in non-STEM disciplines remain comparatively underexplored (Crompton & Burke, 2023; Zawacki-Richter et al., 2019). Examining differences between STEM and non-STEM students is therefore important to determine whether engagement with AI and digital technologies develops equitably across disciplines or whether distinct patterns of technological engagement emerge across academic fields.

Although digital transformation and AI integration in education are global phenomena, contextual factors play a critical role in shaping their implementation and impact. In Qatar, substantial national investments in digital infrastructure have accelerated the adoption of AI-enabled learning environments; however, empirical evidence examining their role in undergraduate learning across disciplinary groups remains limited. Accordingly, this study examines how undergraduate students engage with AI and digital technologies in higher education and how such interactions are associated with personalized learning, while also exploring variations across demographic characteristics. By adopting a quantitative approach to examine the interrelationships among personalized learning, engagement, digital literacy, and adaptive learning, the study contributes to understanding how students interact with emerging digital technologies within contemporary higher education environments. This study positions AI-enabled and digital platforms as technological systems and provides a comparative analysis of how students across STEM and non-STEM disciplines interact with and adapt to these systems.

2 LITERATURE REVIEW

Building on the contextual and conceptual framing established in the Introduction, this section synthesises existing scholarship on the role of digital technologies, including AI, in the post-pandemic digital transformation of higher education. Although digital technologies had been progressively adopted prior to the pandemic, the abrupt shift to remote and hybrid learning environments required large-scale technological integration to maintain educational continuity (Matsieli & Mutula, 2024; Popenici & Kerr, 2017). This transition extended beyond instruction to include assessment practices, student support systems, and institutional governance, signalling a systemic transformation in higher education rather than a temporary technological adjustment. Within this transformation, digital technologies, including AI, have become central components of contemporary higher education environments.

Recent scholarship conceptualizes AI as a central driver of strategic transformation in higher education, enabling institutions to manage scalability, personalization, and complexity in learning environments (George & Wooden, 2023). Systematic reviews document a substantial increase in AI-related research since 2020, with dominant application areas including intelligent tutoring

systems, automated assessment, learning analytics, and AI-based student support mechanisms (Crompton & Burke, 2023; Ouyang & Jiao, 2021; Zawacki-Richter et al., 2019). However, scholars caution that AI adoption is frequently technology-led rather than pedagogy-driven, raising concerns about superficial implementation, limited instructional alignment, and uneven learning outcomes across contexts (O'Dea & O'Dea, 2023). These concerns highlight the importance of examining how students experience the broader digital shift in higher education rather than focusing solely on specific technological tools.

Empirical research generally reports positive associations between AI use and learning-related outcomes, including improvements in academic performance, problem-solving skills, conceptual understanding, and instructional efficiency (Chen et al., 2020; Kuleto et al., 2021; Zhou, 2023). Personalized learning platforms and adaptive instructional systems, in particular, have been shown to enhance learning efficiency by tailoring content and pacing to individual learner needs. Nevertheless, the magnitude and consistency of these learning gains vary across disciplines, instructional designs, and student populations, suggesting that AI effectiveness is highly context dependent.

Importantly, several scholars argue that self-reported learning gains may not always reflect deep learning or critical understanding, particularly when AI tools are primarily used for automation or surface-level task completion (O'Dea & O'Dea, 2023; Popenici & Kerr, 2017). This limitation underscores the importance of examining learning gains alongside other learning-oriented dimensions that shape students' experiences in AI-integrated environments, including engagement, digital literacy, and instructional adaptability.

Student engagement has been consistently identified as a key mechanism through which digitally supported learning environments, including AI-enabled systems, influence educational outcomes. Research indicates that AI technologies can enhance engagement by providing immediate feedback, adaptive support, and data-driven insights into learning progress, especially in online and blended contexts (Crompton & Burke, 2023; Kuleto et al., 2021; Ouyang & Jiao, 2021). However, engagement outcomes depend strongly on pedagogical design, as AI-driven convenience may encourage surface-level participation rather than sustained cognitive involvement if not intentionally structured (O'Dea & O'Dea, 2023; Popenici & Kerr, 2017).

Digital literacy has also emerged as a critical factor shaping students' ability to benefit from AI-integrated learning environments. Defined as the capacity to effectively use, evaluate, and critically engage with digital and AI-based tools, digital literacy influences both access to AI technologies and the quality of learning experiences (Ocaña-Fernández et al., 2019). Uneven digital literacy can exacerbate learning disparities, with some students leveraging AI strategically while others experience dependency, cognitive overload, or ethical challenges (O'Dea & O'Dea, 2023; Zawacki-Richter et al., 2019). Consequently, digital literacy functions both as a prerequisite for effective AI use and as an outcome shaped through sustained interaction with intelligent systems (Chen et al., 2020). Another widely discussed advantage of AI in higher education is adaptive learning, which enables personalized content, flexible pacing, and real-time feedback. Empirical studies suggest that AI-driven adaptive platforms can support learners across both STEM and non-STEM disciplines by adjusting instructional pathways and assessment strategies

(Kuleto et al., 2021; Zhou, 2023). However, adaptive learning alone does not guarantee meaningful learning unless aligned with clear learning objectives and sound pedagogical principles (O'Dea & O'Dea, 2023).

Despite extensive scholarly attention to AI in higher education, several gaps remain. Existing research has predominantly focused on STEM contexts, while learning experiences and outcomes in non-STEM disciplines remain underexplored (Crompton & Burke, 2023; Zawacki-Richter et al., 2019). Moreover, much of the literature emphasizes technological capabilities or institutional perspectives, with limited empirical evidence examining how students interact with digital and AI-enabled systems within post-pandemic higher education environments, particularly in non-Western contexts. There is also a need for quantitative studies examining learning-related dimensions, including engagement, digital literacy, and adaptive learning, to provide a more holistic understanding of how students interact with technological systems.

Addressing these gaps, this study examines the role of the broader digital shift in higher education, including AI-enabled and digital systems, in undergraduate students' learning experiences. By examining personalized learning alongside engagement, digital literacy, and adaptive learning, the study provides a comparative analysis of how digital transformation is associated with students' experiences across STEM and non-STEM disciplines within the Qatari higher education context. This study contributes to technology and engineering education by examining how undergraduate students interact with these technological systems, focusing on how such interactions support the development of technological awareness, system understanding, and interaction capabilities within higher education contexts where such perspectives remain underexplored.

2.1 *Theoretical and Conceptual Framework*

This study is grounded in Social Cognitive Theory (SCT) (Lent et al., 1994) and the Technology Acceptance Model (TAM) (Davis, 1989) to interpret undergraduate students' digital learning experiences in higher education. SCT emphasizes the reciprocal interaction between personal capabilities, behaviors, and environmental conditions. In this study, the growing presence of digital technologies, including AI, represents an environmental factor shaping how students interact with learning systems. From this perspective, student engagement and personalized learning reflect behavioral responses within technology-enabled environments, while digital literacy represents a personal capability influencing students' ability to interact effectively with digital systems. Complementing this perspective, TAM explains how students' perceptions of digital technologies influence their interaction with these systems, highlighting the roles of perceived usefulness and perceived ease of use in shaping engagement with AI-enabled and other digital learning technologies. Conceptually, this study examines the role of the broader digital shift in higher education, including AI integration and related digital technologies, in undergraduate learning experiences. Four interrelated dimensions of personalized learning, student engagement, digital literacy, and adaptive learning are examined as complementary indicators of students' experiences rather than as causal predictors or outcomes. Disciplinary orientation (STEM and non-STEM) is incorporated as a comparative lens to explore whether patterns of interaction with digital technologies vary across academic fields.

3 METHODOLOGY

This study adopted a quantitative cross-sectional research design to examine undergraduate students' experiences with digital technologies, including AI. The study compared learning and technology interaction experiences between STEM and non-STEM students and explored variations across key demographic characteristics. A review of relevant literature informed the identification of four learning-related dimensions: Personalized Learning, Student Engagement, Digital Literacy, and Adaptive Learning. Based on this synthesis, a structured questionnaire was developed to measure these constructs. The instrument included demographic questions, closed-ended items (yes/no), and five-point Likert-scale statements capturing students' self-reported learning experiences.

The survey was administered to 50 undergraduate students enrolled in STEM ($n = 26$) and non-STEM ($n = 24$) programs at a higher education institution in Qatar. Demographic variables, including gender, nationality (Qatari and expatriate), and educational level, were collected. Participation was voluntary, and informed consent was obtained prior to data collection (QU-IRB 310/2025-EA). This study was conducted as part of the Qatar University Young Scientists Center (QUYSC) Summer Internship Program 2025. Data were analyzed using IBM SPSS Statistics. Internal consistency was assessed, while correlation analysis examined relationships among the learning dimensions. Descriptive comparisons examined differences across gender, nationality, and discipline. Given the exploratory nature of the study and the small sample size, the findings are interpreted as indicative patterns rather than generalized conclusions, with a potential risk of Type II error (false negatives).

For transparency, generative AI tools were used only for language refinement and editing to improve clarity and readability. All conceptualization, data analysis, interpretation, and writing were carried out by the authors.

4 RESULTS

4.1 *Reliability of the Measurement Instrument*

Table 1

Reliability statistics for the four learning-related constructs

Construct	Final Items	Cronbach's Alpha
Personalized Learning	5	0.776
Student Engagement	4	0.714
Digital Literacy	3	0.726
Adaptive Learning	5	0.779

The internal consistency of the survey instrument was assessed using Cronbach's alpha (Tavakol & Dennick, 2011). As shown in Table 1, all four constructs demonstrated acceptable reliability ($\alpha = 0.714\text{--}0.779$), indicating satisfactory internal consistency.

4.2 Assessment of Normality

Normality of construct mean scores was examined using the Shapiro–Wilk test for both STEM and Non-STEM student groups (Ghasemi & Zahediasl, 2012). As shown in Table 2, the non-STEM group ($p > .05$) met normality assumptions, while the STEM group ($p < .05$) showed departures from normality. Consequently, non-parametric statistical methods were applied for group comparisons.

4.3 Comparison Between STEM and Non-STEM Students

Table 2

Mann–Whitney U test results comparing STEM and Non-STEM students across learning-related constructs

Construct	Non-STEM Median (IQR)	STEM Median (IQR)	<i>U</i>	<i>Z</i>	<i>p</i> -value
Personalized Learning	2.8	2.8	264.5	-0.938	.348
Student Engagement	2.0	2.0	254.5	-1.137	.255
Digital Literacy	3.8	4.0	310.5	-0.030	.976
Adaptive Learning	2.7	2.7	263.5	-0.954	.340

Group differences were examined using the Mann–Whitney U test. No statistically significant differences were observed between STEM and Non-STEM students across any of the four constructs ($p > .05$). Median values were similar across groups, with slightly higher digital literacy in STEM students. However, given the small sample size, these findings should be interpreted cautiously.

4.4 Item-Level Descriptive Statistics by Discipline

Descriptive statistics for selected learning-related items across non-STEM and STEM students are presented in Table 3. Personalized Learning (PL3) and Digital Literacy (DL5) items recorded relatively high mean and median values in both groups, indicating strong perceived digital learning benefits, including AI-enabled features. Adaptive Learning items (AL4 and AL5) also showed consistently high values across disciplines. In contrast, Student Engagement (SE5) showed comparatively lower mean and median scores in both groups, suggesting moderate engagement levels despite positive perceptions in other learning dimensions.

Table 3

Descriptive statistics for selected learning-related items among non-STEM students (n = 24)

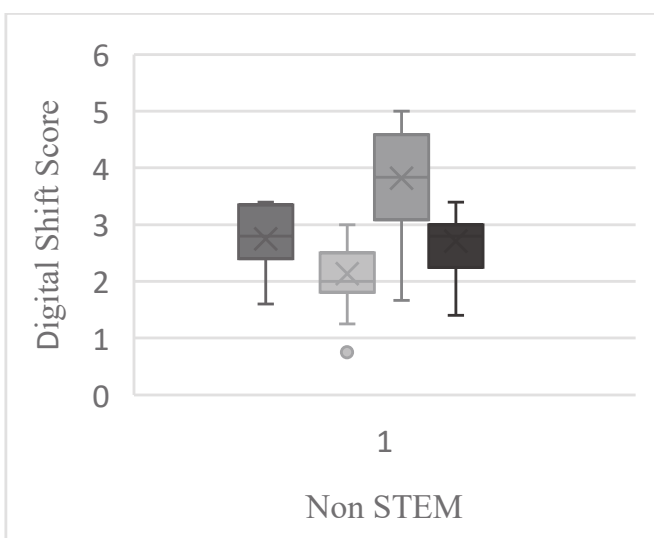
Variable	Non-STEM Mean	STEM Mean	Non-STEM SD	STEM SD	Non-STEM Median	STEM Median
PL3	4.29	4.15	0.62	0.73	4.00	4.00
SE5	3.29	3.46	1.16	0.81	3.00	3.00
DL5	4.21	4.23	1.02	0.65	4.50	4.00
AL4	3.79	3.69	0.93	1.09	4.00	4.00
AL5	4.08	3.77	0.83	0.65	4.00	4.00

4.5 Digital Shift by Education Field and Gender

Boxplot visualizations were examined to explore distributional patterns across groups. Figures 1 and 2 illustrate score distributions for the four constructs among Non-STEM and STEM students, respectively. Visual inspection suggests relatively similar distributions across groups.

Figure 1

Boxplots showing the distribution of personalized learning, student engagement, digital literacy, and adaptive learning among non-STEM students

**Figure 2**

Boxplots showing the distribution of personalized learning, student engagement, digital literacy, and adaptive learning among STEM students

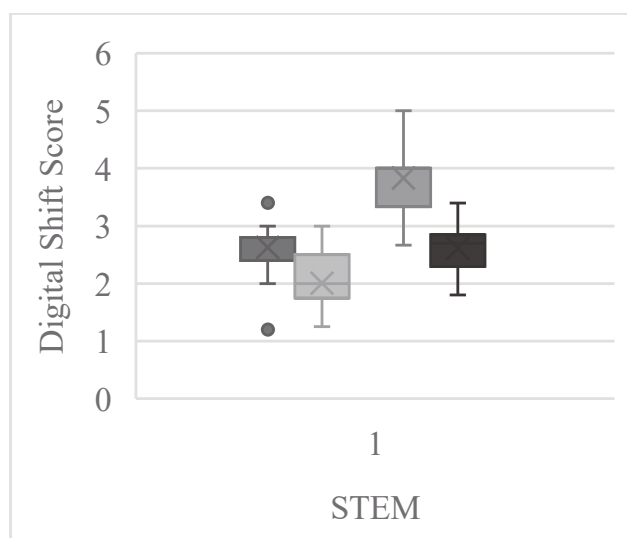


Figure 3

Boxplot comparing digital shift scores between Non-STEM and STEM students

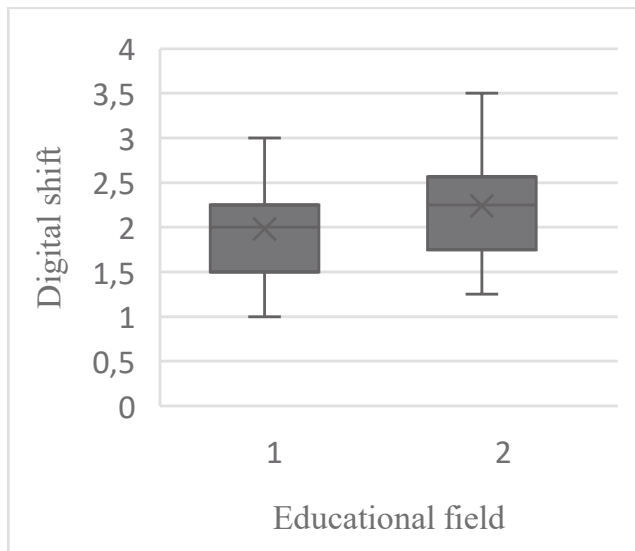


Figure 4

Boxplot illustrating differences in digital shift scores by gender

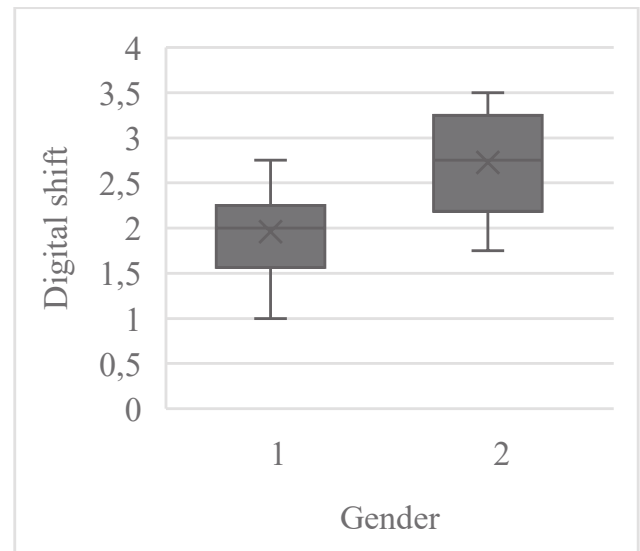


Figure 3 presents overall digital shift scores by disciplinary field, where STEM students display slightly higher median values and a narrower interquartile range. Figure 4 shows digital shift scores by gender, where male students display somewhat higher median values across both groups. These observations are descriptive and should be interpreted cautiously, as inferential tests were not conducted for gender comparisons.

4.6 Correlation Analysis

Table 4

Correlation matrix for selected learning-related indicators among non-STEM students (n = 24)

Variable Pair	ρ	p
PL3 – PL4	.820	<.001
PL3 – PL5	.766	<.001
PL4 – PL5	.749	<.001
PL5 – SE4	.659	<.001
PL5 – AL5	.684	<.001
DL3 – SE4	.564	.004
DL4 – DL5	.542	.006
AL3 – AL4	.813	<.001
AL4 – AL5	.828	<.001

Table 5

Correlation matrix for selected learning-related indicators among STEM students (n = 26)

Variable Pair	ρ	p
PL1 – PL2	.693	<.001
PL3 – DL3	.642	<.001
PL4 – DL3	.765	<.001
PL5 – AL4	.671	<.001
PL5 – AL5	.636	<.001
SE5 – AL5	.663	<.001
DL5 – AL3	.719	<.001
AL3 – AL4	.570	.002
AL4 – AL5	.601	.001

Spearman correlation analyses were conducted separately for non-STEM ($n = 24$) and STEM ($n = 26$) subgroups to examine associations among the learning-related indicators (Franzese & Iuliano, 2018). Only statistically significant correlations ($p < .05$) with moderate-to-strong effect sizes ($\rho \geq .50$) are reported in Tables 4 and 5. Correlation strength was interpreted using conventional thresholds ($\rho = .40$ – $.59$ moderate; $.60$ – $.79$ strong; $\geq .80$ very strong). Both groups exhibited several moderate to strong positive associations across personalized learning, engagement, digital literacy, and adaptive learning dimensions, indicating consistent relationships among the learning-related indicators. However, given the exploratory nature of the dataset, these relationships should be interpreted as indicative associations rather than evidence of causal relationships.

5 DISCUSSION

The findings indicate that undergraduate students experience these systems as interconnected learning environments characterized by digital literacy, engagement, adaptive learning, and personalized learning, rather than as isolated technological functions. This suggests that students' interaction with these technologies reflects a holistic learning experience, where technological competence and engagement are associated with adaptive learning. Interpreted through SCT, these relationships represent reciprocal interactions between learner capabilities and technology-enabled learning environments, where digital literacy may be associated with stronger engagement with adaptive and personalized learning systems (Bandura, 1986). From a technology and engineering education perspective, these environments can be understood as technological systems through which students develop technological awareness and interaction capabilities. The absence of statistically significant differences between STEM and non-STEM students suggests that engagement with these systems may not be strongly influenced by disciplinary background alone. When institutional digital infrastructure is available, students across disciplines appear capable of interacting with these systems in similar ways. From the perspective of the TAM, this similarity may reflect shared perceptions of usefulness and usability in learning contexts (Davis, 1989). This interpretation aligns with prior research showing that digital technologies support learning across disciplines when effectively integrated into instruction (Crompton & Burke, 2023; Zawacki-Richter et al., 2019). This highlights the development of technological capability through interaction with technological systems.

An important implication concerns the role of digital literacy as a foundational capability in digitally transforming higher education environments. The association between digital literacy and adaptive learning suggests that students who feel confident using digital technologies may benefit more from these systems. This aligns with research highlighting digital literacy as a key competency for engaging with emerging digital learning environments (Ocaña-Fernández et al., 2019). Consequently, institutions may need to incorporate structured digital literacy development within undergraduate curricula, particularly in non-STEM disciplines where technological exposure may be more limited. The findings also indicate that technological availability alone does not guarantee active engagement. Although students reported positive perceptions of digital learning environments, engagement levels remained comparatively moderate. This supports arguments that the educational value of AI depends on intentional pedagogical integration rather than technological presence alone (O'Dea & O'Dea, 2023; Popenici & Kerr, 2017). From a

technology education perspective, this highlights the importance of designing learning environments where students actively engage with technological systems, rather than passively using content.

5.1 Conclusion

These findings indicate that effective integration of digital technologies in higher education requires pedagogical approaches that support student engagement and the development of technological capabilities across disciplines. The educational value of these technologies lies not only in their technical functions but also in how students interact with them within learning environments. The study contributes empirical evidence from the Qatari higher education context and highlights how interaction with complex technological systems may support the development of technological awareness and interaction capabilities across STEM and non-STEM disciplines.

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Examining Grade-Level Differences in Design Awareness through Learning Various Technological Contents in Japanese Junior High Schools

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Abstract

Design activities are regarded as an important component of technology education; however, there is limited empirical evidence on grade-level differences and possible developmental tendencies in students' awareness of design through accumulated learning experiences in lower secondary education. This study explores the characteristics of students' awareness of design and examines grade-level differences in this awareness in Japanese junior high school technology education. A questionnaire survey was conducted in November 2025 using a web-based form during regular technology education classes. Participants were 1,357 students in Grades 7–9 from lower secondary schools in multiple municipalities, of whom 1,227 valid responses were analyzed, providing a large-scale dataset for examining students' design awareness. The questionnaire included Likert-scale items measuring design-related awareness and open-ended questions. Design awareness items were categorized into six perspectives, and grade-level differences were examined using the Kruskal–Wallis test. Open-ended responses were analyzed inductively to identify the frequency of design-related perspectives and perceived connections with other subjects and ICT. The results indicated statistically significant grade-level differences across all design awareness categories, suggesting possible developmental tendencies in students' awareness of design as learning experiences accumulate. Awareness related to user perspectives showed consistently high values across grade levels, while awareness of ICT use tended to increase in higher grades, although it remained limited overall. Analysis of open-ended responses showed that students frequently emphasized user needs, whereas references to prototyping, collaboration, and ICT were relatively limited. Perceived connections with other subjects were mainly associated with mathematics, science, and art. These findings suggest progressive grade-level differences in students' awareness of design in technology education, while explicit recognition of collaborative, iterative, and interdisciplinary aspects of design remains limited.

1 INTRODUCTION

The purpose of this study is to explore the characteristics of students' awareness of design and grade-level differences in this awareness among students who have studied lower secondary school technology education in Japan. In this study, "design awareness" refers to students' consciously articulated perspectives and value orientations regarding what they consider important in design activities. It does not refer to procedural design skills themselves, but rather to students' recognition and interpretation of the design process. Examining such awareness provides insight into how students conceptualize design activities beyond observable performance or product outcomes.

In recent years, research in the fields of technology education and STEM education has increasingly positioned design activities at the core of learning and has focused on the perspectives and value orientations that learners bring to design. Within the field of design research, Cross (2001) conceptualized design activity as a form of problem solving and demonstrated that designers engage in distinctive cognitive processes in which problems and solutions are developed simultaneously. Furthermore, Dorst and Cross (2001) proposed the concept of the co-evolution of problem and solution, theoretically explaining that design activity does not proceed in a linear sequence but instead unfolds through iterative and exploratory processes. These insights suggest that design is not merely the application of fabrication skills, but a learning activity that involves particular ways of thinking and making judgments.

Design has likewise been positioned as a core element of learning in the field of technology education. In the Standards for Technological and Engineering Literacy (International Technology and Engineering Educators Association [ITEEA], 2020), design is organized as a set of activities that include identifying needs, understanding constraints, generating and comparing alternative solutions, and prototyping and evaluation. In addition, reports by the National Academy of Engineering (2009) indicate that design learning at the K–12 level develops from simple making activities to more complex and context-dependent problem solving as students progress through grade levels, suggesting that accumulated learning experiences may influence the formation of learners' views of design.

A growing body of research has also focused on learners' perceptions and cognitive processes during design activities, aiming to empirically clarify how design is understood and how decisions are made. For example, Syrjäläinen and Seitamaa-Hakkarainen (2014) analyzed the quality of artifacts produced by secondary school students in design-and-make tasks, revealing how students structure the design process and make judgments and decisions. Danos (2017) focused on visual representation skills (graphicacy) in design activities and discussed how design representations can be fostered within the curriculum. In addition, Kangas et al. (2013) analyzed collaborative design activities and demonstrated how design thinking develops through dialogue and the sharing of ideas with others. Together, these studies suggest that learning related to design is supported by diverse activities that involve not only thinking and judgment, but also representation and collaboration.

In Japan, studies focusing on lower secondary school technology education have also attempted to clarify the substance of learning related to design and problem solving. Yamashita and Moriyama (2022) analyzed optimization thinking in “problem solving through technology” among students engaged in materials processing tasks and revealed cognitive structures through which students refine solutions by comparing conditions and making judgments. Baba, Ibaraki, and Moriyama (2024) implemented a teaching practice incorporating reverse engineering using 3D CAD in materials processing learning and showed that activities focused on interpreting the structure and intent of existing products promote students’ perspectives and ways of thinking about design. Furthermore, Murofushi (2024) examined approaches to design and planning in making-based learning in the technology subject and proposed a perspective that develops design and planning from “seeing as” to “foresight,” positioning making activities as project-based learning.

As described above, prior studies on Japanese lower secondary school technology education have gradually clarified students’ thinking and understandings of design within specific learning contents and classroom practices. However, there has been insufficient systematic and quantitative research focusing on how the accumulation of design experiences across multiple content areas—such as materials processing, biological cultivation, energy conversion, and information technology—shapes students’ awareness of design. In particular, there is limited large-scale empirical evidence clarifying how multiple dimensions of design awareness, such as user perspectives, constraints, iteration, collaboration, and ICT use, relate to one another and vary across grade levels as learning experiences accumulate.

Currently, discussions are underway in Japan regarding a new national curriculum. In this context, it has been proposed that the technology subject be redefined and expanded as “Information and Technology” (tentative name). The perspective emphasized in this proposed subject is described as understanding problems in daily life and society through multifaceted viewpoints that consider both positive and negative aspects of technology, and appropriately utilizing and creating information and production technologies to realize a rich life and society. This perspective can be interpreted as emphasizing a sequence of learning processes that begins with identifying problems related to life and technology and setting tasks, proceeds through forming perspectives grounded in technological relationships (foresight and conceptualization), and culminates in the utilization and creation of information and production technologies.

Against this background, this study aims to explore the characteristics of lower secondary school students’ awareness of design in Japanese technology education. More specifically, it examines grade-level differences in students’ design awareness across accumulated learning experiences in lower secondary technology education, which typically include multiple technological content areas such as materials processing, biological cultivation, energy conversion, and information technology, as an indication of possible developmental tendencies.

2 METHOD

2.1 *Participants and Data Collection Period*

The survey was conducted in November 2025 as a questionnaire-based study using a web-based form. The participants were students in Grades 7 to 9 enrolled in lower secondary schools located in multiple municipalities. The survey was administered during regular technology education class periods.

Among the collected responses, those with missing items and those showing clear response patterns, such as repeated selection of the same option throughout the questionnaire, were excluded. As a result, 1,227 valid responses were obtained out of 1,357 distributed questionnaires (valid response rate: 90.4%).

2.2 *Survey Instrument*

The questionnaire consisted of three sections:

- (i) basic demographic information and learning experiences,
- (ii) Likert-scale items measuring students' awareness of conceptualization and design, and
- (iii) open-ended questions.

2.2.1 *Learning Experiences Across the Four Content Areas of Technology Education*

Students were asked about their learning experiences in the four content areas of the technology subject: materials processing, biological cultivation, energy conversion, and information technology.

2.2.2 *Awareness of Conceptualization and Design (Likert-Scale Items)*

To examine students' awareness and perspectives related to conceptualization and design, a total of 30 items were developed. Each of the six categories consisted of five items. Based on prior research and the characteristics of design learning in technology education, the items were organized according to the following perspectives:

- user perspective and understanding of problems
- goal orientation, evaluation, and understanding of constraints
- idea generation, prototyping, and improvement
- collaboration and connections with other subjects
- use of ICT
- reflection and metacognition

The categories were derived from both international design research (Cross, 2001; Dorst & Cross, 2001; ITEEA, 2020) and Japanese technology education studies (Yamashita & Moriyama, 2022;

Murofushi, 2024). Each item was rated on a five-point Likert scale ranging from strongly agree to strongly disagree. Negatively worded items were included as reverse-coded items to ensure response consistency.

2.2.3 *Open-Ended Questions*

To complement the quantitative data obtained from the Likert-scale items, the questionnaire included the following open-ended questions:

- What do you think is important when engaging in design?
- Have you had any experiences in which learning from other subjects or ICT was helpful when thinking about design?

2.3 *Procedure*

The survey was conducted during class time with the cooperation of technology education teachers. Responses were collected anonymously, and students were informed in advance that the data would be used solely for research purposes. Participation was voluntary, and students were asked to respond based on their own free will. Because the data were collected using ordinal Likert-scale items and did not meet assumptions of normality, the Kruskal–Wallis test was used to examine grade-level differences. To enhance the reliability of the qualitative analysis, two researchers independently coded 20% of the open-ended responses. Inter-rater reliability was calculated using Cohen’s kappa ($\kappa = .80$), and disagreements were discussed until consensus was reached.

3 RESULTS AND DISCUSSION

Before examining grade-level differences, internal consistency of the six categories was assessed using Cronbach’s alpha. The coefficients ranged from .496 to .761, indicating moderate internal consistency for most categories (Category 1: $\alpha = .586$, Category 2: $\alpha = .597$, Category 3: $\alpha = .574$, Category 4: $\alpha = .761$, Category 5: $\alpha = .571$, Category 6: $\alpha = .496$), which was considered acceptable for exploratory analysis. Descriptive analyses were conducted on the Likert-scale items measuring students’ awareness of conceptualization and design. The design-related awareness items were organized into the six categories described above, and differences across grade levels were examined. The results showed statistically significant grade-level differences across all categories.

As shown in Table 1, among the six categories, user perspective and understanding of problems showed the highest mean scores, with a particularly notable increase among ninth-grade students. Significant increases associated with grade progression were also observed in goal orientation, evaluation, and understanding of constraints and in idea generation, prototyping, and improvement. In contrast, collaboration and connections with other subjects showed relatively lower mean values compared with the other categories; although grade-level differences were observed, overall levels remained limited. ICT use and usability showed a marked increase across

grade levels, with especially high values in Grade 9. Metacognition and reflection also showed grade-level differences, with scores tending to increase as learning progressed.

Table 1

Means, Standard Deviations, and Grade-Level Differences in Categories of Design Awareness

Category	Overall M (SD)	Grade 7 M (SD)	Grade 8 M (SD)	Grade 9 M (SD)	H value	p value
1. User perspective and understanding of problems	4.18 (0.62)	3.97 (0.66)	4.12 (0.60)	4.34 (0.56)	42.1	< .001
2. Goal orientation, evaluation, and understanding of constraints	4.01 (0.58)	3.85 (0.61)	3.99 (0.57)	4.13 (0.54)	31.4	< .001
3. Idea generation, prototyping, and improvement	3.94 (0.64)	3.71 (0.67)	3.93 (0.62)	4.09 (0.60)	36.7	< .001
4. Collaboration and connections with other subjects	3.62 (0.73)	3.41 (0.74)	3.58 (0.71)	3.78 (0.70)	28.9	< .001
5. ICT use and usability	3.76 (0.81)	3.48 (0.82)	3.71 (0.80)	4.00 (0.76)	45.3	< .001
6. Metacognition and reflection	3.88 (0.66)	3.65 (0.69)	3.86 (0.64)	4.06 (0.62)	39.5	< .001

M = mean; SD = standard deviation. Grade-level differences were examined using the Kruskal–Wallis test.

These results suggest stepwise grade-level differences in students' awareness of design as students accumulate learning experiences in technology education. In particular, the consistently high values observed for user perspective and understanding of problems indicate that students' conceptions of design extend beyond a production-centered view toward an orientation that emphasizes users and contexts of use. The grade-related increases in goal orientation, evaluation, and understanding of constraints and in idea generation, prototyping, and improvement further suggest that students increasingly perceive design as an iterative process involving consideration of conditions, trial, and refinement rather than as a one-time activity aimed at completing a product. This pattern may reflect the influence of repeated engagement in design activities throughout technology education.

Responses to the open-ended question “What do you think is important when engaging in design?” were inductively categorized, and the frequency of design-related perspectives was organized by grade level (Table 2). Across all grades, user perspective and needs showed the

highest response rates. The next most frequent categories were constraints and ingenuity (e.g., safety and cost), idea generation, conceptualization, and imagery, and practicality and application to daily life. Among seventh- and eighth-grade students, references to constraints and ingenuity and practicality and application to daily life were relatively frequent. In contrast, references to goal and problem setting increased with grade progression. Metacognition and awareness of learning appeared at a stable level across grades, while direct references to prototyping, improvement, and reflection, collaboration, representation, and ICT use were limited.

Table 2

Frequencies of Design-Related Categories Identified in Open-Ended Responses by Grade Level

Category	Grade 7 (%)	Grade 8 (%)	Grade 9 (%)	Total
User perspective and needs	142 (35.9)	116 (36.1)	174 (34.1)	432
Constraints and ingenuity (e.g., safety, cost)	68 (17.2)	60 (18.7)	60 (11.8)	188
Idea generation, conceptualization, and imagery	52 (13.1)	43 (13.4)	60 (11.8)	155
Practicality and application to daily life	51 (12.9)	44 (13.7)	55 (10.8)	150
Metacognition and awareness of learning	64 (16.2)	40 (12.5)	73 (14.3)	177
Collaboration and others' perspectives	39 (9.8)	15 (4.7)	25 (4.9)	79
Representation and visualization (e.g., drawings, design plans)	22 (5.6)	13 (4.0)	19 (3.7)	54
Goal and problem setting	17 (4.3)	21 (6.5)	39 (7.6)	77
Prototyping, improvement, and reflection	8 (2.0)	4 (1.2)	10 (2.0)	22
ICT use	5 (1.3)	3 (0.9)	4 (0.8)	12
Not coded (e.g., no relevant response)	73 (18.4)	58 (18.1)	113 (22.2)	244

Percentages indicate the proportion of responses within each grade level. Multiple categories could be assigned to a single response; therefore, totals exceed 100%. Responses coded as "Not coded" include blank responses and statements not corresponding to any design-related category.

This pattern suggests that lower secondary school students' conceptions of design are structured around user perspective and needs as a core element across grade levels, likely reflecting the sustained emphasis on user-centered design tasks in technology education. The relatively high frequency of references to constraints and practicality among younger students indicates that early design learning tends to prioritize concrete and accessible perspectives such as safety and usability. The increase in goal and problem setting with grade progression suggests that accumulated learning experiences may gradually foster more abstract and conceptual perspectives on design. At the same time, the limited articulation of perspectives related to prototyping, collaboration, and ICT use indicates that these aspects of design awareness remain underdeveloped and may require more intentional instructional support.

Open-ended responses to the question "Have you had any experiences in which learning from other subjects or ICT was helpful when thinking about design?" were analyzed, and the frequency of referenced subjects was organized by grade level (Table 3). References were mainly concentrated on mathematics, science, and art across all grades. Mathematics was consistently cited, with students referring to dimensions, calculations, and ratios as bases for design-related judgments. References to science increased with grade progression, particularly in Grade 9, where students frequently mentioned physical principles such as force, levers, and energy. References to art appeared at similar levels across grades, while references to ICT were observed across all grades. Responses indicating "none" or left blank accounted for approximately 70% of responses in each grade.

Table 3

Frequencies of School Subjects and ICT Perceived as Helpful for Design Thinking, by Grade Level

Category	Grade 7	Grade 8	Grade 9	Total
Mathematics	58 (14.6%)	35 (10.9%)	67 (13.1%)	160 (13.0%)
Science	9 (2.3%)	20 (6.2%)	58 (11.4%)	87 (7.1%)
Art	45 (11.4%)	37 (11.5%)	60 (11.8%)	142 (11.6%)
Home economics	0 (0.0%)	0 (0.0%)	1 (0.2%)	1 (0.1%)
ICT	43 (10.9%)	29 (9.0%)	60 (11.8%)	132 (10.8%)
None / No response	276 (69.7%)	226 (70.4%)	340 (66.7%)	842 (68.6%)

Percentages indicate the proportion of students within each grade level. Each response was coded into a single category. "None / No response" includes blank responses and statements indicating that no subject or ICT was perceived as helpful.

The concentration of references on mathematics, science, and art suggests that students' perceived interdisciplinary connections in design learning are largely limited to subjects directly related to design activities. The emphasis on mathematical processing and scientific principles indicates

that students view design as an activity grounded in rational judgment rather than solely in intuition. The increase in science-related references with grade progression suggests a shift from experience-based reasoning toward reasoning based on principles and laws, reflecting a qualitative change in students' design perspectives. In contrast, the high proportion of "none" or blank responses indicates that many students have not yet consciously articulated connections between design activities and learning in other subjects, even when such knowledge may be implicitly used.

4 CONCLUSION AND DISCUSSION

This study examined Japanese lower secondary school students' awareness of design from multiple perspectives through a questionnaire survey and analysis of open-ended responses, focusing on changes associated with grade progression. Specifically, the study conducted: (1) a quantitative analysis using Likert-scale items organized into six categories of design-related awareness, (2) an analysis of the frequency and response rates of categories identified in open-ended descriptions of students' conceptions of design, and (3) a subject-based analysis of open-ended responses regarding other subjects and ICT perceived as helpful when thinking about design.

The results of the Likert-scale analysis indicated significant grade-level differences across all categories, revealing possible developmental tendencies in students' awareness of design as learning experiences accumulate. In particular, core design perspectives—such as user perspective and understanding of problems, goal orientation, evaluation and understanding of constraints, and idea generation, prototyping, and improvement—showed notable increases with grade progression. These findings suggest that students increasingly come to view design not merely as a making activity, but as a cognitive process oriented toward problem solving. In contrast, awareness related to collaboration and connections with other subjects remained at a relatively low level, indicating that design activities are not yet widely perceived as interdisciplinary or collaborative learning experiences.

Analysis of the first open-ended question showed that "user perspective and needs" was the most frequently mentioned category across all grade levels, indicating that linking design to users and contexts of use is a shared conception throughout lower secondary school. Categories such as constraints and ingenuity, idea generation and imagery, and practicality and application to daily life were also identified, suggesting that many students perceive design as a form of problem solving grounded in realistic conditions. However, references to prototyping, improvement and reflection, collaboration and others' perspectives, and ICT use were relatively infrequent, implying that many students have not yet developed an explicit awareness of design as an iterative and collaborative process. This finding suggests that instructional design in technology education may need to more intentionally scaffold collaborative and iterative aspects of design, as well as the use of ICT as a cognitive tool in design processes.

The second open-ended analysis revealed that mathematics, science, and art were most frequently cited as subjects that supported design thinking, while references to other subjects such as social studies and language arts were rare. Descriptions related to mathematics and science became more

concrete and advanced with grade progression, suggesting that design-related judgments may develop from intuitive reasoning toward reasoning based on principles and evidence. At the same time, the high proportion of responses categorized as “none” or left blank indicates that connections between design activities and learning in other subjects are not always consciously recognized or verbalized by students.

Taken together, these findings suggest that multi-year design learning in Japanese lower secondary school technology education supports the development of students’ conceptions of design from product- or form-centered perspectives toward more integrated perspectives that include user considerations, understanding of constraints, iterative improvement, and metacognition. However, awareness related to collaboration, interdisciplinary learning, and the use of ICT as a core component of design thinking remains limited, representing an important challenge for future curriculum development.

Several limitations of this study should be noted. First, the study employed a cross-sectional design and did not track changes in individual students’ design awareness over time; therefore, the observed grade-level differences should be interpreted as indications of possible developmental tendencies rather than direct evidence of developmental change. Second, analysis of open-ended responses may have been influenced by differences in students’ expressive abilities and response length, meaning that some aspects of design awareness may not have been fully articulated. Third, this study did not examine differences in specific instructional practices or teaching methods, and thus did not identify the learning factors that contributed to the formation of design awareness.

Future research should employ longitudinal designs and detailed analyses of classroom practices to more precisely clarify how particular learning experiences contribute to the development and transformation of students’ conceptions of design. In addition, it is important to design and examine instructional practices that intentionally incorporate collaborative design activities and interdisciplinary learning. Further investigation into instructional approaches that position ICT as a cognitive tool supporting design thinking may also contribute to accumulating knowledge relevant to the curriculum reforms currently being discussed in Japan, particularly those emphasizing problem solving through the integrated use of technology. The findings also contribute to international discussions on design learning in technology education by providing large-scale empirical evidence from the context of Japanese lower secondary education.

5 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Assessing the Engineering Design Process in Technology Education: Insights from Swedish Teachers

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Abstract

One aspect of technology education that can be seen throughout the school curriculum is the teaching of processes such as the engineering design process. This process forms part of what students should learn at the upper secondary level in Sweden. However, teachers have the flexibility to select and adapt examples and subject content to suit their students and the local context. While this flexibility can enhance the relevance and engagement of teaching, it can also lead to challenges when it comes to comparing and collaborating with other teachers, particularly with regard to assessment. Assessment and grading are challenging aspects of teachers' work. Previous studies have highlighted the need for increased support in assessing technology education, especially regarding the evaluation of processes involved in technological development, such as the engineering design process. The aim of this study is to investigate how teachers perceive assessment in relation to the engineering design process and to identify which aspects of assessment teachers emphasize. The participants are seven teachers in Sweden's upper secondary school technology programme. Data collected through focus group interviews was analysed inductively using thematic analysis. The results reveal three themes: the first theme covers what is being assessed, the second theme concerns the differences between higher and lower levels and the third involves challenges of assessment. One conclusion is that there is a need for teacher support in assessment related to technology education and the engineering design process.

Key Words: Technology Education, Assessment, Upper Secondary School, Engineering Design Process

1 INTRODUCTION AND PREVIOUS RESEARCH

The teaching of technological processes, such as problem solving and the engineering design process is one part of technology education that can be seen throughout the school curriculum (de Vries, 2016). In Sweden, the Technology programme is an elective study preparatory education of three years in upper secondary school, selected by about 10% of all students. One mandatory subject on this programme is Technology, that often is taught during year one and two. One of

the goals of the subject is for students to gain knowledge about the engineering design process, and more over to use it as a working method (Skolverket, 2025). However, teachers can choose and adapt subject content to suit their students and the local context and can therefore create assignments that are connected to the local area or based on real-life tasks (e.g. Nordlöf et al., 2024). Moreover, the teacher has the freedom to adapt most of the parameters in the assignments, such as project length and how the students will present their solutions, as the wording in the syllabus is broadly formulated: “Application of the engineering design process within a technology field.” (Skolverket, 2025, p.3). While this flexibility can enhance relevance and engagement in teaching, it can also lead to challenges in comparing and collaborating between teachers, for example in relation to assessment.

Assessment and grading may be among the most challenging aspects of teachers' work. Previous studies have highlighted the need for increased support in assessing technology education, especially regarding the evaluation of processes involved in technological development, such as the engineering design process (Skolforskningsinstitutet, 2025). Previous research reveal that documentation is one important part of the basis of teachers' assessment, such as students' logbooks, where students can express their reflections and progression in words (Douglas et al., 2018; Citrohn et al., 2023).

Another relevant aspect of assessment relates to the nature of what is being assessed. Process based assessment considers students' progression and learning, while product-based assessment focuses on the final outcome or result, such as a CAD model or a physical model. Bowen et al. (2016) conclude that assessment should include both the final result and the interactive working process. In a study related to programming in technology education, which also is a form of problem-solving process, some teachers emphasized the final program (product) while others valued the working process more highly when assessing students' work. Process criteria for assessment seem to be particularly useful for formative purposes (Björklund & Nordlöf, 2023).

1.1 Aim

This study aims to investigate how teachers in upper secondary schools perceive assessment in relation to the engineering design process. More specifically, which aspects of assessment teachers emphasize when describing their teaching. This is investigated by focus group interviews with seven Swedish experienced technology teachers.

2 METHODOLOGY

The data for this exploratory study is based on two focus group sessions with technology teachers in upper secondary schools in Sweden. Data was collected in November 2025.

A convenience sampling strategy was used to find participants through established networks. In total, the author invited nine upper secondary school technology teachers to participate, of those seven teachers accepted. All of them were experienced teachers, six female and one male (Table 1). Four participated in the first focus group and three in the second. They represented five schools and five municipalities.

Table 1

Participants in focus group interviews.

Name	Focus group	Teaching subjects	Experience as teacher
Greta	1	Technology, Mathematics, AI	10 years
Selma	1	Technology, Community development	15 years
Alfred	1	Technology, Programming, AI	13 years
Zara	1	Technology, Programming	20 years
Agneta	2	Technology, Mathematics, AI	20 years
Ellen	2	Technology, Mathematics	15 years
Victoria	2	Technology, Mathematics	6 years

The teachers were informed that the discussions would revolve around assessment. In addition, they were asked to bring an example of an assignment in which they had taught about the engineering design process, in order to provide context for the focus groups conversations.

Focus group was selected since the format allows informants to steer the direction of the conversation, and the teachers' own questions and reflections were of interest to capture (Wibeck et al, 2007). The researcher had prepared a few questions but let the teachers' examples be in the foreground and mainly added in-depth questions and queries to keep the conversation on topic. Each focus group interview lasted for approximately 70 minutes and was video recorded, however, only the audio was used in the study. The interviews were conducted digitally, enabling teachers from different schools and parts of Sweden to participate. The recordings were transcribed, with support from a digital tool with AI capabilities

The data were analysed explorative and thematically to identify the aspects of the assessment of the engineering design process that teachers highlighted in their conversations (Clarke and Braun, 2017). A translation tool with AI features was used as support for translation and language processing.

3 BACKGROUND AND CONTEXT

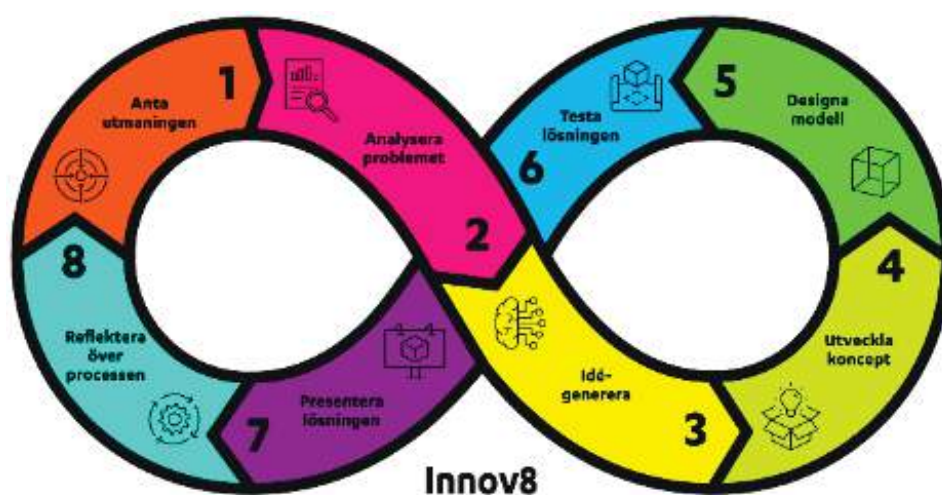
An engineering design process is an iterative step by step method used to solve problems and develop designs for products and systems. It can be illustrated in different ways, depending on the context and the project, and there is not one common way to describe it (de Vries, 2016).

In engineering education, the *conceive, design, implement, operate* (CDIO) initiative is one well known approach (Crawley et al., 2014). In the context of technology education in Sweden, both in primary and secondary school, the process includes a number of steps ranging from identifying the problem all the way to visualizing and trying out the solution.

One way to illustrate and describe this process, that several of the participants in this study used, is as a coherent eight (Fig 1). This illustration is used in Swedish digital teaching materials for upper secondary school, (Unga innovatörer, n.d.). It is an iterative process based on 8 steps: 1) Accept the challenge, 2) Analyse the problem, 3) Generate ideas, 4) Develop concepts, 5) Model design, 6) Try out the solution, 7) Present the solution and 8) Reflect over the process.

Figure 1.

The innov8 process, an iterative process based on 8 steps.



The teachers involved in this study describe how the engineering design process is incorporated into technology education throughout the three school years. They explained that they teach their students about the model, giving them an understanding so that they can use and implement it to develop technical solutions. Some of the teachers described that they focus on the process as an iterative way of working, aiming to help their students to understand how it can be used as a tool for developing technology or solving technological problems. Alternatively, teachers describe the process as a step-by-step approach to a project, with each step corresponding to a different sub-task that students must complete, such as creating sketches, CAD models and reports. Designing furniture is a common task set to students in upper secondary school in Sweden. Three of the teachers involved in this study mentioned this, with one of them describing a design problem in which students were tasked with developing furniture with two or more functions.

How teaching could be designed to create opportunities for learning in and about the engineering design process was examined in a recently published Swedish systematic research review. The results point out a holistic understanding and an iterative approach to improve learning, also the way the assignments are designed by the teacher is one important aspect. Finally, group work is identified as a common way of work, and the interaction between students is important related to learning (Skolforskningsinstitutet, 2025).

4 RESULT

Three themes related to the engineering design process and assessment emerged from the data. The first theme covers what is being assessed, the second theme concerns the differences between higher and lower levels and the third involves challenges of assessment.

4.1 *What is assessed*

The assessing of the engineering design process is handled differently depending on what is in focus. Early in the education, the teacher may put more focus on teaching about the process, later on it is used as a tool for solving a problem:

The focus is now on having this model in the background. I will therefore place less emphasis on going into the process in depth and more on assessing the overall picture.
(Selma)

The teachers described that they gather information to assess of their students by observing and listening to them, as well as talking to them. The teachers may also take notes or tick items off checklists during or after lessons. However, the most common way to create a basis for assessment was to collect the student's documentation in various forms. These could include logbooks and written reports, as well as technical drawings, photos, calculations and CAD models. This documentation is important, as Victoria expressed it:

The basic requirement is that the student demonstrates the development process and documents the steps.

Moreover, students' oral presentations at the end of the project were a common way to collect information for assessment.

The teachers search the collected documentation and information for different types of knowledge and skills. They mentioned more general skills, such as the ability to plan a project, communicate effectively, and cite sources. This aligns with the technology curriculum at this level, which includes working on projects, communicating orally and in writing, and using models. The teachers also described looking for knowledge and skills directly related to technology, such as selecting materials and justifying a proposed manufacturing process to meet the needs of the target group in their designs, as well as considering the sustainability of alternatives. Alfred gives one example:

What [the student] need to submit is a drawing with at least three views, a technical drawing that may also be a CAD model. A document containing a picture showing the furniture from different angles and in different colours, etc., either hand-drawn or digital.

Victoria described what she assesses:

In the text document that the students are to submit, and we have also practised documentation, they are to document the process as a whole, in general terms, and then their own development process. From requirements to finished product. Then they are to show how they take ergonomics into account, as ergonomics is part of the lectures we have had.

Just as Victoria, several of the teachers mentioned written text. Some of them ask their students to write a personal final reflection, particularly when the task has been carried out in groups. Selma describes her approach:

Regardless of whether we are working in a group or on individual projects, I always conclude a task like this with an individual assessment in the form of an essay, in which the students get to reflect...

Overall, the ability to reflect on and express thoughts in writing appears to be highly valued in student assessment.

4.2 *Difference between higher and lower levels*

Documentation also played a central role in the teachers' discussions about the levels of student work in engineering design processes.

Higher levels were associated with detailed documentation of the student's own work. 'It's not just about doing something; you also have to be able to document it correctly' (Alfred). Agneta said that when she reads her students' documentation and has no questions because everything is clear, she knows that it is high-level work. Poor documentation is a sign of a lower level, for example, failing to document at the appropriate times during the process. Ellen described:

If they realise at the end of the project that they've forgotten something, like 'Oh, we also had to submit sketches! Now we have to make one and submit it.' I then say that this is not the right way to document.

In terms of documentation, one difference is that simply listing information is considered a lower level of knowledge, whereas justifying choices and explaining the connections between different parts is considered a higher level.

Greta explains that she can award a project a high grade if the final product – for example, an Arduino program – is well made and successful, even if the students have not documented or reflected on their work extensively. She means that if they solve a complex task neatly and effectively, this demonstrates that they must also have planned well and adopted an effective problem-solving approach. She concludes by saying: “I might do wrong. This is so difficult”

The interviews showed that examples of high-level achievement include thinking one step beyond the task itself and connecting it to knowledge from other subjects. "... a student who thinks beyond the task itself. This also shows that they are at the highest level of the grading criteria" (Selma).

Some teachers mentioned using the question, 'If you had the chance to start all over again, what would you do differently?', to assess their students' ability to reflect on their work and the EDP process. This helps them to identify the students' level of knowledge regarding their own reflection and what they have learned from their mistakes.

Overall, teachers value the students' ability to describe their own development and progress. However, it is not the written text itself that is in focus, such as correct spelling, but rather the reflections and justifications.

4.3 *The challenges of assessment*

An overall challenge in assessment is, in some cases, to actually identify *what* is being assessed. “What exactly is process” (Greta) and “What is being graded, so to speak?” (Alfred) were questions raised from one teacher to the others during the interview. Assessment in technology is regarded as difficult by some of the teachers, Ellen said: “I think it's a bit easier in math than in technology.” She explained further that in mathematics, if you put it simply, teaching can be based on a book, whereas in technology you need to make choices and do interpretations.

Since assessment builds on interpretation, and teachers interpret differently, there is a need of examples and support materials for teachers, which the participant said that they request from the authorities:

I would like examples of projects that would be suitable for the engineering design process and information on how they should be assessed. Because it is difficult to know whether you are doing the right thing or not. (Zara)

Progression and identifying the differences between grading levels were also highlighted as challenging aspects. Likewise, in this aspect the teachers asked for supporting materials, since there is a lack of this kind of support at the upper secondary level of technology education. Sometimes, support materials from other subjects are used in technology education:

I usually go to the assessment guides, for example those found in social studies or history, just to see what the levels are, because there are clear examples of a passing grade there. (Selma)

Moreover, not having colleagues to discuss assessment with is challenging, therefore “opportunities to meet colleagues from other schools are excellent.” (Ellen). In contrast, when you do have colleagues, a challenge can be reaching an agreement, especially when teachers have different background and experiences: “Yes, personally, I think the most challenging thing is to reach a consensus among colleagues, especially in subjects where it is very abstract” (Victoria).

As mentioned before, group work is a common form of activity according to these teachers, and moreover, they find it challenging to assess individuals during group work. Some students prefer to work on their own rather than in a group and do not engage in group work or in discussions with the teacher. The results revealed that one way of handling assessment challenges of group work is to plan for a final assignment in which the students work individually, and which is valued more highly in grading. This means that the group work is considered primarily as practice rather than as a basis for assessment.

Teachers felt that they did not have enough time for all their students. It is difficult to find time to provide feedback and advice to each student on how they can improve, which is an important part of formative assessment.

5 DISCUSSION

In the technology subject at upper secondary level, students should learn *about* the engineering design process, as well as use it as a working method. These two approaches were reflected in the results.

When the teachers in this study describe their teaching of the engineering design process and assessment, several interesting aspects are highlighted. One is that teachers find assessment challenging and feel a need of talking about assessment, even though they are experienced teachers. The result show that the teachers use different examples in their teaching, but all of them let their students approach the process in much the same way. For example, they often let their students work in small groups, but supplements with individual elements or assignments to ensure the assessment.

Overall, students’ documentation is important when teachers assess students, especially written text, which in fact seems to be one of the most important sources for the teachers in this study. This is consistent with previous research, showing that written text, such as logbooks is a useful format when teachers assess students’ work (Douglas et al., 2018; Citrohn et al., 2023). The teachers provide examples of how they assess written texts based on how students articulate their work and intentions. Therefore, reasoning in technology is an interesting research area to investigate further in relation to assessing the engineering design process (see Hultmark et al., 2024).

Written text is a concrete knowledge base that is easy for teachers to collect, especially if they have large classes. Moreover, written text is easier to discuss in words, whereas other aspects of knowledge, such as what the teacher observes in the classroom during their work, may be more difficult to articulate (cf. Nordlöf et al, 2024a). This result indicates that there is a need for a

discussion about how to assess other forms of evidence of what knowledge students have acquired. The focus on written text might disadvantage some students.

The result also indicates that teachers lack support in assessing the subject of technology. Selma described how she used assessment guides in other subjects to better understand grading levels. Since technology is a specific field of knowledge with its own traditions of knowledge, technology teachers also need assessment support tailored to the subject of technology.

In the teachers' statements there are examples of assessment of the process and the product (Bowen et al., 2016; Björklund & Nordlöf, 2023), but still, there is a need for deeper knowledge of how to assess the engineering design process as a whole. The teachers in this study do not fully agree on what the process is or how it is used in technology education, which further complicates assessment. However, it is notable that they use the process differently depending on the learning objectives and on whether students are at the beginning or the end of their studies. The first step in addressing this might be to pinpoint what students are expected to learn about the process and within it. Moreover, models of the process, such as Innov8 (see Fig. 1), could emphasize the work carried out throughout the entire process, rather than focusing primarily on the project's output and documentation.

The results from this rather limited study will form the basis for further research. My aim is to conduct continued and deeper investigations of teachers' assessments, preliminarily designed as a collaborative study in which researchers and teachers work together to develop new knowledge about assessment in technology education. The long-term goal will be to contribute knowledge about assessment that can be useful both for research and for practicing teachers.

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Expanded PBL Curriculum Model for Diverse Educational Settings: Responding to the Needs of Engineering Education

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Abstract

Over the years, engineering education has continually adapted to meet the changing needs of society, technological progress, and industrial demands. In recent years, these drivers have included societal challenges such as sustainability and ethical innovation, technological advances like artificial intelligence (AI) and the growing electrification of homes and transportation, and industrial demands for engineers with strong cross-disciplinary collaboration, communication, and management skills. At the same time, engineering education institutions are facing new and growing challenges, including larger, more diverse student cohorts alongside limited institutional budgets. To address these drivers and challenges, researchers in engineering education have recommended the use of more flexible, student-centred, and active learning strategies, designed to reflect authentic engineering environments. One such suitable strategy is problem and project based learning (PBL), which can be implemented in traditional face-to-face, online and blended environments. However, recent research and global events, such as the COVID-19 pandemic, have highlighted the need for clearer guidance to support engineering educators in adopting PBL in digital learning environments. In this paper, the authors seek to support engineering educators' development, implementation, and evaluation of PBL in online and blended environments by explaining the PBL spectrum and proposing an expanded PBL framework. This proposed framework builds on the PBL Curriculum Model developed by Kolmos et al. (2009) by including additional consideration for diverse educational environments.

Key Words: Engineering Education, Online Learning, Blended Learning, Problem and Project Based Learning, PBL, Curriculum Development.

1 INTRODUCTION

In many engineering education institutions, PBL has been the strategy of choice to prepare the next generation of engineers (Chen et al., 2021). However, PBL is utilised in many different forms and guidance documents often lack a coherent and approachable structure which can be unpacked

and applied easily. This is especially evident when comparing PBL to alternative active learning methods such as the Conceive-Design-Implement-Operate (CDIO) approach. The CDIO approach is accompanied by a comprehensive and coherent set of standards, syllabi, and implementation guidance documents that can be used by engineering educators to support curriculum design, delivery and evaluation (CDIO Initiative, 2026; O'Connor et al., 2023).

One of the most widely utilised guiding frameworks for PBL is the 'PBL Curriculum Model' developed by Kolmos et al. (2009). Although this model has been further detailed (Kolmos, 2012; Kolmos & de Graaff, 2014) and used to describe instances of PBL implementation in subsequent years (Guerra et al., 2017), the authors' more recent work has focused on systemic PBL (Kolmos et al., 2020), PBL principles (Habbal et al., 2024), PBL competences, PBL in a digital age, and future directions of PBL (Kolmos & Ryberg, 2023). While this work has significantly advanced the theoretical foundations of PBL, there remains a need for an expanded and accessible model that reflects the realities of evolving educational environments, including online and blended learning.

This paper addresses this need by (1) defining and explaining PBL in an accessible manner, and (2) presenting an updated PBL Curriculum Model that is clear, coherent, and has the potential to scaffold engineering practitioners' approaches to PBL implementation. The paper does not aim to be an all-encompassing, one-stop resource for PBL, but rather a focused overview of PBL and its applications.

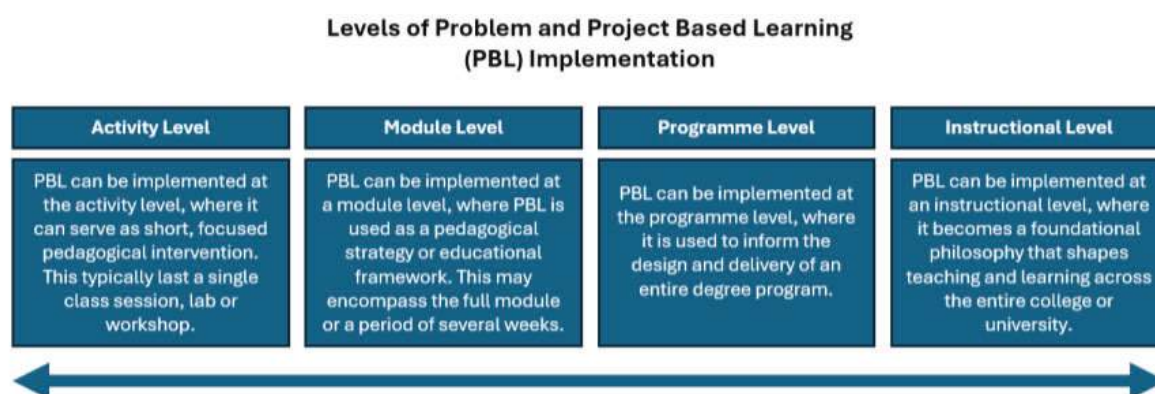
2 LITERATURE REVIEW

2.1 Defining Problem and Project Based Learning (PBL)

PBL is an approach that encourages students to investigate authentic engineering challenges and develop solutions through collaboration and iterative design. PBL implementation approaches can be viewed as existing along a spectrum. At one end of the spectrum, PBL may be implemented through one-off activities or short problem-solving tasks embedded within a module. At the other end, it can form the foundational philosophy of a college or university, often being referred to as systemic PBL (Chen et al., 2021; Kolmos et al., 2020; Kolmos & de Graaff, 2014; Savin-Baden, 2003). This is illustrated in Figure 1.

Figure 1

Levels of Problem and Project Based Learning Implementation



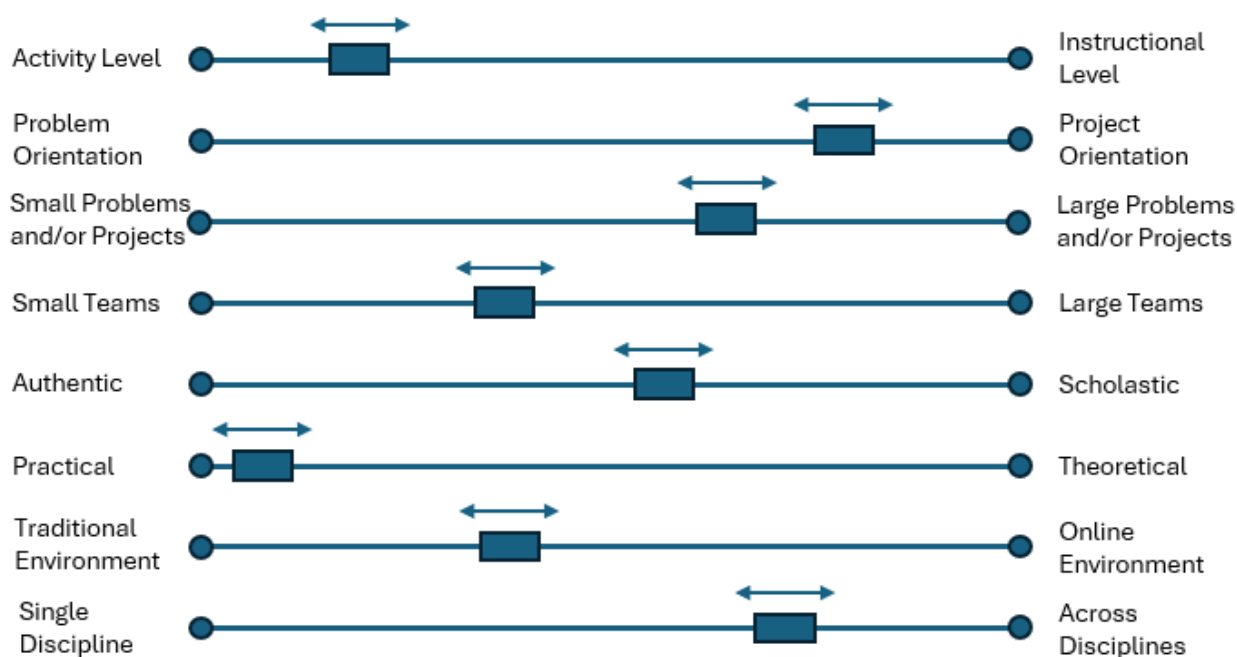
To further complicate matters, PBL approaches can vary in a number of other ways, including:

- Task Orientation: Some PBL approaches are problem-oriented, while others are project-oriented.
- Task type: PBL tasks can be practical, theoretical or a mix of both.
- Authenticity: PBL approaches can be authentic, reflecting professional engineering settings, or more academic in nature, designed specifically for an educational context.
- Size and Duration: The size of the problems and/or projects may be small or large, and their duration can span from a day to months.
- Learning Environment: PBL can be implemented in various learning environments, including traditional face-to-face environments (O'Connor et al., 2025), fully online environments (O'Connor et al., 2024), and blended environments (Rossiter et al., 2010).
- Type of collaboration: PBL can also be implemented within a single discipline or across multiple disciplines to varying levels (Capraro et al., 2013; MacLeod & van der Veen, 2020).

Some of these ways are depicted in Figure 2 as dimensions of variation. Each of the horizontal lines in Figure 2 represent a unique dimension. The rectangles on each horizontal line identify possible positions along that spectrum, and the arrow indicates how it can shift from left to right depending on decisions made during the PBL design process.

Figure 2

PBL Spectrum



It is, therefore, unsurprising that developing a single, universally applicable definition for PBL is an impossible task. This is why scholars such as Edström & Kolmos (2014) and Kolmos & de Graaff (2014) believe it is short-sighted to define PBL at a practice or implementation level. They suggest that PBL should be loosely defined at a conceptual level so it can be adapted across contexts. In line with this sentiment, this paper adopts the following definition at a conceptual level: “PBL is a very comprehensive system of organising the content in new ways and students' collaborative learning, enabling them to achieve diverse sets of knowledge, skills, and competencies” (Kolmos & de Graaff, 2014, p. 147).

3 PBL CURRICULUM MODEL

Having explained and defined PBL, the discussion now turns to introducing a practical model for PBL implementation, namely the ‘PBL Curriculum Model’ (Kolmos et al., 2009). This will then be followed by an updated model intended to better suit the needs of contemporary engineering education.

3.1 The Original PBL Curriculum Model

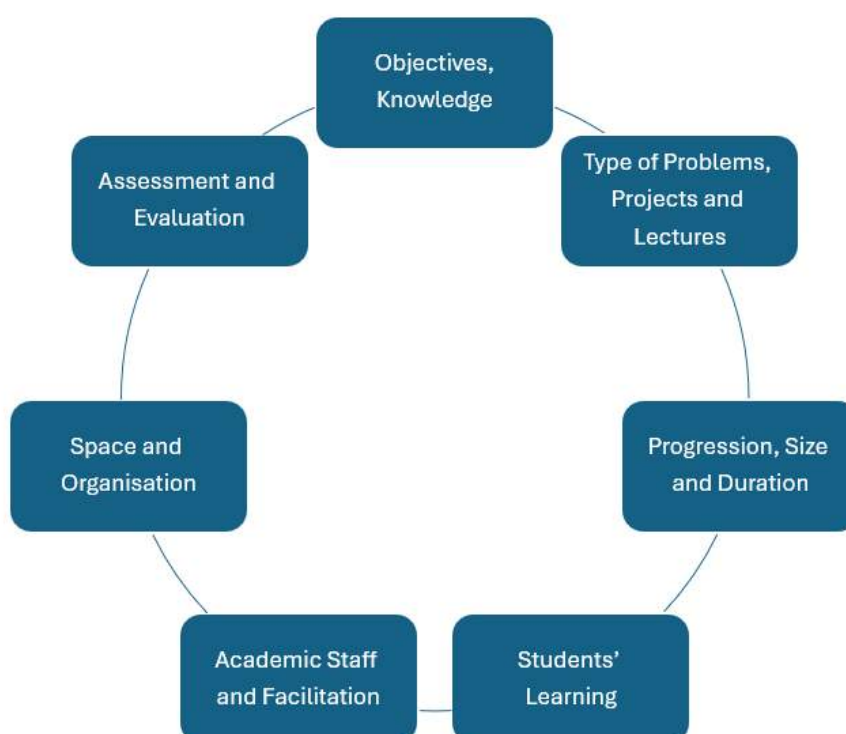
The PBL Curriculum Model is grounded in teaching and learning principles informed by socio-constructivist and student-centred conceptions of learning. These principles can be grouped into three categories: learning approach, social approach and content approach (Kolmos & de

Graaff, 2014). The model is also designed to align with broader curriculum theories of constructive alignment and social constructivism (Kolmos et al., 2009; Savin-Baden, 2007).

The model consists of seven interconnected elements. These elements are listed in **Figure 3**. Each of these elements is described in the work of Kolmos & de Graaff (2014), Kolmos (2012), and Kolmos et al. (2009).

Figure 3

PBL Curriculum Model (Kolmos et al., 2009)



3.2 *The Teaching and Learning Environment*

Although the descriptions of the element ‘Space and Organisation’ in the original model refer to a “virtual space” (Kolmos et al., 2009, p. 18) and the use of “ICT” (Kolmos & de Graaff, 2014, p. 152), these points are treated for the most part as logistical or infrastructural concerns rather than as fundamental decision that shape how PBL is designed, implemented and experienced by students. The authors believe that conflating the teaching and learning environment with infrastructural requirements and resources into one element in the existing model is suboptimal when trying to support the design of PBL approaches in contemporary engineering environments.

Educational research has shown that the environment does not simply provide a setting for instruction but actively influences how teaching and learning take place (Hadgraft & Kolmos, 2020; Means et al., 2013). Therefore, the teaching and learning environment plays a large part in

how PBL is conducted and experienced by students (O'Connor et al., 2024, 2025). This is demonstrated in the work of O'Connor et al. (2024, 2025), who show that students' experiences in comparable PBL tasks, whether online or traditional, are affected by the setting in which teaching and learning take place.

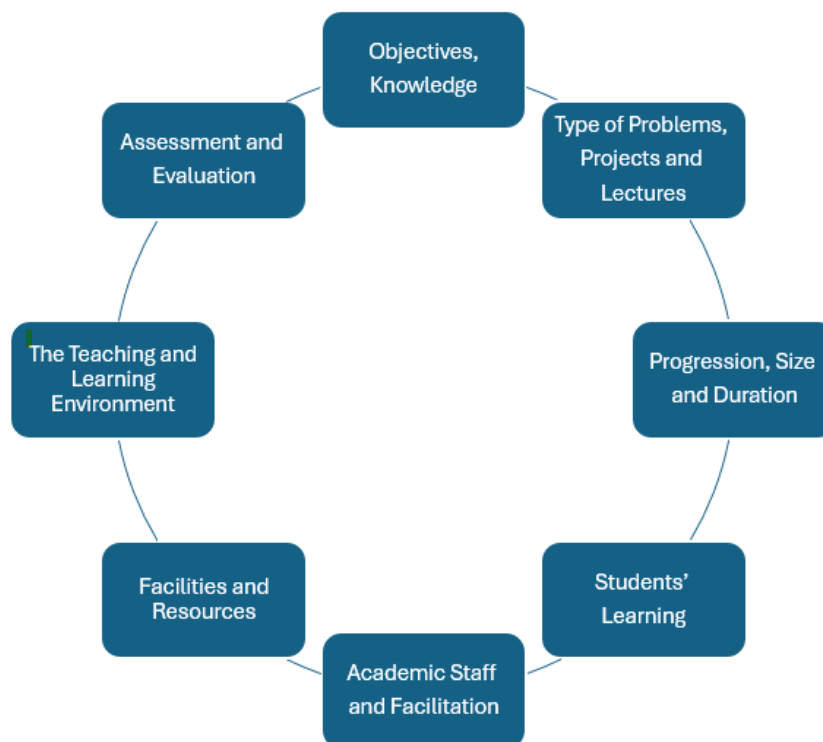
Research conducted both during and before the COVID-19 pandemic shows that non-traditional environments, such as online and blended environments, introduce new challenges and opportunities for educators (Bergman et al., 2024; Graham, 2022; O'Connor et al., 2025; Stenman, 2007). Reported challenges include issues of access and equality (Asgari et al., 2021; Missildine et al., 2013), increased instructor workload and a lack of institutional support (Graham, 2022), and concerns of student engagement and well-being (Graham, 2022; O'Connor et al., 2025; Stenman, 2007). However, these digital environments are also praised for their ability to reduce expenses, removing geographical barriers, and allowing for flexibility in the pace of student engagement (Greenhow et al., 2022; O'Connor et al., 2024, 2025).

As it stands, the original model uses the element 'Space and Organisation' to account for the educational setting (e.g., in-person, online, or blended delivery) and the associated infrastructural requirements, including lecture halls and workshops, and resources such as materials and equipment. The authors posit that the uptake of digital learning environments in engineering education (Graham, 2018, 2022; Hadgraft & Kolmos, 2020) and the need for specific guidance (Graham, 2022) necessitate the addition of a separate element distinct from the requirement for physical or digital facilities and resources. It should be noted that this is not to suggest that these elements operate independently, but rather, as with all elements in the model, they are closely interconnected.

To implement these changes within the Expanded PBL Curriculum Model, the element 'Space and Organisation' has been split into two distinct elements: 'Facilities and Resources' and 'The Teaching and Learning Environment'. Figure 4 shows the new 8-element model.

Figure 4

Expanded PBL Curriculum Model for Diverse Educational Settings



For this short paper, Table 1 includes a brief outline of each of the elements. A more comprehensive table including additional considerations for each element is hosted on OSF (https://osf.io/xe32w/overview?view_only=e2398cf7a64f4a56b3dadc783f881ae3).

Table 1

Description of the Elements in the PBL Curriculum Model

Element	Description
Objectives and Outcomes	This element refers to the educational intentions of the PBL curriculum, and the specific, assessable learning outcomes which are going to be used to evaluate if intentions are realised. By developing the educational intentions, alignment can be ensured between values, such as shared responsibility and socially responsible engineering practice, and purpose, such as developing technical knowledge, professional skills, and competencies. Deciding on the

	objective and outcomes sets a foundation that helps develop a coherent PBL design that links directly to all other elements.
Types of Problems and Projects	This element refers to the characteristics and design of the problems and/or projects that are used in the PBL curriculum. The learning objectives and outcomes are directly related to the types of problems and/or projects. If the projects and/or problems are narrow, so too are the objectives and outcomes. The problems and/or project types must be carefully framed, as they can affect students' learning processes, levels of independence, and the skills, knowledge, and competencies they develop.
Progression, Size and Duration	This element refers to how PBL is structured over time, including progression, size, and duration. Progression can be structured from easier to more complex problems and/or projects. Progression can allow students to receive guidance early on and later advance to self-directed learning, thus gaining more independence as the curriculum advances. The scale of PBL problems and/or projects can vary in breadth and in the size of student teams, which may include collaborating across disciplines. The duration can range from short-term, lasting hours, to long-term, lasting multiple months or even semesters.
Students' Learning	This element ensures that consideration is given to how students enter, experience, and develop within a PBL curriculum. It reminds curriculum designers that students are expected to construct knowledge through inquiry, collaboration, and directed/self-directed learning. Before engaging in PBL, educators must understand students' prior knowledge, as this will affect the appropriate starting point for teaching and learning. For example, has the student cohort already participated in collaborative learning? What knowledge, skills, or competencies should they already be proficient in? Students participating in PBL often arrive with minimal experience in collaboration and project management. This is why the curriculum must aim to develop effective teamwork and communication skills, promoting a transition to co-constructing knowledge rather than a familiar individualised approach, and to encourage increased levels of self-directed learning.
Academic Staff and Facilitation	This element refers to academic staff as facilitators, supervisors, and trainers. It also includes staff's existing expertise, required training and workload. Having well-trained academic staff is vital for PBL success. Where academic staff lack expertise in facilitating teamwork, the facilitation role becomes significantly more challenging. This is why leading PBL institutions provide staff with training to help them transition from lecturer to facilitator (Chen et al., 2019) the management of common student issues experienced in collaborative environments, such as team conflict and social loafing, while also enabling them to judge when students require support rather than encouragement to keep working independently as a team to find solutions.
Facilities and Resources	This element refers to facilities and resources that are required to support students in carrying out PBL activities. The facilities and resources in PBL are diverse, encompassing both physical and digital provision. An institution's

	facilities can be viewed as spaces and infrastructure. Examples of physical facilities include lecture rooms, workshops, and libraries. Examples of digital facilities include digital libraries, virtual laboratories, online learning platforms, and conferencing software (Microsoft Teams, Zoom, etc.). An institution's resources can be viewed as materials, tools, and supporting systems available to students and staff. Examples of physical resources include hand tools, machining tools (manual and CNC), building materials (fabrics, metals, composites, etc.), stationery, communal computers, tutoring services, writing centres, math labs, and counselling and mental health services. Examples of digital resources include recorded-lectures, online collaborative document software (Microsoft Word cloud software, Google Docs, etc.), cloud storage, online tutoring, online writing and math support centres, online counselling and mental health services.
The Teaching and Learning Environment	This element refers to the teaching and learning environment within which the PBL approach is designed and implemented. When planning a PBL curriculum, engineering educators have the option to organise teaching and learning in (1) traditional on-campus settings, (2) fully online environments, or a mix of both in a (3) blended format combining (Chen et al., 2021). The benefits and challenges associated with each teaching and learning environment should be carefully considered to ensure that the PBL approach aligns with the desired learning outcomes and the available staff (who should be adequately trained), facilities and resources.
Assessment and Evaluation	This element refers to assessing student learning in PBL and the effectiveness of the PBL curriculum as a whole. Assessment of PBL should be aligned with the objectives, learning outcomes and the learning methods. Assessment should extend beyond measuring disciplinary knowledge to include elements such as professional skills and competencies. Methods of student assessment in PBL should encompass both formative and summative assessment. Formative assessment is strongly encouraged due to its alignment with the PBL principles, as it supports awareness of the learning process.

4 CONCLUSION

In conclusion, this paper defines and explains PBL while also presenting an expanded PBL Curriculum Model designed to scaffold engineering practitioners' approaches to PBL development, implementation and assessment. The updated model has the potential to help curriculum designers develop PBL approaches for contemporary engineering educational environments.

5 DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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Artificial Intelligence in Primary Science and Technology Education with a Focus on Implementation of AI in a Learning Context: Results of a Scoping Review

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Abstract

Artificial intelligence has become an integral component of 21st-century life, necessitating ongoing adaptation to the profound social and technological transformations it precipitates (Yim & Su, 2025). AI impacts not only the everyday world, where it encompasses a wide range of technologies and applications, but also future primary education.

Primary education faces the challenge of raising awareness among learners and teachers for an AI-driven living environment and leveraging the technology's potential responsibly (Irion & Kuzu, 2025). In everyday school life, AI can be used particularly in science and technology lessons in primary schools, as this is where a basic understanding of the technological environment is acquired, as well as the ability to cope in an increasingly complex world. It is important to investigate how AI can be integrated into both instructional preparation and classroom learning activities, contributing to the ongoing development of primary education (Irion & Kuzu, 2025). Building on these perspectives, there is a need for structured frameworks that specify which AI-related -should be fostered in primary education in order to systematically support learners' understanding and use of AI in their everyday lives. A theoretical framework for AI-competences in primary education is adopted and divided into *fundamental knowledge, use & control, reflection (in everyday life)*.

This article presents a scoping review of the literature on the use of Artificial Intelligence in a teaching and learning context in primary science and technology education. The scoping review identifies central aspects of AI use in primary science and technology education and outlines the current state of research in this field.

Key Words: Artificial Intelligence, Primary School, Technology Education, Science Education

1 INTRODUCTION

The term artificial intelligence (AI) was first introduced in 1955 by John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon in a research funding proposal (De Florio-Hansen, 2020). Since the release of ChatGPT in 2022 at the latest, however, AI has assumed a central role in society. “The advent of artificial intelligence in many areas of life marks the beginning of one of the most significant transformations in human history” (Autenrieth et al., 2024, p. 26).

Increasingly powerful AI systems are taking over tasks traditionally performed by humans, gradually blurring the boundaries between human and machine intelligence (Autenrieth et al., 2024). Given this strong relevance to learners’ everyday lives, the role of AI in school education has come into focus. The Standing Conference of the Ministers of Education and Cultural Affairs of Germany has developed policy recommendations that explicitly emphasise AI-based learning materials and underline that foundational and future-oriented competences are not contradictory but mutually supportive (KMK, 2025). Overall, AI is gaining increasing importance in school education.

Despite these rapid developments in society and education, the development of AI-related competences among young learners remains at an early stage, with a lack of clear conceptualisations and effective implementation approaches what needs to be expected (Yim & Su, 2025). To understand AI applications, both students and teachers require basic knowledge about how algorithms work (De Florio-Hansen, 2020). In this context, there is a growing demand to introduce AI-competence education already at the primary level and integrate it into early childhood and primary education.

In view of these technological transformations, the present article examines the use of AI in primary science and technology education and provides an overview of existing applications through a scoping review. It focuses primarily on the use of AI and its implementation. These findings are then discussed in terms of AI skills in primary schools, and implications for further research are drawn.

2 LITERATURE REVIEW

2.1 *Artificial intelligence*

A review of the term 'artificial intelligence' (AI) reveals the challenge in achieving a uniform definition (Scheiter et al., 2025). In general terms, *intelligence* can be described as the ability to solve different kinds of problems. In technological contexts, AI refers to the simulation of this capability by computer systems (Stiperberger & Renner, 2023).

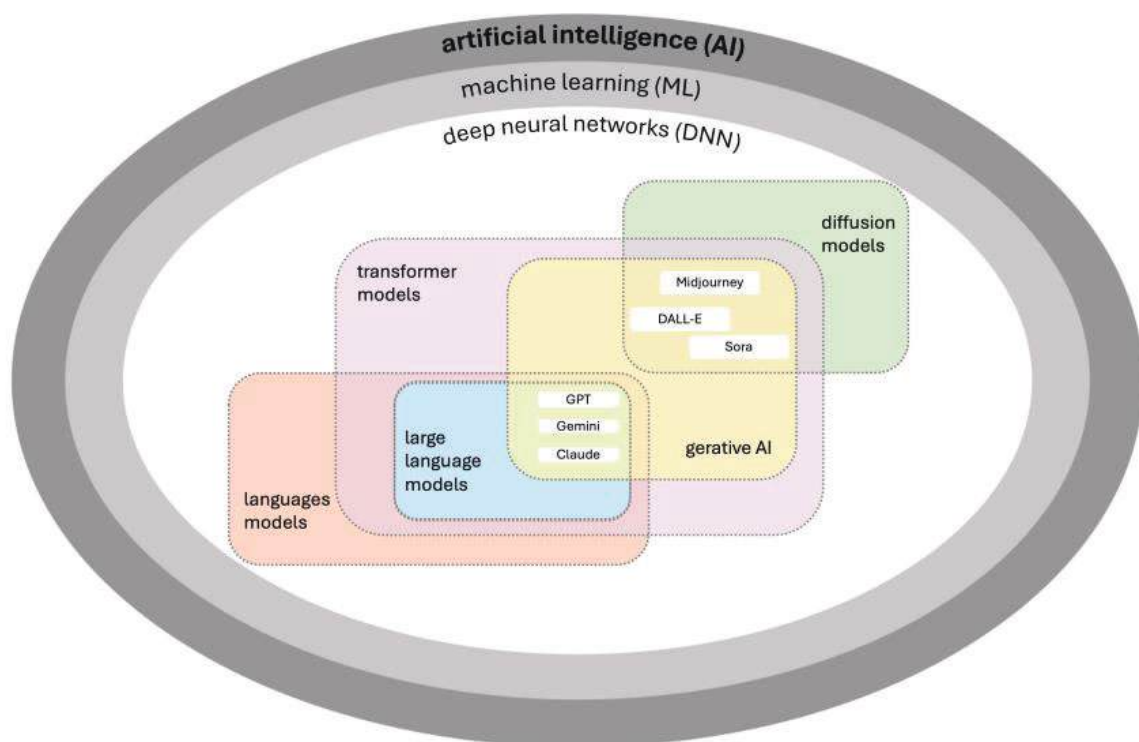
Accordingly, Scheiter et al. (2025, p. 6), define AI as “a field of computer science concerned with the creation of intelligent machines through algorithms”. A wide range of technologies and fields of application are encompassed by the use of AI (Scheiter et al., 2025). The European Commission’s guidelines for teachers on the use of AI (2022) provide a practice-oriented perspective by defining AI as software designed to perform tasks that would normally require human intelligence, including learning and reasoning. In addition, AI systems can be trained on

data to independently generate predictions, recommendations, and decisions, sometimes without direct human involvement.

Technically, AI can be divided into several major areas (Scheiter et al., 2025), including machine learning (supervised, unsupervised and reinforcement learning, as well as deep learning), logic- and knowledge-based approaches (e.g. knowledge representation, inductive programming, expert systems), and statistical methods such as Bayesian estimation, search and optimisation techniques. This classification highlights the diversity of methods that fall under the umbrella of AI. Based on Buchholtz et al. (2024), AI can be structured into several interconnected components, as shown in Figure 1. Machine learning encompasses algorithms that identify patterns in data and make decisions based on them. Deep neural networks process complex structures within large datasets. Language and transformer models enable the comprehension and generation of text; large language models (LLMs) are based on this architecture and produce human-like language. Diffusion models generate visual or audiovisual content. The overarching concept of generative AI refers to approaches that combine multiple methods to autonomously create new content (Buchholtz et al., 2024).

Figure 1

Areas of AI (adapted from Buchholtz et al., 2024)



2.2 Artificial intelligence in primary science and technology education

Artificial intelligence has become part of everyday life and is increasingly embedded in the experiences of primary school children, even when it is not always directly visible in the digital

tools they use (Irion & Kuzu, 2025). In this context, AI is expected to play a key role in nearly all areas of children's future lives and should therefore be systematically included in digital basic education (Autenrieth et al., 2024). Similar to findings from research on traditional literacy, which highlight the importance of starting early with reading and writing development (Kandlhofer et al., 2016), it can be assumed that basic AI-competences should also be addressed from the primary level onwards. Primary education places particular emphasis on understanding fundamental AI concepts and relating them to concrete applications (Chung et al., 2025). Introducing AI at this stage can support the development of early interest, foster responsible attitudes, and enhance students' motivation and engagement (Su & Yang, 2024).

At the same time, it is emphasised that, from a didactic perspective, AI should connect to children's everyday realities and therefore has a place in contemporary teaching, as existing prior knowledge needs to be taken up, related, and further developed (Scheiter et al., 2025). AI can be a useful tool for differentiated tasks, interactive learning activities, and playful learning designs; however, it should remain a supplementary resource and cannot replace social, creative, and hands-on learning (Scheiter et al., 2025).

The use of AI can be linked to science and technology education due to its connection and emergence in the everyday lives of students. Within science education, primary school has a dual function: children learn to interpret natural phenomena and, at the same time, develop basic scientific concepts and methods (Möller et al., 2011). Technology education at the primary level aims to equip students with fundamental technological practices, as well as with knowledge and skills that are relevant for lifeworld (Möller, 2002).

Consequently, elementary schools are tasked with the responsibility of "responsibly harnessing both the fascination and the potential of AI for learners and teachers and preparing children for a world shaped by AI" (Irion & Kuzu, 2025, p. 4). In particular, learning with, about and despite AI can take place in science and technology education.

2.3 *AI-competences in primary education*

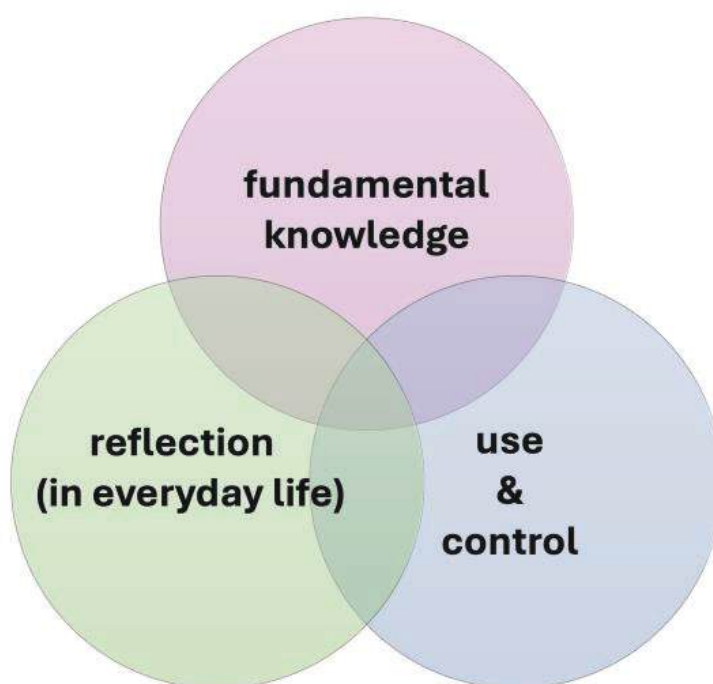
Teaching AI-competences in primary education is a relatively recent development (Yim & Su, 2025). The concept of AI-competences was introduced by Kandlhofer et al. (2016), highlighting that technical skills for understanding core AI concepts are a fundamental prerequisite (Yim & Su, 2025). The development of AI competences follows a stepwise process, beginning with basic conceptual understanding (UNESCO, 2022).

AI-competences frameworks and national guidelines aim to address existing gaps in research and practice by providing guidance for the development of age-appropriate AI learning resources (Yim & Su, 2025). As Autenrieth et al. (2024) argue, making use of AI's potential and dealing with its challenges requires a reflective understanding of AI systems from multiple perspectives. In recent years, a number of models for AI-competence development have been proposed, including those targeted at school students. Notably, UNESCO (2024) published the AI Competency Framework for Students as a global reference for integrating AI into national curricula. Likewise, the OECD (2025) introduced the AILit Framework, with a particular focus

on primary and secondary education. However, most of these frameworks address the full educational continuum or only partly consider primary school learners. To better capture AI-competences at the primary level, three key domains were derived from Alles et al. (2025), Chiu et al. (2024), Irion & Kuzu (2025), OECD (2025) & UNESCO (2024). As shown in Figure 2, these domains include *fundamental knowledge*, the *use & control* of AI, and *reflection (in everyday life)*.

Figure 2

Framework of AI-competences in primary education (Osnabrügge based on: Alles et al. (2025), Chiu et al. (2024), Irion & Kuzu (2025), OECD (2025) & UNESCO (2024))



In the area of *fundamental knowledge*, primary school science and technology students should develop basic understanding of artificial intelligence, including data, algorithms, and how AI systems work (e.g. Alles et al., 2025). A key goal is that learners understand that AI systems process data and use algorithms to generate likely outcomes or predictions (UNESCO, 2024). The domain of *use & control* focuses on enabling children to develop basic operational skills in working with AI systems through selected AI tools (e.g. Irion & Kuzu, 2025). This includes using AI as a support for completing tasks and learning simple strategies for effective input formulation, often referred to as prompting (e.g. OECD, 2025). In the domain of *reflection (in everyday life)*, attention is given to the opportunities and limitations of AI. Students should be able to identify and critically reflect on the effects of AI use on individuals, social relationships, and society more broadly (Irion & Kuzu, 2025). Examples for each category are shown in Table 1. Overall, the primary-level AI-competence framework draws on established framework but adapts them to the age-specific needs and capabilities of young learners.

Table 1

Example competencies for primary science and technology education (based on Alles et al., 2025 & OECD, 2025)

Category	Technology education	Science education
fundamental knowledge	if-then or rule structures that underlie automated decision-making processes	understanding scientific phenomena through AI
use & control	formulation of prompts	use of AI, e.g. in experiments
reflection & everyday life	recognising and evaluating misinformation	use of AI to reflect CO ₂ emissions on the environment

3 PROBLEM STATEMENT

Artificial intelligence is becoming increasingly influential across social, economic, and educational domains. This trend is also evident in children's everyday lives, as AI-based applications such as Siri and Alexa are already widely used (Su & Yang, 2022). At the same time, there is a lack of clarity regarding the assumptions and competences underlying the use of AI (Yim & Su, 2025).

Research has increasingly taken up this topic, exploring both the opportunities and the challenges of AI in school settings. As a result, the question arises of how AI can be meaningfully integrated into primary science and technology education. However, it is still unclear to what extent and in what ways AI is currently used in primary-level science and technology classrooms.

To address this gap, the present scoping review investigates the following research questions:

1. What types of AI applications are used in primary science and technology education?
2. What goals are associated with the implementation of AI in primary science and technology education?

4 METHODOLOGY

The research questions were developed using a scoping review approach (Von Elm et al., 2019). Scoping reviews aim to systematically map the available literature, consolidate existing evidence, and identify gaps in knowledge, while deliberately refraining from a formal appraisal of study quality. In addition, they support decisions about the scope and value of conducting a subsequent systematic review and provide a basis for formulating recommendations for future research. As such, scoping reviews constitute an efficient and transparent method for synthesising research and identifying priority areas for further study.

Table 2*Identification information*

Database	web of science & Scopus
Search date	22.12.2025
Search strings	TS=(schoolchild* OR school-age child* OR "elementary school child" OR "elementary student*" OR "primary student*" OR "primary school" OR "elementary school" OR "primary education" OR "elementary education" OR "primary level" OR "elementary level" OR "primary grade*" OR "elementary grade*" OR "lower grade*" OR "early school year*" OR "early childhood education" OR "grade 1" OR "grade one" OR "grade 2" OR "grade two" OR "grade 3" OR "grade three" OR "grade 4" OR "grade four" OR "year 1" OR "year one" OR "year 2" OR "year two" OR "year 3" OR "year three" OR "year 4" OR "year four" OR "first grade" OR "second grade" OR "third grade" OR "fourth grade" OR K4 OR "K-4" OR "K 4" OR K5 OR "K-5" OR "K 5") NOT (TS= ("higher Education" OR "pre-service teachers" OR "middle school" OR "highschool" OR "pre-service teachers" OR "kindergarden" OR "adult" OR "metastases" OR "veterinary" OR "secondary education" OR "higher education" OR "tertiary education" OR "postsecondary education" OR "post-secondary education" OR "university*" OR "college*" OR "third level education" OR "out of school")) AND TS=("science learning" OR "scientific learning" OR "science education" OR "science teaching" OR "science instruction" OR "science classroom" OR "science lesson*" OR "science activity" OR "science activities" OR "scientific inquiry" OR "inquiry-based learning" OR "inquiry learning" OR "guided inquiry" OR "scientific literacy" OR "science literacy" OR "scientific understanding" OR "scientific knowledge" OR "science understanding" OR "technology learning" OR "technical learning" OR "technology education" OR "technical education" OR "technology instruction" OR "technology teaching" OR "technology-

based learning" OR "technology-rich learning environment*" OR robot* OR STEM)

NOT (TS=
(medic* OR linguistics* OR "surgery" OR medicine* OR "health insurance"
OR "foreign language learning" OR "vocabulary" OR "language learning" O
R "cancer" OR "review"))

AND

TS=("artificial intelligence" OR "AI" OR "intelligent system*" OR "AI-
based system*" OR "educational AI" OR "AI in education" OR AIEd OR
"ChatGPT" OR "Mistral" OR "DeepSeek" OR "Gemini" OR "Bard" OR
"LaMDA" OR "Claude" OR "Grok" OR "Bing AI" OR "LLaMA" OR "Sage"
OR "Fobizz" OR "machine learning" OR "ML" OR "machine intelligence"
OR "neural network*" OR "convolutional neural network*" OR
"large language model*" OR LLM OR "generative AI" OR "GenAI" OR
"foundation model*" OR chatbot* OR "AI tutor*" OR "virtual tutor*" OR
"intelligent tutoring system*" OR "text generation" OR "speech recognition"
OR "image recognition" OR "automated feedback" OR "AI-
supported assessment")

NOT (WC
= (Hematology OR Surgery OR Oncology OR Medicine OR Immunology O
R Cell Tissue Engineering OR Transplantation OR Surgery
OR Orthopedics OR Urology OR Dermatology OR geriatrics OR
Gerontology))

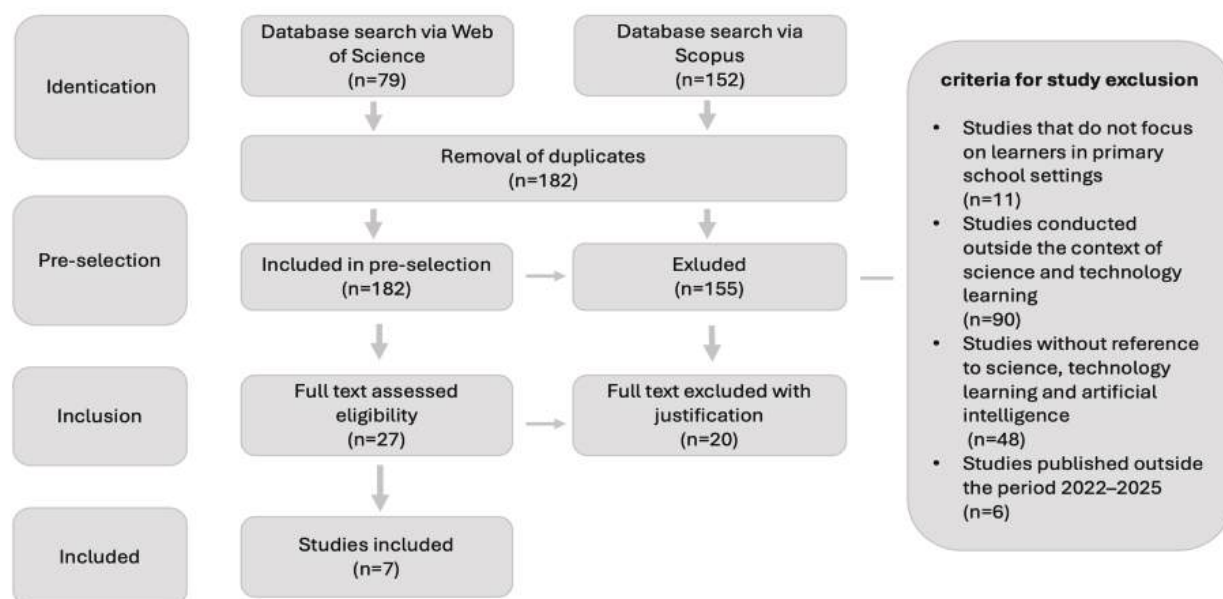
Search filter	Publication years: 2022 - 2025; Document Types: Article; Languages: English

Number of results	N = 231

Table 2 provides an overview of the search strategy, including the databases searched, the search date, the query, the search filters, and the number of records retrieved. The study selection process followed the PRISMA guidelines and is illustrated in Figure 3.

Figure 3

Diagram for identifying studies



The text was written as a German version and translated with generative AI tools (Perplexity, DeepL, and DeepL Write) to English.

5 FINDINGS

The studies included in the scoping review (n=7) are summarized in Table 3. Among them are six quantitative studies examining the use of AI in science education, as well as one qualitative study in which teachers were interviewed about their experiences with implementing AI in a learning context.

Table 3

List of identified studies

Code*	Study title/ source	Authors	Country/ context	Methodology / design	Sample	Main findings
FNS	<i>Facilitating the Acquisition of Natural Science</i>	Niyoxon et al., 2025	Uzbekistan	Pedagogical pilot study in primary schools	221 primary students (Grades 1–4)	Significantly higher learning performance, understanding and engagement;

	<i>Knowledge by Primary School Students through Artificial Intelligence: Case Study – 3D Modelling of Lessons and Virtual Classrooms</i>					support of abstract thinking; more ecologically sustainable teaching
EAM	<i>Experimenting with AI-based mobile applications to improve student engagement in ornamental plant learning in rural Indonesian schools</i>	Setyawan & Purbohad i, 2025	Indonesia (rural)	Quasi-experimental (pre–post-test)	93 students (Grades 5–6)	35% increase in understanding; higher enthusiasm and engagement; improvement linked to high activity level in app use
ALB	<i>Affirmative Large Language Model-Based Dialogue Robot for Broadening or Deepening the Perspective of Children</i>	Uchida et al., 2025	Japan	Experimental comparison of two conditions (affirmative vs. refutational/control)	53 students (Grade 6)	Affirmative strategy led to significantly greater expansion/deepening of perspectives (objective and subjective) and more positive impressions (anthropomorphism, likeability, perceived intelligence)
GAC	<i>Generative AI + AR: a novel embodied</i>	Cai et al., 2025	China	Quasi-experimental pretest–post-test design	62 students	Significant gains in learning motivation and curiosity

	<i>conversation al agent in an interactive learning environment</i>			with control group and interviews	(Grade 6)	(dimension of critical thinking); better learning performance; high technology acceptance
EEM	<i>Exploring the Effects of the CER Model- Based GenAI Learning System to Cultivate Elementary School Students' Computational Thinking Core Skills in Science Courses</i>	Zhao et al., 2025	China	Quasi- experimental study (three groups: CER-GenAI, CER without GenAI, causal- explanation GenAI without reflection)	118 students (Grade 5)	CER-GenAI system significantly improved science achievement and CT skills (especially pattern recognition and algorithms); no pre-test differences, significant post- test group effect
EIV	<i>Effects of immersive virtual reality on primary student's science performance in classroom settings: a generative AI pedagogical agents- enhanced 5E approach, Interactive Learning Environments</i>	Wei et al., 2025	China	Mixed- methods design (experiment + qualitative data)	80 students (Grade 6)	IVR with GPA-5E significantly improved academic performance, self- efficacy and collective efficacy; qualitative data indicated vivid, enjoyable learning and simplification of abstract concepts
TPE	<i>Transforming Primary Science Education: Unlocking the Power of</i>	Al- Karasneh et al., 2025	Saudi Arabia	Qualitative study with semi- structured interviews	43 primary school teachers	Reported support for personalised and motivating learning, interactive simulations,

*Generative
AI to
Enhance
Pupils' Grasp
of Scientific
Concepts*

scientific
curiosity,
creativity and
problem-solving,
simplification of
complex
concepts;
supports
constructivist and
inquiry-based
learning

* Each study was assigned a code to facilitate the understanding of the subsequent tables.

5.1 What types of AI applications are used in primary science and technology education?

To answer the first research question, the analysis focuses both on the technological foundations of artificial intelligence and on its thematic application in science classrooms. Table 4 presents the thematic integration of artificial intelligence within science education. The table highlights how AI was incorporated into different teaching contexts. With the exception of the interview study (TPE), AI was consistently connected to one or more science-related topic.

Table 4

Applications from AI in science and technology education in the studies

Code	Applications in Science and Technology Education
FNS	Use of virtual reality (VR) through a 3D modelling of a virtual classroom addressing topics such as the solar system, plant development, and animal body structures → use of AI systems to control students' attention, provide real-time answers to questions, and employ gamification elements and interactive simulations
EAM	Application of an AI-based mobile app for recognizing ornamental plants, provide and compare real-time information
ALB	Deployment of the social communication robot CommU, powered by the LLM GOT-4 (OpenAI) and speech recognition from WebSpeechAPI, to explore topics such as living organisms, the environment, and maintaining a clean school → sing AI to conduct critical dialogues and discussions on scientific or sustainability topics.
GAC	Integration of augmented reality (AR) and an embodied conversational agent (ECA) “Virtual Scientist” to study plant growth under sunlight setting → using AI for personalised and context-sensitive dialogues in real time

EEM	Implementation of a GenAI-based learning system addressing the principle of levers → using Ai for enabling the generation and explanation of answers to students' questions
EIV	Use of a virtual robot within an immersive virtual environment (IVR) to introduce tools and instruments → Using AI to better understand complex scientific concepts through 3D visualisation and dynamic interaction, feedback & use of scaffolds
TPE	Overview of applications includes: Personalized learning support to account for individual differences Development of comprehensive and interactive learning experiences through visual representations and simulations of natural phenomena (e.g., the water cycle) Use of tools such as ChatGPT to provide real-time feedback and individualized instruction Chat-based feedback sessions to clarify abstract and complex scientific concepts Analysis of student interactions to support teachers in improving science instruction

Table 5 illustrates the different types of AI applications identified in the reviewed studies. Three studies used AI in virtual environments (VR, AR, IVR). Additionally, one study made use of a robot, another employed an AI-based learning system, and one implemented an app.

Table 5

Technical applications of artificial intelligence in the studies

Type of AI Application	Related Studies
use of VR / AR / IVR / 3D (integrating LLMs)	FNS, GAC, EIV
use of robots (integrating LLM)	ALB
AI-based learning system (integrating GenAI)	EEM
LLM-based mobile application (mobile app plant recognition)	EAM

5.2 *What goals are associated with the implementation of AI in primary science and technology education?*

To answer the second research question, which explores the implications of artificial intelligence use in educational settings, Table 6 offers a structured overview. The identified implications are

grouped into the categories shown in the table. Each category lists the studies that explicitly discuss the respective implication by their abbreviations, making it clear which aspects of AI use were addressed in each study.

Table 6

Implications of use of AI in science and technology education in the studies

Category	Related Studies
emotional and affective dimensions	FNS, EAM, GAC, EIV
cognitive learning objectives	FNS, EAM, GAC, ALB, EEM, EIV, TPE
individual learning needs	EEM, EIV
methodological approaches	TPE
reflection	ALB, EEM, TPE
theory–practice transfer	EAM, GAC, EEM
value-oriented and future competencies	ALB, TPE

6 DISCUSSION

The present scoping review provides a systematic overview of the current state of empirical research on the use of AI in primary science and technology education. Seven studies were included in the analysis, offering insight into how AI is currently integrated into classroom practice and which forms of implementation are being used.

Across the reviewed studies, artificial intelligence was predominantly implemented in technologically advanced learning environments, including AR and VR, immersive virtual scenarios, social robots, and generative AI systems. These applications require not only teachers but also students to possess basic operational skills in interacting with AI. In this context, AI primarily functioned as a didactic tool for supporting subject-related learning rather than as an explicit object of instruction. The results further indicate that the reviewed studies focus mainly on cognitive and affective learning outcomes in science education. All studies reported positive effects on learning performance, conceptual understanding, motivation, or student engagement. In particular, technology-rich environments such as virtual or agent-based scenarios were associated with increased curiosity, enjoyment, and self-efficacy, highlighting the potential of AI to make complex and abstract scientific content more accessible for primary school learners.

When these findings are interpreted in relation to the AI framework for primary education outlined in the literature review, a more differentiated picture emerges. The model distinguishes three domains: *fundamental knowledge, use & control*, and *reflection (in everyday life)*. The analysis shows that these domains are not addressed equally. The domain of *use & control* is

strongly represented, as students in all studies actively interacted with AI systems such as chatbots, learning platforms, apps, or virtual agents to solve tasks, ask questions, and receive feedback. In contrast, the domain of *fundamental knowledge* is weakly developed. Although advanced AI technologies such as large language models, generative AI, and intelligent agents were used, their underlying principles were rarely made explicit. Concepts such as data, algorithms, or the probabilistic nature of AI outputs were largely neglected, leaving AI as a “black box” for many learners. An even more pronounced gap can be observed in the domain of *reflection (in everyday life)*. Only a small number of studies addressed reflective or value-oriented aspects of AI, such as students’ perceptions of AI systems, trust in AI-generated information, or broader societal implications. Yet this domain is crucial for fostering responsible and critically informed engagement with AI, particularly in primary education, where foundational attitudes towards technology are formed.

7 CONCLUSION

This scoping review aimed to map how AI is currently implemented in primary science and technology education and which educational goals are associated with its use. The results demonstrate that AI-based applications are already embedded in diverse and innovative learning environments and positively affect students’ achievement, motivation, and engagement.

However, when examined through the lens of the primary-level AI relevant competences a clear imbalance becomes apparent. While the domain of *use and control* are covered in all studies, the domains of *fundamental knowledge* and especially *reflection (in everyday life)* remain largely underrepresented. Taken together, the findings suggest that although AI offers substantial educational potential in primary science and technology education, it is currently used mainly as an instrumental means to support subject learning or to be immersed in scenarios. The systematic development of AI-competences, particularly in terms of reflective and informed engagement with AI, is given comparatively little attention, indicating an important area for future research and instructional development.

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Mapping Student Motivation Across a Long-Format Transdisciplinary Design Project: A Work-in-Progress Study

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Abstract

Design-based learning, a common educational practice within technology and engineering curriculum offers students open-ended challenges that can spark high levels of initial engagement. However, the large scale and time span of these design projects can cause fluctuating motivation as learners experience design realities, such as ambiguity, iteration, and a demand for meaningful outcomes. These “highs and lows” of engagement, analogous to a motivational rollercoaster, can deter students from persisting through difficult stages of their design projects, thereby reducing the potential impact of the project on learning, skill development, and production of valuable design outputs. This paper proposes a study to map changes in student motivation and engagement across a semester-long transdisciplinary design project situated within an upper-level undergraduate course integrating human-centered design and innovation development. In this study, students will complete repeated survey measures at four key points during the project using the Situational Motivation Scale and the Utrecht Work Engagement Scale – Student Version. Semi-structured interviews will be conducted at the end of the semester to further explore students’ experiences and perceptions. By examining longitudinal patterns in motivation and engagement, this proposed study aims to identify critical periods of motivational decline and growth during long-format design projects. The findings establish a baseline understanding of students’ motivational trajectories that can inform the design and timing of future instructional interventions intended to support sustained engagement in design-based learning environments.

Key Words: Design Education, Motivation, Engagement, Transdisciplinary Design

1 INTRODUCTION

Design-based learning has become a central instructional approach in engineering and technology education, offering students opportunities to engage in authentic, open-ended problem solving that mirrors professional practice. While these experiences provide powerful learning opportunities, they also place sustained motivational demands on students that extend beyond those encountered in traditional short-term assignments. Understanding how motivation and engagement evolve over the course of extended design projects is therefore essential for designing instructional environments that support persistence and deep learning. As a result, this paper **proposes** a study to map changes in student motivation and engagement across a semester-long transdisciplinary design project situated within an upper-level undergraduate design course. By examining longer-term patterns in motivation and engagement, this proposed study aims to identify critical periods of motivational decline and growth during long-format design projects. The findings from such a study can help establish a foundational understanding of students' motivational trajectories that can inform future instructional interventions intended to support sustained engagement in design-based learning.

1.1 *Design-Based Learning and Long-Format Projects*

Design-based learning emphasizes authentic, open-ended problem solving in a way that can be positioned to teach concepts through design and to teach about design practices. Central to this approach is the use of extended projects that require students to integrate technical knowledge, collaborate in teams, and iteratively develop solutions over prolonged periods of time. These learning environments can help promote meaningful engagement and deeper conceptual understanding by situating content within realistic and socially relevant contexts (Frank et al., 2003; Reynolds et al., 2009).

Within this context, motivation and engagement are distinct but complementary constructs that together shape how students experience and persist through design work. Motivation, as defined within the Self-Determination theory and operationalized by the *Situational Motivational Scale* (SIMS), refers to the underlying reasons or regulatory processes that drive student participation in a specific activity. The SIMS distinguishes four types of situational motivation: intrinsic motivation (engaging in an activity for its inherent interest and enjoyment), identified regulation (engaging because activity is personally valued), external regulation (engaging due to external pressures or rewards), and amotivation (a lack of intention to engage) (Guay, Vallerand, & Blanchard, 2000). Engagement, in contrast, is commonly conceptualized as a multidimensional construct encompassing the behavioral, emotional, and cognitive investment that students bring to their learning tasks (Fredericks, Blumenfeld, & Paris, 2004). As operationalized by the *Utrecht Work Engagement Scale – Student Version* (UWES-S), project specific engagement is captured through three dimensions: vigor (energy and mental resilience while working), dedication (sense of significance, enthusiasm, and pride in one's work), and absorption (deep concentration and immersion in a task) (Shaufelo & Bakker, 2004). Together, these frameworks provide a comprehensive lens for understanding not only whether students participate in design work, but how invested and energized they are while doing so.

Long format design projects, however, place unique demands on students, requiring sustained effort, motivation, and engagement over multiple weeks or months. The design process further contributes to these sustained demands. Engineering design is inherently iterative and occurs across multiple phases, including problem scoping, ideation, prototyping, testing, and refinement (Atman et al., 2007). Each phase presents distinct cognitive and emotional challenges that may influence students' motivational experiences. Early project stages may generate excitement and creativity, while later stages may involve increased workload, technical complexity, and performance pressure. As a result, motivation and engagement within long-format design projects should not be viewed as static constructs, but rather as dynamic experiences that evolve throughout the project lifecycle. This variance in motivation can be thought of as a "motivational rollercoaster," in which different stages of the project bring varying levels of motivation and engagement, with low points often coinciding with moments of uncertainty, revision, and project completion fears.

1.2 *The Knowledge Gap*

Despite the widespread use of long-format design projects and the recognized importance of sustained engagement, relatively little research has systematically examined how student motivation and engagement change over the duration of extended design experiences. Prior work has documented common barriers to student engagement in engineering contexts, including time constraints, competing academic demands, and cognitive overload (Simmons et al., 2018). These challenges often intensify as projects progress, potentially contributing to fluctuations in students' motivational states.

Much of the existing literature in design and project-based learning has focused on instructional strategies, course structures, or intervention-based approaches intended to improve student outcomes (Frank et al., 2003; Atman et al., 2007). While this work has provided valuable insights into effective pedagogical practices, it has typically relied on cross-sectional or single-timepoint measures of engagement and motivation. As a result, instructors and curriculum designers often lack empirical guidance regarding when students are most likely to experience motivational decline or heightened engagement during the project timeline.

Without a clear understanding of these temporal patterns, efforts to support student motivation risk being reactive or poorly timed. Establishing a baseline map of how motivation and engagement naturally evolve across long-format design projects is therefore an important first step toward developing targeted and evidence-informed instructional supports. Addressing this gap requires longitudinal measurement approaches capable of capturing within-student changes across key phases of the design process.

1.3 *Proposed Study Overview*

Building on the need to better understand temporal patterns of motivation in design-based learning environments, the purpose of the study proposed in this paper is to longitudinally examine changes in student motivation and engagement across a semester-long transdisciplinary design project. Using repeated survey measures throughout the duration of the project, this study seeks to map motivational trajectories and identify periods of growth and decline in engagement

during extended design work. By establishing model motivational patterns, this work can provide empirical guidance for educators seeking to align instructional supports with students' motivational needs. Rather than assuming when students require additional scaffolding or feedback, this approach can enable data-informed decisions about the timing of future pedagogical interventions.

To achieve this study's purpose, the following research questions are posed to guide the investigation:

- (i) How do students' situational motivation profiles (intrinsic motivation, identified regulation, external regulation, and amotivation) change across the duration of a semester-long transdisciplinary design project?
- (ii) How do levels of project-specific engagement (vigor, dedication, and absorption) change across major phases of the design project?
- (iii) Are there identifiable periods of motivational decline or growth that occur consistently across the design project timeline?
- (iv) How do students describe their motivational and engagement experiences during different phases of the design project?

To address these research questions, a longitudinal repeated-measures design will be implemented within an upper-level transdisciplinary design course. Later sections will outline the research methodology, participant context, instruments, and data collection procedures.

2 LITERATURE REVIEW

2.1 Motivation and Engagement in Design-Based Learning

Design-based learning environments provide a rich context for examining student motivation and engagement. Long-format design projects are commonly implemented to simulate real-world engineering and innovation practices, requiring students to engage deeply in problem solving, critical thinking, collaboration, and iterative development processes (Frank, Lavy, & Elata, 2003). These projects often span several weeks or an entire academic term, positioning them as sustained learning experiences rather than short-term assignments. Prior research suggests that authentic, project-based tasks can increase students' interest and perceived relevance of coursework by connecting academic content to meaningful real-world applications (Reynolds, Mehalik, Lovell, & Schunn, 2009).

Self-Determination Theory (SDT) offers a well-established framework for understanding the quality and type of student motivation in educational contexts. SDT posits that human motivation exists along a continuum ranging from amotivation through various forms of extrinsic regulation to intrinsic motivation, and that sustained, high-quality motivation is fostered when three fundamental psychological needs are met: autonomy (the need to feel ownership and choice over one's actions), competence (the need to feel capable and effective), and relatedness (the need to feel connected to others) (Deci & Ryan, 1985; Ryan & Deci, 2000). Recent qualitative research

has begun to examine how these needs operate within engineering design and challenge-based learning environments specifically. Pantzos, Pears, and Buckley (2025) investigated motivation among engineering Master's students engaged in challenge-based learning courses, finding that students' motivational profiles were shaped by the degree to which their needs for autonomy, competence, and relatedness were met or frustrated by the learning environment. When courses provided structured tasks, meaningful feedback, and positive collaborative relationships, students reported motivation grounded in intrinsic regulation (engaging in project work because they personally valued it or found it inherently interesting). Conversely, when tasks lacked clear rationale, project choice was absent, feedback was limited, or team dynamics were negative, students' psychological needs were frustrated and motivation declined. Importantly, this research confirms that motivation in complex design and project-based contexts is not static, it responds dynamically to environmental conditions and can shift across the duration of the learning experience. This literature can highlight the importance of understanding not only the level but also the quality and type of student motivation in extended design projects and point to specific project conditions and phases where motivational support may be most needed.

Despite these perceived benefits, maintaining consistent motivation and engagement throughout extended design experiences presents unique challenges. Unlike traditional coursework that may involve discrete and predictable tasks, long-format design projects require students to persist through ambiguity, evolving project requirements, and iterative cycles of refinement. These characteristics make motivation and engagement within design-based learning inherently dynamic rather than static. Consequently, engagement in these environments should be understood as a fluctuating experience that evolves across the duration of the project rather than a fixed trait or singular outcome.

2.2 *Long-Format Design Projects and Temporal Challenges*

While students often begin long-format design projects with high levels of enthusiasm and energy, motivation frequently fluctuates as projects progress. Early project stages are commonly characterized by excitement and creative exploration; however, as technical complexity increases and project demands intensify, students may encounter periods of discouragement and uncertainty. These motivational “highs and lows” reflect the emotional and cognitive demands inherent in extended design work and highlight the temporal nature of engagement within project-based learning environments.

Research has identified several factors that contribute to motivational decline during long-format projects. Common challenges include increasing workload demands, unclear task expectations, social loafing within teams, limited instructional interaction, and perceptions of project irrelevance or impracticality (Chen et al., 2008; Dawes & Senadji, 2010; Carpenter, Yakymyshyn, & Micher, 2016; Kuester & Griesemer, 2024). As projects progress, these factors may compound, creating periods where students experience reduced persistence and lower emotional investment. Such patterns suggest that motivation during extended design experiences is not uniform, but instead varies in response to project structure and individual student experiences.

The iterative nature of the engineering design process further contributes to these temporal challenges. Design work unfolds across multiple phases, including problem definition, ideation,

prototyping, testing, and refinement, each of which introduces distinct cognitive and emotional demands (Atman et al., 2007). Transitions between phases often require shifts in skill application, collaboration strategies, and workload intensity. These transitions may correspond with changes in student motivation and engagement, reinforcing the need to examine how motivational patterns align with project milestones.

Despite recognition of these challenges, much of the existing literature has focused on describing design processes or proposing instructional strategies rather than empirically documenting how student motivation evolves across the full duration of long-format projects. As a result, instructors often rely on intuition when determining when students may require additional support. Systematically mapping motivational trajectories across extended design experiences represents an important step toward developing data-informed approaches to supporting sustained engagement.

2.3 *Measuring Motivation and Engagement Over Time*

Understanding how motivation and engagement evolve throughout long-format design projects requires measurement approaches that are sensitive to task context and capable of capturing change across time. Traditional approaches to assessing student motivation often rely on global or trait-based measures that reflect general academic attitudes rather than situational experiences tied to specific learning activities.

Situational motivation frameworks offer a more appropriate lens for examining task-level motivational experiences. The SIMS was developed to measure students' immediate motivational states in relation to specific activities and is grounded in SDT (Guay, Vallerand, & Blanchard, 2000). The SIMS distinguishes between intrinsic motivation, identified regulation, external regulation, and amotivation, allowing researchers to examine not only overall motivation levels, but also changes in the quality and type of motivation over time. The instrument is designed to be adapted to specific task contexts, therefore, it is well suited for repeated measurement within long-format design projects. A key psychometric strength of the SIMS for longitudinal research is that it was explicitly designed to detect intraindividual changes in motivation across measurement occasions, distinguishing it from trait-based instruments that assume motivational stability (Guay et al., 2000). Recent validity evidence has further supported the robustness of the SIMS across educational contexts, confirming strong internal consistency across all four subscales and appropriate factor loadings in short-term situational assessment contexts (Wasicek & McHugh, 2024).

In parallel, engagement represents a complementary construct that captures how students behaviorally, emotionally, and cognitively invest in their work. The UWES-S provides a validated framework for measuring project-specific engagement through the dimensions of vigor, dedication, and absorption (Schaufeli & Bakker, 2004). These dimensions reflect students' energy levels, sense of meaning and enthusiasm, and degree of immersion in academic tasks. When used in repeated-measures designs, the UWES-S enables researchers to examine how engagement fluctuates across different phases of extended learning experiences. The psychometric properties of the UWES-S have been examined across multiple undergraduate populations, with confirmatory factor analysis supporting the three-factor structure of vigor, dedication, and

absorption and demonstrating satisfactory reliability across subscales (Carmona-Halty, Schaufeli, & Salanova, 2019). The instrument's demonstrated measurement invariance across student groups further supports its use in repeated-measures designs where consistent interpretation of scores across time points is essential.

Together, situational motivation and engagement measures provide a comprehensive lens for examining the underlying drivers of student participation and the observable manifestations of effort and persistence. Employing repeated assessments of these constructs across key project milestones offers an empirical approach to capturing motivational trajectories that are often discussed conceptually but rarely measured across in design education contexts.

3 METHODOLOGY

3.1 *Research Design*

The proposed study will employ a longitudinal repeated-measures research design to examine changes in student motivation and engagement across a semester-long transdisciplinary design project. The focus of this study will be to document how motivational and engagement patterns naturally evolve throughout the project lifecycle. Repeated survey measures will be administered at biweekly intervals to determine what key points exist within design project structures as they pertain to student motivation and engagement. This approach enables within-student comparisons across time and supports the identification of temporal patterns in motivation and engagement.

In addition to quantitative survey data, qualitative data will be collected through an open-ended reflection question embedded within the final survey and through semi-structured interviews conducted at the conclusion of the project. This mixed-methods approach allows for triangulation between numerical trends and students' self-reported experiences, providing additional contextual insight into observed motivational patterns.

3.2 *Context and Participants*

The study will be conducted within an upper-level transdisciplinary design course at a large Midwestern university. The course integrates principles of human-centered design, innovation development, and entrepreneurial thinking, culminating in a semester-long team-based design project. The project spans nearly the entirety of the academic semester, approximately 16 weeks, with the first three weeks dedicated to introductory course content before project work begins. Students work in multidisciplinary teams to identify real-world problems, develop conceptual solutions, and produce project deliverables, such as prototypes and product pitches, aligned with technical and user-centered design criteria.

Participants will consist of undergraduate students enrolled in the course during the study semester. Students represent a range of academic majors and disciplinary backgrounds, reflecting the transdisciplinary nature of the course. Participation in the study will be voluntary, and students will be informed that their decision to participate or not participate will have no impact on course grades or standing. All participants will be at least 18 years of age.

3.3 *Instruments*

Student motivation will be measured using an adapted version of the SIMS (Guay, Vallerand, & Blanchard, 2000). The SIMS is a 16-item instrument grounded in SDT that assesses four types of situational motivation: intrinsic motivation, identified regulation, external regulation, and amotivation. Participants will respond to items using a 7-point Likert-type scale ranging from 1 (corresponds not at all) to 7 (corresponds exactly). Instrument wording will be adapted by replacing references to “this activity” with “this design project” in order to contextualize the measure to the focal course project, consistent with published guidelines for situational administration.

Student engagement will be measured using the UWES-S (Schaufeli & Bakker, 2004). The UWES-S consists of 9 items measuring three engagement dimensions: vigor, dedication, and absorption. Responses will be recorded on a 7-point frequency scale ranging from 0 (never) to 6 (always), reflecting how often students experienced each statement while working on the design project. As with the SIMS, item wording will be adapted to reference engagement with the semester-long design project rather than general academic studies.

In addition to scaled survey items, an open-ended reflection question will be included to allow participants to describe factors that influenced their motivation and engagement during the project. Semi-structured interviews conducted at the end of the semester will further expand on survey responses and provide qualitative insight into students’ project experiences.

3.4 *Data Collection Timeline & Procedures*

Data will be collected at biweekly intervals during the semester-long design project to capture changes in student motivation and engagement across major project phases. At each timepoint, participants will complete an online survey containing the SIMS and UWES-S. The final survey will additionally include an open-ended reflection question prompting students to describe factors that influence their motivational and engagement experiences. Surveys will be administered as homework assignments available electronically for completion within a short response window. Semi-structured interviews will be conducted following project completion with a subset of volunteer participants to further explore themes emerging from the survey data. All data collection procedures will be conducted following institutional review board approval, and informed consent will be obtained from all participants prior to participation.

3.5 *Planned Data Analysis*

Quantitative survey data will be analyzed using descriptive and longitudinal comparison methods to examine changes in motivation and engagement across the four measurement points. Subscale scores for the SIMS (intrinsic motivation, identified regulation, external regulation, and amotivation) and UWES-S (vigor, dedication, and absorption) will be calculated by averaging relevant item responses. Trends in mean subscale scores will be examined across project phases to identify patterns of motivational growth and decline. Qualitative responses from open-ended survey items and interviews will be analyzed using thematic analysis to identify recurring themes related to students’ motivational experiences and project challenges. Integration of quantitative

and qualitative findings will support triangulation and provide contextual interpretation of observed motivational trajectories.

3.6 *Generative AI Disclosure*

Generative AI was used as a proofreading tool as well as editing assistant to reduce wordcount, as well as a tool to soundboard ideas and concepts in early-stage development.

4 DISCUSSION

This proposed study is designed to provide a foundational understanding of how student motivation and engagement evolve across the duration of a semester-long transdisciplinary design project. By adopting a longitudinal measurement approach, the research will help address a gap in design education literature, which has largely relied on cross-sectional or outcome-based assessments. Mapping motivational trajectories can offer a more nuanced view of student experiences, capturing not only overall engagement levels but also the timing and magnitude of motivational shifts that occur throughout extended project work.

The findings from this study are expected to have important implications for instructional design in project-based learning environments. Identifying periods of motivational decline or heightened engagement can inform the strategic timing of instructional supports such as feedback, reflection activities, milestone scaffolding, and team facilitation. Rather than applying uniform interventions throughout the semester, instructors may be better positioned to align pedagogical practices with students' evolving motivational needs. This approach supports a move toward data-informed instructional planning in design education contexts.

From a research perspective, this work will help establish a baseline framework for future intervention studies. By first documenting natural motivational patterns, subsequent research can more effectively test targeted instructional strategies designed to support sustained engagement during critical project phases. In this way, the proposed study represents an initial step in a broader research agenda focused on improving design-based learning experiences through empirically grounded motivational support.

Several limitations should be acknowledged. The study will be situated within a single course context, which may limit generalizability to other institutional settings or disciplinary domains. Additionally, self-report measures are subject to response bias and may not fully capture all dimensions of student motivation and engagement. Future work should consider integrating observational or performance-based measures to complement survey data and extend the robustness of findings.

Acknowledgements: The authors acknowledge support for this work from the National Science Foundation [2439279]. However, this content is solely the responsibility of the authors and does not necessarily represent the official views of the National Science Foundation.

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Making a Makerspace: The Innervate Lab as a Reimagined Technology Education Space

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Abstract

With the growing emphasis on creativity, collaboration, and reflective thinking in technology and design education, technology labs are expected to shift from technical priorities to open, collaborative spaces. Designed within an existing technology education facility, the paper explored what it means to “technology lab” that merges the technical with the reflective, the cultural with the material, and the innovative with the contemplative. This paper presents the intellectual and aesthetic journey of creating an innovative makerspace within a technology education context and explains how this work embodies a sustainable model for training future technology educators. Our approach was informed by the belief that traditional technology labs and makerspaces provide foundational tenets, such as promoting foundational literacy, while also promoting the spirit of community and tinkering, respectively. With this background, we developed a lab that emphasized culturally inclusivity and relevance through the bridge of technology and holistic learning. From this framework emerge three intersecting, vital pillars that make the makerspace unique and relevant in an urban context: contemplation, creativity, and sustainable design and material reuse, and contemplative practice as a mode of inquiry. By uniting design, technology, and reflection, Innervate offers a model for culturally responsible technology education laboratory. It demonstrates how reimagining space, materials, and pedagogy can bridge inner and outer worlds, transforming making into a pathway toward meaning and community.

Key Words: Makerspace, Creativity, Contemplation, Culturally Relevant Pedagogy, Sustainability

1 INTRODUCTION

Recent technology and engineering education (TEE) approaches emphasize creativity, collaboration, and critical thinking; therefore, transforming technology education labs from technical priorities into collaborative, open, and innovative spaces is expected. As classrooms confront the realities of climate instability, rapid advances in artificial intelligence, student alienation, and rising mental health challenges, educators are being called upon to cultivate

learning environments that are responsive, humane, and culturally relevant (Zakoth et al., 2024). Makerspaces, in particular, have emerged as powerful sites for interdisciplinary learning, yet many remain grounded in narrow conceptions of productivity, efficiency, and fabrication. The Innervate Makerspace was developed in response to an intentional effort to reimagine what a TEE space can be, whom it serves, and what kinds of learners and educators it seeks to develop (Brown & Toumey, 2017). Located within a traditional TEE setting, Innervate was designed as a philosophical, pedagogical, and aesthetic intervention. Rather than treating space as neutral, the makerspace was conceived as an active participant in learning, one that communicates values, invites reflection, and shapes how technology is understood and practiced. Its development was guided by a commitment to cultural relevance in a diverse, urban context, where emerging educators must navigate complex social, environmental, and technological realities alongside their students.

Previous studies and practices have informed the three interwoven facets of makerspace: sustainability, creativity, and contemplation (Blikstein, 2018; Cangiano & Romano, 2019). These dimensions were not separate initiatives but interwoven features, reinforcing one another through design, materials, and pedagogical practice. Sustainability addresses the environmental, economic, and management issues raised in the existing makerspace. For emerging educators, this approach reframes TEE as a means of engaging students with sustainable practices, not as a shop teacher running a technology lab solely through technical aspects (Ericson et al., 2014). Creativity serves as the second pillar, particularly in relation to emerging technologies such as artificial intelligence (Henriksen et al., 2016). In a time when young people are navigating algorithmic systems daily, creativity becomes essential for helping learners critically engage with technology rather than passively consume it. Contemplation forms the foundation upon which sustainability and creativity are grounded. Through practices such as journaling, guided reflection, and meditation exercises, contemplation supports the development of self-worth, empathy, and awareness. For emerging educators working in high-pressure urban environments, contemplative practice offers a way to address student burnout, disconnection, and emotional fatigue, while also cultivating their own reflective teaching identities (Rahmani & Zitouni, 2022).

The purpose of this study is to document how a traditional technology lab can evolve in relation to the three emerging facets and propose the Innervate makerspace as a model for a learning platform for TEE. Therefore, our study, a narrative of ideation and materialization, was founded on this umbrella question: how can we make traditional technology labs more creative, collaborative, and reflective? As we informed the approach and application for our space, we specified these three questions, which are explicated in the Results section:

- (i) What does a technology lab mean from practical, epistemological, and ontological stances?
- (ii) What are the key design elements of a technology-based makerspace that incorporate sustainability, creativity, and contemplation?
- (iii) How can the traditional technology lab evolve into an innovative, relevant makerspace by embracing sustainability, fostering creativity, and encouraging contemplation?

2 LITERATURE REVIEW & FRAMEWORK

In designing the foundational framework for this makerspace, we draw upon scholarship that critiques the limitations of traditional TEE spaces while calling for learning environments that are culturally relevant, intellectually expansive, and responsive to contemporary urban contexts. Our review engages literature that reconceptualizes making as a site of creative cognition and intelligence, emphasizing studies that provide evaluative approaches for design education (Zhu et al., 2025).

First, contemplative approaches (stemming from wisdom traditions like Yoga) in pedagogy have increasingly been theorized in education as an epistemological orientation that reshapes how classrooms integrate self-inquiry and wellbeing (Rockefeller, 2022). Scholarship on the “contemplative turn” in education argues that reflective and inward-facing practices cultivate forms of attention, presence, and meaning-making that challenge purely instrumental or mechanistic conceptions of learning (Ergas, 2018). Drawing from Indian philosophy and aesthetic traditions, recent work has further demonstrated how contemplative inquiry can deepen students’ engagement with scientific concepts by integrating experiential awareness and ethical sensitivity into classroom practice (Pandya, 2024). Consequently, as Vivekananda argued, the natural progression of introspection and reflection towards creativity empowers educators and learners to problem-solve with a social conscience (Mitra & Prakash, 2023). When enacted within technology and engineering learning environments, this orientation encourages students to incorporate their own perspectives, values, and lived experiences into both the design process and the artifacts they create (Emdin, 2021; Henriksen et al., 2016).

Furthermore, sustainable practices in making and design have increasingly emphasized reflective and conscientious engagement with objects, materials, and consumption, particularly in response to its economical, operational, and environmental issues raised in existing makerspaces (Singh, 2022). Early iterations of the maker movement emerged from community-based and collaborative practices, including informal garage projects, maker fairs, and volunteer-driven spaces that prioritized participation and shared knowledge (Keune & Peppler, 2019). As the movement expanded, makerspaces took on varied forms, such as hackerspaces in Europe, Fab Labs within universities, and commercially oriented Tech Shops, each reflecting different institutional goals and access structures (Van Holm, 2014). However, the growing emphasis on institutionalization and business models often led to an over-prioritization of expensive tools at the expense of people, processes, and sustainability, contributing to challenges related to staffing, maintenance, and long-term viability (Love et al., 2022). Scholarship on maker education claimed right-to-repair approaches support this orientation by enabling participants to disassemble, repair, and repurpose objects using open-source tools and shared knowledge, reducing waste while fostering social interaction and agency (Cangiano & Romano, 2019). Collectively, these approaches have been shown to reduce environmental impact while cultivating creativity, collaboration, and empowerment, particularly within marginalized communities (Premyanov et al., 2024).

Finally, in TEE, tools and spaces play a crucial role in expanding creativity (Lewis, 2009). From an epistemological perspective, technological knowledge can be expressed as praxeology, or practical knowledge (Lux & Ray, 1966). The tools in a makerspace are not simply for productivity but for extending human capabilities by externalizing mental ideas through drawing, making, and

sharing ideas. While traditional views of creativity focused on fluency, originality, and flexibility as the main elements, recent perspectives emphasize that creativity is contextual and completed when supported by practicality. Our makerspace is based on constructionism, the theory that schemas are transformed during the process of makers handling and creating objects (Seymore & Harel, 1991).

3 METHOD & MAKING OF THE LAB

3.1 *Methodological Orientation*

Methodologically, this work aligns most closely with narrative and design-based qualitative inquiry, while remaining nontraditional in form (Creswell & Poth, 2013). The makerspace itself is treated as the primary unit of analysis, with particular attention paid to its evolution over time. Narrative elements used to examine the nature and educational potential of the space included: (a) perceptions and understanding of traditional technology labs (b) use of makerspaces in contemporary culture, and (c) our attempt of innovating a traditional lab to emphasize culturally relevant facets. These materials were examined holistically to understand how the space functioned pedagogically in practice. Rather than seeking generalizable claims, this study offers a situated account of how a makerspace emerged through faculty expertise, institutional context, and engagement with contemporary educational challenges.

3.2 *Rationale for The Name, Innervate*

The name *Innervate* was chosen deliberately to reflect the philosophical grounding of the makerspace: inner exploration as the impetus for shared inquiry and making. The name draws inspiration from Eastern pedagogical traditions articulated by thinkers such as Rabindranath Tagore and Swami Vivekananda, who emphasized creativity, self-realization, and education as a process of awakening rather than accumulation (Pandya, 2024). Within contemporary scholarship on creativity and identity, *Innervate* aligns with the idea that learning environments shape not only skills but also a sense of self (Zhu et al., 2025). The makerspace thus seeks to emphasize inner development alongside external creation, positioning making as an act that connects mind, body, culture, and technology (Emdin, 2021).

3.3 *AI disclosure*

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

4 THE RESULTING SPACE & CONCENTRATIONS

4.1 *Traditional Understanding of Technology Labs*

In TEE, the laboratory goes beyond being a place for learning; it serves as a platform where knowledge and practice coexist in a complex way. In 1979, British sociologist Stephen Woolgar and French anthropologist Bruno Latour authored a book chapter "An Anthropologist Visits the Laboratory", where they described the daily practice of scientific activity in the lab (Latour & Woolgar, 1979). They described a laboratory not as a place to practice scientific experiments to discover new knowledge, but as a space where documents are constantly written, external contacts are made via phone calls, miscellaneous tools are cleaned and repaired, and, from a social constructivist perspective. If an anthropologist were to visit a technology lab where engineers are working and describe their work, it would not be much different from what Latour and Woolgar describe. Similarly, a technology lab would be described not as a place where knowledge is transmitted to students, but as a complex structure of technology where people constantly communicate, create, solve problems, and within that, new ideas are co-constructed with the people, practicing under the fundamental nature of technology education (Reed, 2001).

Although TEE shares a spirit of promoting technological literacy for all people, epistemological knowledge of technology varies across location, time, and social needs (ITEEA, 2020). In the United States, technology labs are often perceived as mechanical shops where making takes place (Haynie, 2008). For this reason, many technology labs are often called technology shops. The shop culture of the United States is the legacy of Industrial Arts and Technology Education where the focus was partially shared with vocational education until the 1970s (Lux & Ray, 1966). Terminologically, a shop refers to a place where things are manufactured or repaired, like an auto shop. On the other hand, where the focus is on design and creativity, technology labs are often called design studios, fabrication labs, or engineering labs. As the word "design" suggests, a design studio is a place to sketch ideas and create prototypes. Design studios are commonly found in industrial design departments at post-secondary schools, and the term "design studio" is also frequently used in design thinking education, which emphasizes design (Crowther, 2013).

Makerspace is broadly defined as an unstructured collaborative fabrication space with a variety of tools, software, and materials that facilitate social interactions by fostering a shared spectrum of interests (Blikstein, 2018). Some spaces were called a "hacker space" for computer-oriented labs or a "fab lab" for fabrication-focused labs. The term "maker" is broader and refers to the daily activities of building or creating something that everyone can engage in, any kind of making.

4.2 *Key Design Elements of a Technology-based Makerspace*

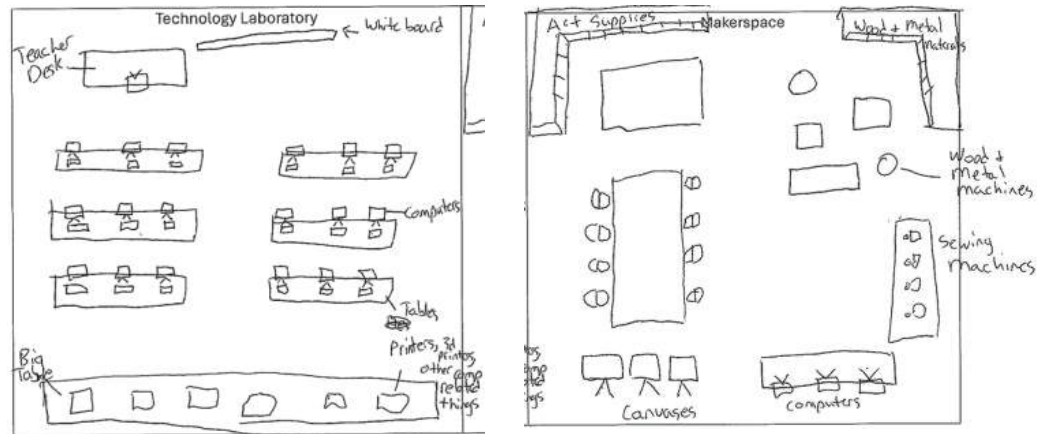
The intertwined history and epistemological distortions of TEE give rise to misconceptions and mistrust regarding it. Adopting an epistemological approach to analyze perceptions of technology labs and makerspace, we sought to identify fundamental components that represent reflective, sustainable, creative practices of TEE. Table 1 is an analysis of technology labs and makerspace from an epistemological perspective.

Table 1*Epistemological Analysis of Technology Labs and Makerspaces*

Types	What people think of technology labs	What people think of makerspaces
Objectives	To promote technological literacy To implement the technology curriculum	To support collaborative, hands-on projects To foster innovation, creativity, and critical thinking
Operations	Systemic, Top-down, by school schedules	Unstructured, Bottom-up, By appointment or walk-in, workshop
Accessibility	Only for technology students and teachers	Open to the public or membership
Activities	Curriculum-aligned activities, e.g, bridge design, model house, mouse-trap cars, treasure box, rollercoaster, electronic cars, robotics arm,	Making projects, Computer programming, 3D printing, physical computing woodworking
Value	Process-oriented Process as learning	Outcome-oriented Product as an outcome
Pedagogy	Learning by doing (Dewey, 1916)	Constructionism, Learning through making (Papert & Harel, 1981)
Tools	Technical tools required for technology projects, such as saws, hammers, hot-glue guns, 3d printers, and laser engravers	Making tools required for making projects such as digital fabrication, electronics, and manual crafting.
Materials	Curriculum materials, e.g., wood sheets, electronics components, cardboard, and form boards	Crafting and prototyping materials, e.g., cardboard, wood scraps, fabrics, electronics components, 3D print filaments.
Participants	Technology students	All kinds of people
Culture	Structured, rigid, and educational.	Unstructured, flexible, fun, and open.

Room Configuration

(drawn by student)



The comparison between technology labs and makerspaces is not to claim that TEE labs are deficient or that makerspaces excel. Instead, we aimed to understand the perceived images of TEE laboratories and makerspaces. The difference between technology labs and makerspaces that we identified through an epistemological approach is that technology labs generally focus on promoting technical competency and technological literacy (ITEEA, 2020), while makerspaces share a similar value focus with technology labs, but their primary purpose is to support making and collaboration (Blikstein, 2018). In operation, technology labs tend to be structured and hierarchical, whereas makerspaces are more unstructured and operate with a flexible, improvisational approach. Regarding the process-outcome stance, technology labs are primarily used for educational purposes, so the activity itself is valued as a learning experience, while products are often valued as much as the process. Some makerspaces are operated for educational purposes and can be process-oriented, but in general, people come to makerspaces to complete their projects. Lastly, we asked our teacher education students to draw an image of a technology lab and makerspace. As shown in Table 1, the configuration of technology labs is typically structured, rigid, and systematic, whereas makerspaces have a flexible, ill-structured, and value-open culture.

In either case, as technology laboratories evolve and community-driven makerspaces take shape, these learning environments increasingly emphasize creativity, shared inquiry, and participatory learning. In developing Innervate, we drew inspiration from these pedagogical spaces while intentionally integrating elements we viewed as culturally emergent and relevant to contemporary technology education.

4.3 *Designing Innervate: Embracing sustainability, creativity, and contemplation*

4.3.1 *Prior status & intentional transformation*

Before its transformation, the Innervate Makerspace existed as a conventional computer laboratory adjacent to a secondary maker room containing fabrication equipment. The primary lab, as shown in Figures 1 and 2, consisted of fixed rows of desktop computers, neutral tones, minimal visual stimulation, and limited opportunities for collaboration. Similarly, as depicted in

Figure 2, the adjoining space functioned largely as a woodshop or machine-based environment, supporting tool-centric instruction rather than interdisciplinary or reflective learning. Together, these spaces reflected a traditional model of technology education, functional and efficient, yet less aesthetic and collaborative.

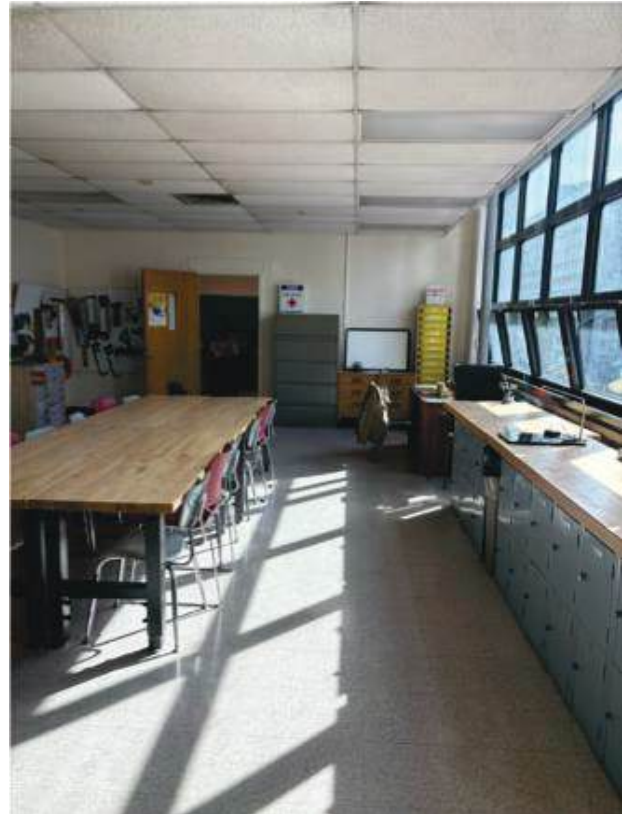
Figure 1

Original Computer Lab



Figure 2

Original Machine-based Lab



Elements such as color, sound, tone, texture, and spatial arrangement influence how educators and students show up in a space, affecting attention, emotional safety, and relational presence (Greene, 1995). In traditional technology labs, the absence of aesthetic intention can implicitly communicate rigidity, hierarchy, and exclusion. In contrast, culturally responsive environments invite participation by signaling that learners are seen, heard, and valued (Emdin, 2021).

As part of the methodological approach, the redesign of the lab involved not only the introduction of new technologies, such as 3D printers, CNC routers, digital fabrication tools, updated laptops, and textile equipment, but also to the cultivation of an aesthetic identity. Collaborative tables replaced fixed seating to encourage dialogue and shared making. Walls were repainted to introduce warmth and visual contrast, quotes emphasizing creativity and reflection were installed, and student-designed murals and artifacts were displayed prominently throughout the space.

4.3.2 *Aesthetics & Context*

The aesthetic transformation of the Innervate Makerspace reflects the deliberate application of sustainability, creativity, and contemplation as integrated design principles. Rather than treating aesthetics as secondary to function, the redesign positioned the environment itself as a pedagogical agent, one that communicates values, invites participation, and shapes how technology education is experienced (Henriksen et al., 2016, Emdin, 2021). Student input informed decisions about layout, visual symbolism, and how the lab should function as a shared learning environment. This choice was grounded in the understanding that cultural relevance cannot be imposed from above; it must emerge through affirmation of student identity and voice (Emdin, 2021). Drawing on Greene's notion of aesthetic education as an awakening to possibility, inviting students into the design process positioned them not merely as users of the space, but as co-creators of its meaning and purpose (Greene, 1995).

Figure 3

Innervate Collaboration Room



Figure 3 shows the aesthetic transformation and collaborative functions of Innervate. It reveals a transition: a shift from the traditional technology education environment marked by limited color, fixed layouts, and minimal opportunities for collaboration. The space prioritized utility and efficiency, with little visual or cultural signaling to support belonging, dialogue, or creative exploration.

Figure 4

Student Design in Innervate Collaboration Room



Figure 5

Innervate Making Room



Second, creativity is expressed through openness and adaptability. Flexible collaboration desks replace fixed seating, allowing the space to shift between individual making, group critique, and collective ideation. Figures 4 and 5 illustrate how student-designed artifacts, murals, and project displays foreground student voice and cultural identity. Particularly, the wall murals shown in Figures 3 and 4 are student-designed, as inspired by class discussions. This was an application of being mindful of the context, since the lab is situated in downtown Brooklyn, and also amplifying student culture and identity. Contemplation grounds the space aesthetically and pedagogically. Quotes from educators, philosophers, and artists are intentionally placed throughout the lab to invite reflection and slow engagement. Areas for journaling, meditation, and quiet observation counterbalance the intensity of fabrication activities, supporting presence and meaning-making within an engineering context.

5 CONCLUDING DISCUSSION

This paper retrospectively examines the background, philosophical foundations, operation, and direction of the Innervate Makerspace. The project began with a very simple question: how can we make traditional technology workshops more creative, collaborative, and reflective? For us, this was answered through our guiding questions, commitment to the *inner* aspect, and materialization through the three facets. While hands-on activities are crucial in TEE for expanding human capabilities, traditional technology workshops have often overly emphasized the technical aspects. Therefore, student-centered workshops, co-led by faculty and students, enact the three dimensions through contemplative practices, while utilizing sustainable materials

to guide participants in developing creative solutions to community issues and local challenges. While many makerspaces initially receive significant investment and achieve early success, many eventually downsize or close due to high maintenance costs, staffing difficulties, and funding challenges. Innervate Makerspace, located within a technology education department, aimed at high impact with low costs, prioritizing sustainability and contemplation in its design. In the future, we hope to expand our approach to making this makerspace into artifact-based studies that examine the role of our facets in each course and workshop.

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Navigating the Tension Between Confidence-Building and Professional Responsibility in Technology Teacher Education

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Abstract

This study examines how teacher educators in technology teacher education for grades 4–6 describe their didactic approaches to strengthening student teachers' confidence when engaging with programming. As programming has become a mandatory component of technology education in Swedish primary schools, it has also entered technology teacher education. While previous research has focused on the integration of programming and on student teachers' attitudes or competence, less attention has been paid to how teacher educators respond didactically to student teachers' hesitation and uncertainty.

The study draws on semi-structured interviews with teacher educators responsible for teaching programming in technology education. The interviews focus on their teaching aims, task design, and strategies. Using qualitative content analysis, the study identifies patterns in the ways in which teacher educators support their student teachers' confidence, paying particular attention to their didactic considerations. The findings show that teacher educators lower thresholds, normalise uncertainty, and create positive experiences in order to reduce fear and encourage participation.

However, the study also reveals a tension. While teacher educators prioritise strategies that build confidence and enable participation, questions remain about how this work supports professional readiness for independent teaching. Confidence-building emerges as necessary, yet not sufficient in itself. The study contributes a more nuanced understanding of how emotional and professional dimensions are balanced within the structural constraints of technology teacher education.

Key Words: Technology Teacher Education, Programming, Confidence, Didactics

1 INTRODUCTION

Many student teachers in technology education for grades 4-6 encounter programming for the first time during their university studies. Unlike students in computer science or engineering programmes, they often lack prior experience of coding or computational concepts. Programming is therefore introduced simultaneously as new content and as a future teaching responsibility.

Previous research shows that both pupils, teachers and teacher educators struggle to make programming meaningful within the technology subject (Hallström & Frejd, 2023; Perez et al., 2025; Sentance & Csizmadia, 2017). Programming is often experienced as difficult to integrate with other areas of technological knowledge, leading to uncertainty about what counts as programming in technology education. Research has also examined how programming has been integrated into school curricula (e.g., Cederqvist, 2021; Fessakis et al., 2013; Sentance & Csizmadia, 2017; Vinnervik, 2021), highlighting the importance of didactic strategies that connect programming to broader technological understanding (Hamidi et al., 2023; Nordlöf et al., 2022; Perez et al., 2024).

To prepare competent technology teachers, teacher educators will need to understand not only the conceptual challenges of programming but also the emotional and motivational ones. This is because it appears to influence engagement and willingness to teach programming (Çoban et al., 2020). When teachers experience uncertainty about their subject knowledge, they may simplify tasks or avoid deeper engagement, thereby shaping the learning opportunities offered to pupils (Sentance & Csizmadia, 2017). For student teachers encountering programming for the first time, confidence is therefore not merely an individual feeling, but a condition that may affect how they position themselves in relation to both the subject and their future professional responsibility. In this study, confidence mainly refers to student teachers' experience of being able to work with programming activities, as described by teacher educators. Confidence is thus understood as an experiential and emotional aspect of learning, connected to the willingness to participate, try, and continue, rather than as a measure of how much one knows. However, since programming is simultaneously introduced as a future teaching responsibility, confidence in relation to teaching remains closely connected. While conceptual understanding of programming is important for professional competence, the present study focuses specifically on how teacher educators address student teachers' engagement and willingness to participate in programming activities.

While previous research has examined student teachers' attitudes and competence in relation to programming (e.g., Çoban et al., 2020), less attention has been paid to how teacher educators actively address student teachers' expressed worry, fear, or lack of confidence in their teaching practice. Thus, although confidence appears to matter for how programming is enacted in schools, we know comparatively little about how it is handled within technology teacher education. Since teacher educators play a central role in framing programming as both content and future teaching responsibility, examining their approaches is essential for understanding how engagement with programming is enabled and constrained in teacher education.

By focusing on teacher educators' didactic reasoning rather than student teachers' outcomes, this study contributes new insight into how programming is introduced, framed, and made accessible within technology teacher education.

The aim of this paper is to examine how teacher educators address student teachers' lack of confidence in programming and how this is related to preparing them for professional responsibility in technology education.

Research questions:

- How do teacher educators describe student teachers' lack of confidence in programming?
- What didactic strategies do they describe using to address this?
- How are these strategies related to preparing student teachers for professional responsibility?

2 METHOD

This study draws on interview data collected within a larger research project exploring programming in Swedish technology teacher education. The present analysis focuses specifically on how teacher educators describe building student teachers' confidence and how this work relates to professional preparation.

2.1 Participants

Twelve teacher educators from eleven Swedish higher education institutions participated in the study, Table 1. They had between three and thirty years of experience as teacher educators (mean = 11 years). The group included teacher educators working in both pre-service and in-service teacher education for grades 4–6. Ten participants held a teaching degree for compulsory school, four had completed doctoral studies, and six had formal university-level education in programming. All participants were assigned pseudonyms to ensure confidentiality.

Table 1

Characteristics of the participants

Total participants	12 (7 women, 5 men)
Average years in the profession of teacher educator	11 years (range: 3–30)
Taught in preschool, primary, lower, secondary schools	9
In-service teacher education only	3
Teacher education degree	10
Postgraduate education	4
Programming qualifications (higher education)	6

2.2 *Procedures*

Data were generated through semi-structured interviews. Prior to each interview, participants were asked to select and reflect on a concrete teaching example in which programming was integrated into technology education. This example served as the entry point for discussing teaching aims, task design and how student teachers' difficulties or uncertainties were addressed. Follow-up questions were used to encourage participants to elaborate on their reasoning. Each interview lasted between 50 and 60 minutes and was conducted via Zoom. All interviews were carried out in Swedish, audio- and video-recorded, and transcribed verbatim by the author. The study followed ethical guidelines for educational research, and informed consent was obtained from all participants.

2.3 *Analyses*

The present analysis draws on interview data collected within a larger research project. Although the interview guide used, in that project, did not explicitly focus on confidence-building, this theme emerged repeatedly in the participants' descriptions. The present analysis therefore focuses on how confidence-building was constructed in the interviews and on the tensions that appeared between building confidence and preparing for professional responsibility.

The analysis followed principles of qualitative content analysis (Graneheim & Lundman, 2004). The transcripts were read several times to gain an overall understanding of the material. Meaning units were identified in sections where the teacher educators described teaching examples, student teachers' reactions, and their own didactic intentions. These meaning units were condensed and coded with attention to how confidence was constructed and addressed. Through iterative comparison of codes and categories, an overarching tension between confidence-building and professional preparation was identified and further examined in relation to the data.

2.4 *Use of Generative AI tools*

Generative AI tools were used to support the writing process for language editing. No generative AI tools were used to produce empirical analyses, interpret data, or generate research findings. All analytical decisions and interpretations are the sole responsibility of the author.

3 RESULTS

Before examining the strategies used to address confidence, it is interesting to consider how teacher educators describe student teachers' initial relation to programming. Across interviews, student teachers are portrayed by teacher educators as hesitant and uncertain, often lacking prior experience of programming. Programming is described as something unfamiliar and technically demanding, which contributes to fear of failure and reluctance to engage. Several teacher educators refer to students being "afraid to try" and surprised when they succeed, indicating that confidence is perceived as fragile and closely tied to initial experiences of success or failure. In these accounts, lack of confidence is not framed as a general personal disposition, but as emerging

in relation to programming as subject content. The uncertainty described is linked to limited prior exposure, perceived technical complexity, and concerns about not knowing enough.

The analysis shows that teacher educators describe several ways of addressing student teachers' concerns and lack of confidence in relation to programming in technology education for grade 4-6. The analysis identified three recurring didactic strategies, which were: lowering thresholds, normalising uncertainty, and creating joy and positive experiences. Across these strategies, a recurring tension also appeared in the educators' descriptions concerning how confidence-building relates to preparation for professional responsibility.

3.1 *Lowering thresholds*

A recurring pattern in the data is that teacher educators describe lowering the threshold for participation by selecting simple tasks and accessible tools. Programming is positioned primarily as something student teachers need to experience and manage themselves before it becomes a question of how to teach it. By reducing complexity and narrowing the scope of tasks, teacher educators aim to make participation feel manageable rather than risky. Teacher educator Beata describes her reasoning when selecting an activity for her students. This shows how simplification is used to reduce fear and hesitation:

‘I want to show them [the students] something that is easy to use so that they [the students] won't be afraid to try it. And I do very simple things.’

In this description, lowering the threshold is closely linked to the students fear of trying. Similarly, teacher educator Clara describes how student teachers are often surprised by their own success when engaging with programming tasks:

‘Most of them [the students] feel a little surprised that they are succeeding at this. Especially those who feel that they don't know anything about programming.’

Here, lowered thresholds create opportunities for early experiences of success. For student teachers who initially perceive programming as inaccessible, managing to complete a task becomes an important step towards participation and continued engagement.

Across interviews, lowering thresholds is presented as a way of making programming approachable and of enabling student teachers to engage with the activity.

3.2 *Normalise uncertainty*

A second strategy involves framing uncertainty and difficulty as expected aspects of working with programming. Rather than presenting programming as something that should function smoothly, teacher educators describe making breakdowns and errors visible and discussable. Teacher educator Clara describes how technical problems are deliberately used as learning opportunities, where uncertainty becomes something to be explored rather than avoided:

‘Then I try to use that in my teaching too. Like, “-oh, look, this is how it can go”, and when we end up in this situation, “- well, what can we do then?”’

In this description, uncertainty is normalised through action. Technical difficulties are not hidden or resolved in advance but instead used to demonstrate how problems can be approached, discussed, and managed in practice.

Similarly, teacher educator Ingrid describes how she explicitly relates to limitations in knowledge and resources, framing them as conditions to work within rather than as failures:

‘It's true that I don't have sufficient knowledge, as I don't know anything about programming. But I do have this time. How can I make the most of it?’

Here, uncertainty is presented as shared and legitimate. By articulating her own constraints, the teacher educator models a way of dealing with limited knowledge and resources.

In these accounts, uncertainty is described as shared and legitimate. This strategy differs from lowering thresholds in that it does not remove difficulty but reframes it as part of the learning process. In some descriptions, this also involves modelling how to respond to uncertainty in teaching situations, suggesting a more explicit connection to professional practice.

3.3 *Creating joy and positive experiences*

A third recurring strategy concerns creating positive experiences. Teacher educators describe activities that generate visible results and feelings of accomplishment. By designing activities where student teachers quickly see tangible outcomes, programming activities are framed as engaging and rewarding rather than intimidating.

Teacher educator Gustav describes student teachers’ reactions when they see concrete results from their work:

‘They [the students] were so happy when they saw their own little message pop up on the screen and realized they had solved a problem.’

Here, the immediate feedback and visible results appear to generate strong positive emotions, which in turn contribute to student teachers’ sense of accomplishment and confidence.

Similarly, teacher educator Leif emphasises the importance of deliberately framing programming as enjoyable and interesting:

‘I try to make it fun for them [the students] to discover that this is quite enjoyable to do, so that they [the students] can spread the word.’

In these descriptions, joy and success are presented as important for changing student teachers’ relationship to programming and encouraging further engagement.

3.4 *A recurring pattern across strategies*

Confidence-building is described as central to enabling student teachers' engagement with programming across the three strategies. However, the teacher educators' descriptions reveal that time constraints often influence this work. In several interviews, teacher educators reflect on what can realistically be achieved within the available framework. Gustav describes how certain technically demanding elements are prepared in advance, as there is limited time for student teachers to work through these aspects themselves:

‘What they [the students] can't do is connect sensors or motors... we solved that by having everything pre-wired and connected.’

Clara reflects on time constraints:

‘If the aim is simply to get them to learn a little more, then yes, you could probably achieve that in 1.5 hours. But you don't really have time to give them a lot of knowledge.’

Others explicitly question whether their teaching is sufficient:

‘I'm a little unsure whether it's enough.’ (Beata)

‘They can't learn everything at once, so we just scratch the surface a little bit.’ (Helena)

‘There's a lot to squeeze in.’ (Julia)

Across these accounts, a recurring pattern becomes visible: strategies that support participation and reduce fear are foregrounded, while the development of deeper subject knowledge and preparation for independent teaching is described as constrained by time. Teacher educators express a desire to both build confidence and prepare for independent teaching but describe limited time as making it difficult to fully address both.

3.5 *Summary of results*

Taken together, the findings show that teacher educators describe confidence-building as a central part of introducing programming. The three identified strategies operate at different levels: lowering thresholds addresses task design, normalising uncertainty concerns how knowledge and difficulty are framed, and creating joy foregrounds emotional experience. While these strategies consistently support engagement, references to deeper professional preparation are less prominent and often linked to time limitations. The tension between enabling participation and preparing for professional responsibility thus emerges as a recurring pattern across the educators' descriptions.

4 DISCUSSION

This study examined how teacher educators navigate the tension between building student teachers' confidence in programming and preparing them for their future professional responsibility of teaching it within technology education. The findings suggest that confidence-building is a central element in how programming is currently approached in technology teacher education.

The results indicate that teacher educators describe programming as an area that many student teachers approach with hesitation and limited prior knowledge. In response, they describe selecting tasks and organising activities in ways that make the content appear more manageable. Programming is presented as demanding and unfamiliar, and confidence becomes closely tied to whether student teachers feel able to engage with it at all. This reflects earlier research showing that programming is difficult to integrate and define within the technology curriculum (Hallström & Frejd, 2023; Perez et al., 2025; Sentance & Csizmadia, 2017), and indicates that similar forms of uncertainty appear in teacher education.

The three strategies identified, lowering thresholds, normalising uncertainty and creating positive experiences, illustrate how confidence-building is embedded in everyday didactic decisions. In this sense, they can be understood as didactic responses to student teachers' initial hesitation, where teacher educators actively shape the conditions for participation through their instructional choices. Rather than being an additional concern, attention to emotional and motivational aspects appears to structure how programming is introduced. Attention to student teachers' emotional and motivational responses shapes task design, framing of difficulty and the overall organisation of teaching. These strategies are in line with research that emphasises the significance of emotional and motivational factors in programming education (Çoban et al., 2020).

At the same time, the findings indicate that confidence-building alone is not presented as sufficient for professional preparation. When systems are pre-configured, when learning goals are framed in terms of generating interest, and when time constraints limit the scope of engagement, certain aspects of technological knowledge, such as system integration and troubleshooting, are described as receiving less attention. Several teacher educators explicitly question whether this is "enough." Confidence-building thus appears as an important entry point into programming, but not as a complete preparation for teaching it independently.

The tension identified in this study lies in the fact that strategies which successfully support initial engagement do not automatically ensure readiness for independent teaching. This tension can be understood in relation to teacher education as a second-order didactic context, where student teachers are expected both to learn subject content and to develop the ability to teach that content. From this perspective, the strategies identified in this study can be understood as forms of implicit modelling (Iskov, 2020), where teacher educators support participation through their own teaching practices. At the same time, fewer examples were described of how these practices are made explicit as objects of reflection in relation to future teaching, leaving questions about longer-term professional competence more open.

Although this tension is particularly visible in programming, where many student teachers lack prior experience, it may reflect a broader didactic challenge. In subjects such as mathematics and science, teacher educators have similarly been described as simplifying content or adjust expectations to support engagement. Research in these fields has raised related concerns about how such adjustments may influence opportunities for deeper subject and didactic development (e.g., Ball et al., 2008; Hodgen & Askew, 2007).

This study demonstrates both the necessity and the limits of confidence-building in teacher education. It enables engagement with programming yet does not in itself prepare student teachers for independent teaching. At the same time, teacher educators work within strict time constraints that shape what can be prioritised. Under such conditions, focusing on confidence-building becomes a practical necessity rather than a lowering of ambition. However, when much of the available time is devoted to enabling participation, less space may remain for sustained engagement with subject depth and didactic complexity, as described by the teacher educators. The challenge, therefore, is not whether confidence should be built, but how teacher education structures can provide sufficient time and coherence for confidence to develop into professional competence.

In this way, the findings point to a broader challenge for teacher educator practice, namely, how to balance the immediate need to enable participation with the longer-term aim of developing subject-specific and didactic competence.

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Exploring the Affective Domain in Technology Education: A Constructivist Grounded Theory Approach

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Abstract

This research explores the affective domain within Irish Technology education, focusing on how the presentation of emotions, values, and motivation in our written curriculum influences teachers' professional learning, pedagogical decision-making, and perceptions of technological capability. Considering the lived experiences and reflections of teachers, with participants (n=36) ranging from experienced teachers to student teachers undertaking initial technology teacher education (ITTE), we seek to understand how affective learning processes shape teacher engagement with technological teaching and learning practices. Drawing on three interrelated theoretical perspectives, this study constructs a theoretical framework through which affect and balanced technological capability is analysed; (1) Biesta's (2010, 2017, 2022) conception of subjectification and educational purpose emphasises how teaching should cultivate "human flourishing" rather than focus solely on skills or knowledge; (2) Mitcham's (1994) philosophy of technology as human activity, situates technological activity as a deeply human and value-laden practice; (3) Krathwohl et al. (1964) taxonomy of the affective domain offers a structured framework for exploring emotions, attitudes, and values in learning. Together, these perspectives offer a holistic, reflective and value-informed practice which contributes to teachers' professional identity formation. Grounded in a constructivist and pragmatic paradigm, the research employs Charmaz's Constructivist Grounded Theory (2006, 2014) to explore how teachers interpret, express, and act upon affective experiences in their teaching of technology. Data are gathered through reflective questionnaires and follow-up focus groups. The iterative process of theoretical sampling, coding, and memo writing enables the development of an emergent, data-driven model of affective engagement in technology education. Methodological and ethical rigour is maintained through ongoing reflexivity, recognising the influence of researcher identity, positionality, and bias on interpretation. The study aims to generate a grounded theoretical understanding of how affective factors inform teachers' practice and professional growth, offering insights for teacher education, curriculum design, and affective pedagogy in technological learning contexts.

Key Words: Affective, holistic, constructivist grounded theory, technology education, teacher education.

1 INTRODUCTION

This study is situated within a constructivist philosophical perspective that understands knowledge as constructed through experience, interpretation, and interaction within educational practice. It represents a deliberate conceptual and methodological journey, beginning with engagement with philosophical literature on education, affect, and values, alongside a critical analysis of the Junior Cycle technology curriculum, particularly the aims and Statements of Learning (SOLs). These foundations inform the articulation of the research paradigm and the selection of a constructivist grounded theory methodology, in which theory is treated as emergent rather than imposed. A conceptual framework, defined as an argument for the significance of the research topic and the appropriateness of the chosen approach (Ravitch & Riggan, 2017), functions here as a mapping device that integrates researcher experience, theory, and curriculum (Crawford, 2020). Consistent with constructivist grounded theory, this framework was progressively developed through the research process rather than fixed in advance. Theory is treated as a generative and organising force that makes epistemological positioning explicit and provides coherence across the study (Collins & Stockton, 2018), recognising that qualitative inquiry cannot be theory-free (Lincoln & Guba, 1994).

A constructivist grounded theory approach underpins the development of an initial questionnaire designed to explore technology teachers', at different stages of their careers, perceptions and enactment of the affective domain. The findings are subsequently coded and analysed within the proposed theoretical framework, forming the basis for a future modified Delphi study with experts in the field.

The objectives of the broader research are to explore:

- (i) How affective dimensions of learning are articulated within the Junior Cycle technology curriculum, particularly through the aims and Statements of Learning, and how these are interpreted by teachers in theory and in practice;
- (ii) Teachers' understandings of affect and its role in shaping student engagement, motivation, and meaning-making in Junior Cycle technology education;
- (iii) The ways in which teachers' and students training to be teachers; professional experiences, values, and positionality influence their enactment of affective learning within technology classrooms;
- (iv) Areas of convergence and divergence between curriculum intentions, teacher practice, and expert perspectives on affective learning in technology education;
- (v) Explore the possibilities of an intervention which could be created to support teachers (at all stages in their careers) to embed the affective domain in technology lessons in a meaningful, value-informed way.

1.1 *Researcher Experience: Identity and positionality*

The motivation for this research arises from the researcher's sustained engagement with technology across personal, professional, and educational contexts as a learner, designer, teacher,

and teacher educator. Experiences of technology as a practical, hands-on activity embedded in everyday making and repair revealed it as a human and value-laden endeavour shaped by intention, emotion, and meaning rather than technical function alone. Work with trainee teachers reinforced the role of affect in shaping professional identity and pedagogical judgement, while classroom observations consistently showed that students who struggle in more traditional subjects often thrive in technology classrooms. Although widely noted anecdotally, this phenomenon remains under-theorised, pointing to an under-explored affective dimension of technological learning and providing a rationale for empirical investigation.

2 LITERATURE REVIEW

2.1 *Emotions, experiences and motivation in teaching and learning*

The experiences of both educators and students are central to creating emotionally rich, values-driven learning environments. Teaching is understood as a relational and collaborative process rather than a one-way transfer of knowledge, involving mutual learning between teacher and student (Freire, 1998). Emotional engagement plays a critical role in this progression, supporting confidence, motivation, and learner autonomy (Immordino-Yang & Damasio, 2007). This study examines how experienced and ITTE technology teachers understand and enact values-based learning, and how recognition of the relationship between emotion and motivation informs pedagogical decision-making in technology education (Beard, 2018; Mishra & Koehler, 2006; de Vries, 2016, 2020; Jones et al., 2013).

2.2 *‘Affect’, ‘Technology’ and ‘Education’*

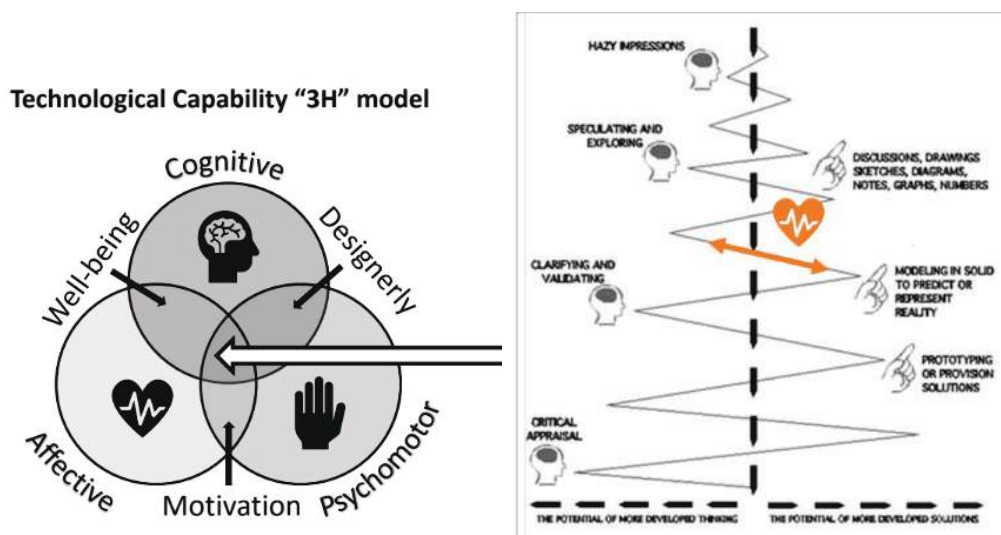
The language used to describe learning, teaching, and technology shapes how technological educational intent is understood and enacted. Affect, technology, and education are conceptually intertwined, as reflected in their linguistic and philosophical origins. Technology derives from the Greek *technē* (art, craft, skill) and *logos* (word, reason, study), reflecting an early understanding of technology as purposeful human skill and ethical practice rather than mere tools (Mitcham, 1994). This contrasts with later industrial conceptions of technology as applied scientific knowledge associated with efficiency and control (Heidegger, 1977). Mitcham’s framework positions technology as objects, knowledge, activity, and volition, emphasising its grounding in human intention, a view reinforced by McLain et al. (2019), who argue that technology is constitutive of human identity and meaning-making. In educational contexts, technology can therefore be understood as a non-neutral, mediating force shaping learning, agency, and subjectivity (Selwyn, 2016). Similarly, across linguistic and philosophical traditions, ‘education’ is understood as a process of formation and becoming rather than solely knowledge transmission or examination performance. Concepts such as *oideachas*, *bildung*, *paideia*, and *tarbiyah* embed affective and moral development within their core meanings, foregrounding values, identity, and ethical orientation as central to learning. These traditions align with Biesta’s (2017) emphasis on subjectification and support the position that affective engagement is not ancillary to education, but a constitutive element of meaningful educational experience.

Philosophical inquiry into reflection and human experience has long shaped educational thought, from Socrates' assertion that "the unexamined life is not worth living" (Plato, 2002) to contemporary explorations of meaning-making in learning. The term *affect*, derived from the Latin *affectus* meaning "to influence or move", has evolved to describe the emotional and motivational dimensions of human engagement (Oxford University Press, 2025), and is widely understood in educational contexts as shaping how learners engage, value, and internalise experience (Harper, 2024; Krathwohl, Bloom, & Masia, 1964; Tomkins, 1984). Krathwohl et al.'s (1964) taxonomy conceptualises affective learning as a progression from awareness and response to valuing and the internalisation of values that guide action, a process that resonates with Freire's (1970) notion of praxis, where reflection and action are inseparable. Critical reflection further enables learners to become conscious of their own formation (Mezirow, 1990; Brookfield, 1995), while McNiff and Whitehead (2010) frame education as "experimenting with life and creating something new". Within this study, students, ITTE teachers, and experienced teachers, are all engaged in ongoing adaptation and reflection within a constructivist paradigm that recognises learning as shaped by prior experience and context (Carlile & Jordan, 2005). This orientation aligns with Dewey's (1938) view of education as growth, Chomsky's (2000) call for education beyond employability, and Aristotle's concept of *phronesis* as practical wisdom. Biesta (2017) extends this perspective by positioning education as *subjectification*, concerned with learning how to exist in, with, and for the world. In technology education, this view is reinforced by Kimbell and Stables' (2007) conception of capability as grounded in human motivation to change and improve, and by Mitcham's (1994) framing of technology as involving not only objects, knowledge, and activity, but also volition; highlighting that emotional and motivational dimensions are integral to technological practice. From this perspective, capability is understood as reflective, value-laden engagement with the world, underscoring the affective domain's role in cultivating motivated, reflective, and ethically aware individuals rather than merely supporting instrumental outcomes. This body of research proposes that the affective domain holds equal importance alongside the cognitive and psychomotor domains. Accordingly, a balanced conception of technological capability is proposed, in which all three domains are afforded equal emphasis (Figure 1), (Plunkett & Dunbar, 2023, 2024, 2025; Plunkett, Dunbar, & McLain, 2025).

Figure 1.

3 H Model Head (Cognitive), Hand (Psychomotor) and Heart (Affect)

Balanced technological capability at the intersection of all three domains, and the inclusion of ‘Heart’ on the APU model (Kimbell & Stables, 2007) to highlight ‘affect’ explicitly.



2.3 Theoretical Framework

The theoretical framework is organised around a cluster of affective constructs emerging from experience, literature, and curriculum analysis. This cluster integrates Krathwohl et al.'s (1964) taxonomy of the affective domain, Mitcham's (1994) philosophy of technology, and Biesta's (2010, 2017, 2022) theory of subjectification to provide a holistic framework for examining affective pedagogy in technology education. Together, these perspectives frame education as a value-laden process of becoming, where Krathwohl's taxonomy explains the development of values and motivation, Biesta emphasises the formation of autonomous and responsible learners, and Mitcham positions technology as a human practice grounded in ethical judgement and purposeful action.

Constructivist grounded theory (Charmaz, 2006, 2014) provides a rigorous yet flexible framework for interpretive theory construction that remains responsive to emerging data. Charmaz identifies four criteria for *quality* in constructivist grounded theory: (1) *Credibility* is established through iterative data collection and analysis, constant comparison across data sources, and sustained engagement with participants' accounts of practice (Charmaz, 2006; Glaser & Strauss, 1967). Existing theories are treated as sensitising concepts rather than explanatory frameworks, supporting (2) *originality* while preserving analytic openness (Blumer, 1954; Charmaz, 2006, 2014). This approach is particularly appropriate for examining affective learning and subjectification as relational, context-dependent phenomena grounded in lived professional experience (Biesta, 2010, 2015). Through co-construction and reflexivity, the analysis aims to achieve (3) *resonance* with teachers' understandings of practice and (4) *usefulness* beyond the immediate study context (Charmaz, 2014). Consistent with a constructivist

epistemology, the researcher's professional experience in technology education is recognised as a source of theoretical sensitivity, with analytic decisions critically examined through ongoing engagement with relevant theory and curriculum specifications

1.1 The Junior Cycle Curriculum

Junior Cycle (JC) represents a critical stage of education in shaping learners' subject choices and future pathways. While STEM education was formally introduced at primary level in Ireland in 2025, technology and engineering are primarily encountered as distinct subjects at JC level. The Framework for Junior Cycle (DES, 2013), alongside the Key Skills framework (NCCA, 2012, 2015) and the Junior Cycle Wellbeing Programme (NCCA, 2017), emphasises values, agency, and meaningful engagement, all of which are central to understanding affect in technology education. The four JC technology subjects, Applied Technology, Engineering, Graphics, and Wood Technology, are well positioned to support these aims through the integration of cognitive, psychomotor (practical), and affective learning, fostering social and emotional development (Erikson, 1968) and technological capability (Buckley et al., 2018). The alignment between the Statements of Learning (SOL), and the proposed theoretical framework is outlined in Table 1.

Table 1

Alignment of Theoretical Framework with Junior Cycle Technology SOL's

Statement of Learning (SOL)	Krathwohl et al. (1964) – Affective Domain	Biesta – Subjectification & Educational Purpose	Mitcham (1994) – Philosophy of Technology
SOL 15: Recognises the potential uses of mathematical knowledge across learning.	<i>Valuing & responding:</i> Developing curiosity, confidence, and positive attitudes towards mathematical reasoning.	<i>Subjectification:</i> Encourages independent thinking and judgement in applying mathematical understanding.	<i>Technology as knowledge:</i> Highlights the role of mathematical knowledge within technological practice and decision-making.
SOL 19: Values the role of science and technology in society.	<i>Characterisation:</i> Internalising values related to ethics, sustainability, and responsible technological action.	<i>Purposeful education:</i> Supports forming responsible citizens aware of societal and global technological impacts.	<i>Technology as volition & activity:</i> Emphasises cultural, ethical and societal significance of technological activity.

SOL 20: Uses appropriate technologies in meeting a design challenge.	<i>Motivation & willingness to engage:</i> Encourages confident use of tools through positive attitudes and persistence.	<i>Agency:</i> Supports autonomous decision-making in selecting and applying technologies.	<i>Technology as activity:</i> Aligns with practical engagement and purposeful technological action.
SOL 21: Applies practical skills in developing models and products.	<i>Responding & valuing:</i> Cultivates pride, satisfaction, and engagement in hands-on making.	<i>Qualification:</i> Supports development of technical capability while fostering judgement and responsibility.	<i>Technology as making:</i> Reflects the centrality of human action, craft, and material engagement.
SOL 23: Brings an idea from conception to realisation.	<i>Commitment & perseverance:</i> Emphasises motivation, initiative, and sustained engagement.	<i>Subjectification:</i> Encourages creativity, autonomy and the capacity to act independently as a designer.	<i>Technology as design:</i> Connects with the intentional, purposive nature of technological creation.
SOL 24: Uses technology and digital media collaboratively and ethically.	<i>Internalisation of values:</i> Emphasises ethical behaviour, empathy, attitudes toward responsible digital practice.	<i>Being-with-others:</i> Supports social learning, collaboration and democratic participation.	<i>Technology as ethical activity:</i> Addresses responsible use, societal implications, and informed digital citizenship.

3 METHODOLOGY

An initial questionnaire was developed based on the Junior Cycle (JC) technology subject aims and aligned with Krathwohl et al.'s (1964) hierarchy of the affective domain. Using 'Delve' qualitative analysis software, a deductive coding approach was used to code curriculum aims to identify affective domain elements that directly informed questionnaire design and ensured alignment between curriculum intent and the investigation of teachers' and ITTE teachers' understanding. Questions were structured according to each level of the taxonomy: Level 1 (Receiving), Level 2 (Responding), Level 3 (Valuing), Level 4 (Organising), and Level 5 (Characterisation). To further explore potential links between wellbeing and academic success, an additional general question on education (Level 6) was included. Questionnaire findings informed the design of follow up semi-structured focus group interviews with patterns of misunderstanding across affective domain levels guiding question focus (Table 2).

Table 2*Group-Level Patterns of Misunderstanding*

Group	Respondents N=36	Most Misunderstood Levels	Themes in Misunderstanding
Experienced Teachers	1–8	L4 – Organising, L5 – Characterisation	Often framed values/beliefs as <i>design preferences</i> or <i>personal style</i> , rather than moral/ethical reasoning. Tendency to separate emotional/values elements from technical teaching priorities.
ITTE Teachers currently on 1st School Placement	9–14	L3 – Valuing, L4 – Organising	“Values” often taken to mean safety/respect in workshops rather than broader ethical integration. Sometimes conflated <i>valuing</i> with <i>procedural engagement</i> .
Final Year ITTE Teachers Post 2nd School Placement	15–25	L5 – Characterisation, L6 – Wellbeing	Focused on creativity and ownership but weaker link to beliefs/values as decision drivers. For wellbeing, answers often centred on personality differences rather than academic connection.
2nd Year ITTE Teachers - No School Placement experience	26–36	L4 – Organising, L5 – Characterisation, L6 – Wellbeing	Answers tended toward socially acceptable or generic statements. Wellbeing seen as just emotional state, not part of learning process.

3.1 Disclosure Statement

Generative AI was used solely for language refinement, including grammar and clarity. All substantive analysis, coding decisions, interpretations, and conclusions were conducted exclusively by the authors.

4 FINDINGS

Table 3 ‘Focus Group Interview Findings’ presents a summary of the progression from initial process-oriented codes through focused analytic categories to the identification of a core social

process. The analysis suggests that affective learning in Junior Cycle technology education is constructed through teachers' everyday pedagogical decisions rather than enacted as a procedural curricular component. Participants described working within structural, curricular, and policy constraints that shape how affective considerations are addressed in the reality of everyday practice. Affective engagement was commonly understood as implicit and embedded within routine classroom activity, particularly through the use of structure, task personalisation, and mediated engagement with success and failure. The core process, *affective pedagogy under constraint*, captures how teachers negotiate competing demands while supporting motivation, resilience, values, and wellbeing through relational and adaptive practice.

Table 3

Focus Group Interview Findings

CGT Analytic Level	Category / Process	Description (Grounded Interpretation)
Initial Coding (process-focused)	Time pressure	Teachers describe limited time, workload, and curriculum demands as shaping their capacity to attend to students' emotional and motivational needs.
	Curriculum constraint	Participants explain adapting classroom practice in response to assessment requirements and expectations around content coverage.
	Implicit affective practice	Affective learning is described as occurring through everyday teaching practices rather than through explicit planning or formal terminology.
	Learning task personalisation	Teachers create opportunities for student choice and relevance in order to increase engagement and ownership.
	Error as learning opportunity	Mistakes and failure are positioned as integral to learning rather than as deficits.
	Emotional safety through structure	Predictable routines and clear expectations are used to support emotional regulation and student participation.
Focused Coding (analytic categories)	Care–performance balance	Teachers describe negotiating tensions between supporting wellbeing and meeting performance and assessment demands.
	Competing demands	Affective pedagogy is shaped by time pressure, curriculum overload, and administrative responsibilities. Affective learning is addressed indirectly rather than abandoned.

	Tacit affective pedagogy	Teachers support motivation, confidence, and values without using formal affective domain language, relying on experiential and professional knowledge.
	Emotional safety as pedagogical condition	Structure is constructed as enabling emotional security, particularly for students who experience difficulty in less structured academic subjects.
	Personal meaning and engagement	Choice, relevance, and real-world connections function as mechanisms for emotional investment and sustained engagement.
	Emotion within making processes	Practical learning is experienced as emotionally charged, involving frustration, pride, and recovery from failure, mediated by teacher support.
	Wellbeing as environmental condition	Wellbeing is understood as emerging from classroom culture, relationships, and everyday teaching practices rather than discrete programmes.
	Development of affective judgement	Affective pedagogical competence is described as developmental, shaped through experience, reflection, and mentorship over time.
Theoretical Coding	Core social process: Affective pedagogy under constraint	Teachers actively construct affective learning through everyday pedagogical decisions within structural, curricular, and policy constraints. Affective pedagogy is enacted through relational and adaptive practice rather than implemented as a structured curricular component.
Theoretical Outcome	Grounded theoretical explanation	Affective learning in technology education is embedded, negotiated, and context-dependent, relying on professional judgement to balance care, meaning, and performance within constrained conditions.

5 DISCUSSION

The findings suggest that affective learning is not enacted as a predetermined curricular component, but is constructed through teachers' everyday pedagogical judgements within structural and curricular constraints, and is therefore embedded in practice rather than explicitly planned. This raises questions of consistency and equity, as students' affective learning experiences may depend on individual teachers' capacity and willingness to recognise and engage with the affective domain. This interpretation extends Krathwohl et al.'s (1964) taxonomy by suggesting that affective engagement in technology education unfolds dynamically through practice rather than as a linear progression, emerging through design and making activities shaped by classroom relationships and experiences of success and failure. The core process, *affective pedagogy under*

constraint, aligns with Biesta's conception of education as subjectification alongside qualification and socialisation (Biesta, 2010, 2017), positioning affective pedagogy as an ethical and contextual practice grounded in professional judgement. This also resonates with Mitcham's (1994) view of technology as a human, value-laden activity in which affective dispositions such as resilience and responsibility are integral to technological capability.

As stated in the Researcher Experience section, many teachers report that learners who struggle in traditional subjects often thrive in technology classrooms, demonstrating creativity, persistence, and ownership. While commonly noted, these observations remain largely anecdotal, pointing to an under-explored affective dimension of technological learning that warrants systematic study. This has particular implications for teacher education, as teachers' capacity to recognise and respond to affective engagement appears central to students' experiences. Biesta's (2017) emphasis on the relational nature of education highlights the role of teachers in fostering meaningful learning and supporting wellbeing. Developing affective literacy within teacher education and professional learning may therefore enable teachers to embed wellbeing and values more intentionally within curriculum and classroom practice, justifying the methodological orientation of this study.

6 CONCLUSION AND FUTURE WORK

Further inductive coding of the focus group discussions will form the rationale for a Delphi study involving experts in the field of technology education. Through this iterative process of data generation and analysis, the research questions are continually revisited, and a theoretical framework is progressively constructed to ground and explain the emerging findings. The overarching aim is to explore how affect is understood and enacted within Junior Cycle technology education and to use these insights to inform the development of an intervention: 'ALIVE – Affective Learning Inspiring Values in Education', designed to support teaching and learning that is meaningful, value-informed, and responsive to practice.

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Towards Reflective Incorporation of Generative AI in Design Practice and Education

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Abstract

This paper examines the experiences of novice designers as they incorporate generative AI (GAI) technologies into their design processes. We aim to investigate how novice designers engage with GAI technologies, how these tools transform the design thinking process, and how designers' beliefs and practices shift with continued use. Previous research has revealed both benefits and risks of GAI incorporation, including efficiency gains, cognitive offloading, loss of ownership, and diminished critical thinking. However, little is known on how working with GAI is actually experienced by novice designers actively engaged in the learning process.

To explore this, we conducted a study spanning 14 weeks with 11 international User Experience Design students, completing a series of design activities in which different GAI tools (LLMs and text-to-image models) were incorporated. They were encouraged to experiment and reflect on their processes and, upon completion, report on their experience in semi-structured post-interviews. The semi-structured interviews were analysed through reflexive thematic analysis.

Findings reveal that an effective incorporation of GAI tools in creative design practice is not a straightforward process. Rather, it develops gradually. We uncovered novice designers' beliefs, conceptualisations, and intentions of incorporating GAI technologies evolve with their reflective involvement with the tools. Initial perceptions of the technology as inherently powerful shift with a better understanding of the role of the tools within design practice, through experience and engagement. Two intention-driven uses of GAI were identified: using GAI as an efficiency enhancer and as a performance enhancer, intentions that imply different impacts on learning outcomes. These shifts are accompanied by substantial changes in designers' cognitive approaches, as the interaction design of GAI tools imposes constraints on both creativity and problem-solving.

These insights inform future educational strategies that support metacognitive awareness, foster intentional use, and support cognitive resilience.

1 INTRODUCTION

Generative Artificial Intelligence (GAI) was rapidly adopted across a wide range of industries as its potential becomes increasingly evident (Epstein et al., 2023; Sai et al., 2025). Particularly in creative domains such as design, GAI tools found their way into multiple stages of the creative design process (Asadi, 2023; Lai et al., 2023; Takaffoli et al., 2024). From outsourcing fundamental design activities such as idea generation and creative exploration to cognitive internalisation and extension, designers uncovered different ways of GAI incorporation, with these tools progressively shaping their cognitive processes and decision-making during design practice (Hernández-Orallo & Vold, 2019; Palani & Ramos, 2024; Saadi & Yang, 2023; Schut & Detweiler, 2025).

As the incorporation of GAI tools becomes the standard in design practice and education (Jin et al., 2025), we aim to explore the experiences of novice designers when interacting with the technology, the implications of incorporation within the design thinking process, and the implicit transformation that designers undergo in these relatively novel circumstances. By understanding these experiences, we can adapt the fundamental educational approach of design practice to accommodate GAI in a manner that preserves and enriches the cognitive development required for creative design practice.

2 LITERATURE REVIEW

With the rapid embedding of GAI technologies within design practice, researchers and educators continuously weighed potential benefits against known limitations to discern the role and extent of GAI tool integration within the creative design process (Melker et al., 2025; Wang et al., 2025; Weinberg & Chan, 2025). While certain studies identified benefits of GAI incorporation in educational settings, including efficiency gains, cognitive offloading and creativity boosts (Asadi, 2023; Chen et al., 2020; Wei et al., 2025), a growing body of research also highlighted important limitations and risks. These include reduced critical thinking skills (Gerlich, 2025), blurred lines of ownership and agency (Schut & Detweiler, 2025; Xu et al., 2024), enhancement of existing and emerging cognitive biases (Popescu & Schut, 2023), as well as increased cognitive outsourcing. A growing body of research emphasises GAI literacy as a response to the overbearing presence of GAI in design, as a step towards mindful incorporation (Long & Magerko, 2020; Pinski & Benlian, 2024). As such, *in addition* to the design thinking competencies traditionally expected of novice designers, GAI integration introduces new expectations for designers. These include basic AI literacy, knowledge of GAI models as well as their capabilities and limitations, specialised skills to use GAI, abilities to assess GAI outputs, as well as prompting skills (Annapureddy et al., 2025).

However, the challenge of GAI integration extends beyond gaining knowledge on GAI and learning how to effectively incorporate these tools. It also involves acknowledging the shift in

cognition that the incorporation of such tools implies and adjusting educational approaches accordingly. Through the lens of metacognition, Tankelevitch et al. (2024) identified specific metacognitive demands GAI technologies impose on their users in the context of prompting, evaluating and deciding to rely on GAI outputs, and deciding on appropriate automation strategies. These demands are particularly significant for novice designers who do not yet possess the capabilities to confidently wield design thinking; therefore, they experience a different version of creative design thinking, learning and reasoning that is shaped by GAI incorporation.

3 METHODOLOGY

3.1 Study Context

The study was conducted over a 14-week period, incorporating a preliminary survey, a series of assignments, and concluding with semi-structured post-interviews. The participants engaged in a total of 6 assignments, each involving experimentation with GAI tools in various design tasks and contexts. The assignments were designed to encourage participants to openly explore the possibilities and limitations of GAI tools in the context of the creative design process. An overview of the design activities can be found in table 1. The GAI tools used for this study were among the most readily available tools at the time, namely ChatGPT 3.5, Midjourney V4, and Stable Diffusion 1.5.

Table 1

Overview of the design activities performed during the study

Stage	Nr. Assignments	Focus of stage	Design Challenge(s)
1 st	1	Ideation with intentional incorporation of GAI tools alongside prior design skills	Redesign a student learning space within the university.
2 nd	4	Exploration of GAI limitations and designers' ability to navigate them	(a) Conceptualise an inclusive feedback system for people who are deaf in a design class. (b) Conceptualise a service that can help you die in a (futuristic) society where you can't die naturally. (c) Design a device that can help single parents remotely parent/overwatch their kids while they are at work.

			(d) Conceptualise a post climate collapse device/tool to help explore and search spaces that are (now) uninhabitable.
3 rd	1	Full design thinking process addressing a real-world, externally proposed challenge	Motivate and persuade beach visitors in the Netherlands to abolish littering.

3.2 *Participants*

The study was conducted in an international User Experience Design program at The Hague University of Applied Sciences in the Netherlands, as part of a second-year course in which our research group acted as a client. The participants' involvement was a choice based on their personal interest in consciously using GAI tools in the creative design process.

Our sample consisted of 11 international students from predominantly European countries. Their experience with GAI technologies varied. All participants were previously trained in the Stanford d.school design thinking process, as well as in creative techniques for divergent and convergent thinking. Their fundamental design training took place prior to the widespread availability of GAI technologies (Nov 2022).

3.3 *Data Collection and Preparation*

Although the study involved multiple data collection points, we only cover outcomes resulted from the analysis of the semi-structured post-interviews, as they provided deep insight into participants' reflective reasoning, along with their perceptions and experiences concerning GAI incorporation in their design thinking process.

The post-interviews ranged in duration from 50 to 60 minutes. They comprised the following topics: (a) the perceived value of GAI tools within the design thinking process, (b) the experience of interacting with GAI tools, and (c) the perceived impact of GAI tools on creativity within the design thinking process. We opted for semi-structured interviews as a research technique to facilitate in-depth exploration of the personal experiences of the participants, allowing researchers to ask follow-up questions based on the received responses.

All interviews were audio-recorded and transcribed verbatim to capture participants' responses. The transcripts were reviewed against recordings to ensure accuracy in transcriptions. The interviews were subsequently analysed in accordance with the 6-phase approach to reflexive thematic analysis proposed by Braun & Clarke, as detailed in the following section.

3.4 *Reflexive Thematic Analysis*

Reflexive thematic analysis was deemed appropriate as it aligns with the study's aim of exploring and understanding the experiences of novice designers when incorporating GAI within their design thinking process. As we recognise the implications and influence of our theoretical background and analytic preconceptions, we opted for an inductive, primarily latent approach to ensure our claims stay close to the data set. The thematic analysis followed the 6-phase method proposed by Braun & Clarke (2006, 2019, 2021). The interview transcripts were repeatedly reviewed to familiarise the researchers with the data and inform the initial set of codes. Data was manually coded in Atlas.ti, refined iteratively, and organised into potential groups to identify potential coding patterns. The initial codes were then merged and sorted iteratively, using Miro and paper, until a satisfactory thematic map, capable of capturing the contents of the data, was developed. In each iteration, the researchers reviewed the potential themes against the coded extracts in Excel, merged related themes, created sub-themes, discarded inconsequential ones and reviewed the relationships between them. Defining and naming themes intersected generating the report, as "Writing is an integral part of analysis, not something that takes place at the end" (Braun & Clarke, 2006). For writing the report, GAI tools such as ChatGPT and Grammarly were utilised as paraphrasing tools and grammar checkers.

4 RESULTS

4.1 *Theme 1 - GAI: Leader or Underling?*

Our analysis indicates that with time, experience, and exposure to GAI tools, participants gradually change their stance towards GAI. Participants themselves described their beliefs about GAI technologies as gradually evolving through exposure and experience, elaborating on how these shifting perspectives influenced their intention of incorporating GAI, their relationship with and use of GAI tools within the creative design process.

We identified 2 common ways in which novice designers conceptualise GAI: (1) GAI as powerful and (2) GAI as limited. As participants gained more experience in interacting with GAI, their beliefs gradually shifted from the former to the latter. One participant's account illustrates this shift in perception of GAI tools, from initially seeing GAI as "a really smart tool" (P2) and "that nerd student next to you" (P2) at the start of the study to "the partner you have to check, like a junior" (P2).

These evolving perspectives influenced not only their conceptualisations of the tools but also the way they engaged with them. Participants reassessed their role within the design process, shifting from allowing themselves to be guided by GAI tools initially perceived as "the leader" to taking charge of the design process and reframing GAI as "the junior" that requires critical oversight.

Ultimately, most participants began to recognise both the benefits and limitations of GAI incorporation through experimentation, leading to a dynamic approach of GAI incorporation depending on design activity. Continuous experience reshaped participants' beliefs on GAI,

revealing tensions between their initial intentions and actual use, an aspect explored in the following theme.

4.2 Theme 2 – Faster or Better? Faster AND Better!

We observed that the intentions that guided GAI usage varied in line with the participants' level of experience with the technology and their evolving beliefs, as formerly described in theme 1, the specific type of GAI tool used (text-based or image-based), and the circumstance of the activity performed. We identified two overarching intentions behind GAI incorporation: (1) using GAI as an efficiency enhancer, and (2) using GAI as a performance enhancer.

4.2.1 Intention of using GAI as an efficiency enhancer

Most participants suggested that their primary intention behind incorporating GAI in their design process stems from their expectations that GAI tools will enhance efficiency. Within their discourse, participants described GAI technologies as capable of “simplifying tasks that are just time-consuming,” (P1), which in turn allows for “more time to actually do problem-solving” (P1) or other activities they deemed relevant.

As participants aimed for a more efficient process, their modality of interaction prioritised minimising effort and maximising time and cost effectiveness, which resulted in using GAI tools to generate results that were either final or required minimal level of refinement such as ideas, concepts, insights or factual data, conceptualising GAI as a provider of near-complete solutions.

Reflecting on their modality of interaction, participants evidenced that when their use of GAI tools was result-oriented, they experienced **design fixation**, encountered setbacks due to the need to introduce additional evaluation steps in their design process, and had their attention redirected towards prompt engineering and “correct” incorporation of GAI within their design process rather than focusing on the task at hand.

Although most participants recognised these drawbacks retrospectively, the majority adamantly pursued this modality of interaction throughout their process. Their decision was often justified pragmatically, through the lens of efficiency. One argument concerned the perceived impact of the project at hand, with one participant noting that “it sounds a bit lazy, but for students, (...) why not use it? It saves you some time” (P4). Another argument emphasised low engagement with certain activities, with P3 suggesting that “it saves time with some tedious things”. Additionally, proper resource allocation was considered, with P6 describing how the tools “can be your friend and save you a lot of time, allowing you to focus on more important things”.

4.2.2 Intention of using GAI as a performance enhancer

As participants gained experience and became more aware of the limitations as well as the possibilities of the tools, some began to discern the tasks in which GAI can act as an enhancer rather than a provider of immediate solutions. Through experimentation, their approach shifted from focusing on automation to using GAI for performance enhancement. Participants uncovered

when GAI tools could outperform designers, for example, in accessing and processing vast amounts of information: “I think this is powerful for ideation. Because it has more depth, like it has every data. Compared to my brain, my experience is limited – but here it’s unlimited” (P10). By leveraging these tools accordingly, they elevated aspects of their design process, such as their exploration and ideation: “for the ideation phase, it can be an extension of your creative skills” (P6).

Although not explicitly stated, most participants who used GAI as a performance enhancer implied that for GAI tools to act as augmenters, deliberate incorporation and active reflexivity of the tools' incorporation, as well as acknowledgement of the implications of the tools, should be consciously considered. For example, when describing their experience with GAI incorporation, participants reflected on their process and disclosed their strategies for a GAI incorporation that would augment their process while avoiding fixation and loss of control over the creative process to GAI tools. These strategies were often presented in contrast to the perceived limitations and uncovered pitfalls of GAI incorporation within the design process.

4.3 *Theme 3 – Shifting sands of GAI*

4.3.1 *GAI’s interaction shapes the creative design process*

When reflecting on the processes where GAI was used, several participants reported that the interaction structure constrained both their creative process and cognitive processes. For instance, P1 concluded that inputting information into ChatGPT and subsequently receiving a response changes the divergent nature of exploration, as it focuses on topic specifics rather than allowing lateral thinking. Additionally, P1 highlighted that the flow of the process in which GAI is used is similarly constrained by the tool, as it becomes “more sequential” (P1).

Moreover, participants recognised a shift in their cognitive approach, from focusing on the creative process itself and the steps necessary for achieving the desired result to focusing on creating relevant prompts to wield the tool to their advantage, revealing the importance of the dynamic between designer and the context of creation in which GAI is now integrated:

“And then you're not thinking about solutions and out of the box ideas and how to come up with some amazing designs. You're just thinking, ‘how can I make this prompt work for this tool’, which is again, when you reflect on it’s strange.” (P1)

4.3.2 *AI-generated outputs shape the interaction between GAI and designer*

A perceived factor for over-trust and over-incorporation of GAI tools seemed to be a lack of confidence in the designers’ capabilities paired with an overly positive conceptualisation of GAI tools, which was attributed to the perceived confident tone of the GAI outputs: “I think it takes the lead when you're not really confident in what you're (...) because it speaks with this confidence and type of like ego like, ‘Yeah, I'm definitely right’.” (P1)

As GAI was deemed increasingly persuasive, participants noted that they had diminished control and decision-making power over the AI-generated content they adopted and the processes in which GAI was used: “it restricts your creativity based on the results it gives you. You read once and then you start thinking in that direction. (P6)

With time, participants became wary of their positioning towards GAI (particularly ChatGPT):” keep your balance of using this and being aware that you're the person behind this. You're the director behind the scenes; it's not telling you what to do.” (P3)

5 DISCUSSION

Within this study, we explored novice designers’ interactions with GAI tools, the implications of GAI incorporation within the design thinking process, and the implicit transformation that designers undergo in these relatively novel circumstances. Firstly, we uncovered that novice designers’ beliefs and conceptualisations of GAI technologies evolved with their active involvement with the tools, supported by reflective thinking. We distinguished two different intention-driven patterns of use, for (1) the purpose of efficiency and (2) for performance enhancement. We identified ways in which the interaction design of GAI tools influenced the cognitive processes of the participants and ultimately, highlighted shifts in designers’ practice when incorporating these tools. Taken together, these findings revealed that the processes of learning to incorporate GAI into creative practice and adapting to a creative process in which GAI is pervasive are not linear; rather, they unfold along a spectrum influenced by a combination of internal and external factors. We found that when GAI tools are incorporated within the creative process, they assume a central position. Instead of merely taking the role of scaffolding or support, GAI tools reconfigure the creative process, positioning their constraints and capabilities as focal points around which the process is structured (Blom, 2019). This dynamic has direct implications for novice designers who choose to incorporate these technologies, requiring a heightened level of intentionality within their approach, critical awareness, and the development of more advanced design competencies (Tankelevitch et al., 2024).

From an educational perspective we suggest that educators should opt for an early integration of GAI tools that explicitly instils reflective thinking. Early exposure alone is insufficient. Educators must support novice designers’ understanding of these technologies through contextualised GAI literacy and curate experiences of GAI incorporation early on. As the results indicate that novice designers tend to conceptualise and use GAI as an outsourcing mechanism when tasks seem unstimulating, educators should provide structured opportunities for novice designers to explore GAI as a performance enhancement tool rather than a substitute for design cognition. By shaping the conditions of GAI incorporation, educators can influence students’ intentions of incorporation and conceptualisations of what performance enhancement looks like in design practice.

As GAI technology will continue to advance beyond educators’ control, design education cannot rely on cognitively (over)loading novice designers through expecting GAI literacy and optimisation of “correct” GAI incorporation, in addition to design cognition. Instead, pedagogical efforts should prioritise the development of cognitive and interaction strategies around these technologies that help novice designers mitigate the disruptions GAI introduces to the design

thinking process and keep design thinking central, rather than optimising “correct” GAI incorporation.

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Reflection as a Mirror of Learning: Examining Course and Program Goal Alignment in Interdisciplinary STEM Education

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Abstract

This study examines the extent to which the goals of both an individual course and the overall M.Ed. program 'Integrative STEM Education' are achieved, as reflected in students' reflections. The program aims to deepen understanding of interdisciplinary STEM, develop PCK and TPACK related to integrative pedagogies, and prepare students to lead interdisciplinary STEM education in various frameworks. It is grounded in constructivist and constructionist pedagogy and emphasizes engineering design, sustainability, and ethics in STEM education. Project-Based Learning (PBL) serves as a central methodological pillar, implemented through courses in which students design solutions to real-world, ill-defined problems, fostering innovation, problem-solving, and STEM literacy. Courses are intentionally interconnected and scaffold learning through an interdisciplinary lens. Extensive reflection, in multiple formats, is embedded throughout the program as a formative process supporting both learning and assessment. This aligns with perspectives such as Dewey's 'reflection as inquiry', Schön's 'reflection-in-action/on-action', and Mezirow's 'transformative reflection'. Reflection fosters metacognition, conceptual understanding, interdisciplinary integration, professional growth, and evidence of emerging skills—serving not only as a learning mechanism but also as an indicator of achievement. The aim of this study is to analyze how students' reflections correspond to the intended learning outcomes of several courses and how they reveal alignment with the broader aims of the program. Qualitative thematic analysis was conducted on students' reflections to explore: (1) What themes emerge from students' final reflective tasks? (2) To what extent do these reflections indicate achievement of course-level learning outcomes? (3) How do the reflections demonstrate alignment between individual course goals and the overarching program objectives? The findings reveal strong alignment parallel to exposing authentic challenges, informing the program's iterative refinement within a design-based research framework. A key methodological contribution of this study lies in using reflective tools to evaluate integrated goals at both the course and program levels.

Key Words: STEM Education, Reflection, PBL, Skills, Students' Perspectives

1 INTRODUCTION

The M.Ed. 'Integrative STEM Education' program is designed to prepare educators to lead pedagogical and organizational changes toward interdisciplinary STEM education in formal and nonformal learning environments. A distinctive feature of the program is the central role of the *Engineering Design Process* as a fundamental approach for integrating interdisciplinary STEM knowledge to address real-world problems. Students engage in problem-solving processes similar to those used in industry and academia, working in multidisciplinary teams in which each member contributes domain expertise to collaboratively design creative and implementable solutions.

This paper focuses on the reflective processes inherent to the program as a reflection of the students learning in this program. Reflection has long been recognized as a central component of professional learning in teacher education, supporting the development of conceptual understanding, pedagogical judgment, and intentional practices. Foundational scholars, including Dewey (1933), Schön (1983; 2017), and Mezirow (1990), emphasized that reflective processes enable educators to critically examine their assumptions, connect theory and practice, and develop adaptive expertise. More recently, research in STEM teacher education has emphasized reflection as a powerful mechanism for fostering metacognition, disciplinary integration, and meaningful engagement with complex, ill-defined problems (Kang & van Es, 2019; Zohar & Barzilai, 2015).

Corresponding with these perspectives, the *M.Ed. program in Integrative STEM Education* highlights structured reflective processes designed to support conceptual and practical teacher growth. Throughout the program, students engage with multiple reflection tools, including concept maps, position papers, structured journals, and project-based reflection assignments, which guide them in articulating their understanding, evaluating their pedagogical decisions, and making explicit connections across disciplinary and methodological domains.

This study examines how students' summative reflections demonstrate the achievement of key learning outcomes in several courses and the extent to which these reflections collectively indicate the attainment of the overarching aims of the program. This study positions reflection as a window into learners' conceptual trajectories, interdisciplinary reasoning, and evolving pedagogical positions. Through qualitative thematic analysis of students' reflective writing, we identified patterns that revealed how in-service teachers internalized core ideas emphasized throughout the program, such as interdisciplinary integration, PBL-oriented thinking, engineering design principles, and various 21st century skills.

By linking students' reflections to course-level outcomes and program-wide goals, this study contributes to broader discussions regarding the role of reflection as an indicator of learning achievement in STEM teacher education programs.

2 BACKGROUND

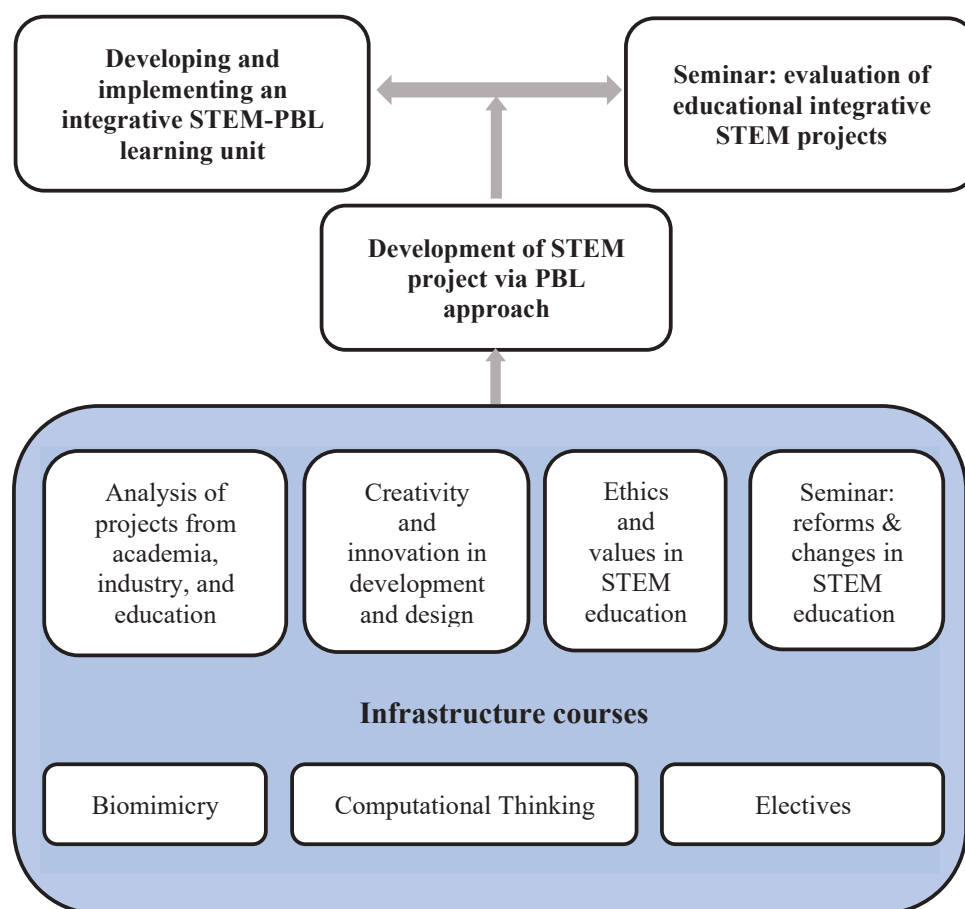
2.1 *M.ED. in integrative STEM education rationale and structure*

The M.Ed. 'Integrative STEM Education' program is designed to prepare educators to lead pedagogical and organizational changes toward interdisciplinary STEM education in formal and nonformal learning environments. Grounded in research, educational policy, and expert consultation, the program cultivates a deep understanding of STEM fields whilst developing the pedagogical content knowledge (PCK) and technological PCK (TPACK) necessary for effective STEM instruction. Its overarching goal is to cultivate educators with an interdisciplinary mindset—professionals capable of recognizing both the unique and shared elements of STEM disciplines and guiding learners in transferring knowledge, skills, and problem-solving approaches across domains (Dagan et al., 2019; Ragonis et al., 2025). The program's pedagogical foundations draw on constructivism, constructionism, collaborative learning, the engineering design process, and inquiry-based approaches. Project-Based Learning (PBL) is a central methodological pillar. Students work in teams on authentic, ill-defined and open-ended problems, engaging in sustained inquiry that emphasizes the learning process parallel to the final product. This approach develops critical thinking, creativity, collaboration, and responsibility for one's learning (Dagan 2022; 2023; Dagan et al., 2023; Ragonis et al., 2023). Reflection—implemented continuously throughout the program—supports metacognition and deepens students' understanding of teaching practices and STEM research. The M.Ed. program aims to broaden teachers' understanding of STEM disciplines and expose them to emerging interdisciplinary fields informed by developments in industry and academia. At the graduate level, the program equips educators with the foundations needed to implement innovative teaching and learning practices.

The curriculum is structured as a coherent two-year developmental sequence (Figure 1). Foundational courses introduce interdisciplinary STEM concepts such as biomimicry, computational thinking, and ethics in science and technology. These courses scaffold learning toward two core project-based courses: Development of an Interdisciplinary STEM Project via PBL and Developing and Implementing an Integrative STEM-PBL Learning Unit. An accompanying research seminar focused on evaluating these courses, supports research literacy, and reflective inquiry.

Figure 1

Program structure



2.2 Reflection as an educational tool

Reflection is acknowledged as a fundamental and rigorous meaning-making process in education, which John Dewey (1933) defined as the “active, persistent, and careful consideration of any belief... in the light of the grounds that support it”. This process moves the learner from a state of perplexity to settledness through systematic exploration and experience (Dewey, 1933; Rodgers, 2002; 2020). In learning, reflection serves as the reconstruction or reorganization of experience which adds to the meaning of experience (Mezirow, 1990; Lundgren & Poell, 2016). It is the essential thread that makes continuity of learning possible (Rodgers, 2002; 2020). Effective reflection facilitates the development of understanding (Loughran, 2002), by exposing and criticizing the tacit understandings or “knowing-in-practice” that guide spontaneous action (Dewey, 1933; Schön, 1983; 2017). The highest form, critical reflection, involves challenging the validity of the fundamental presuppositions on which one’s beliefs are based, thereby triggering transformative learning (Mezirow, 1990). This is particularly important when considering teachers as change agents of educational transformation (Schön, 2017), who recognize the changing conditions in which they operate and can revise their ideas and assumptions (Mezirow,

1990). From a cognitive perspective, reflection is closely related to the broader construct of metacognition. Metacognition refers to individuals' awareness and regulation of their own cognitive processes, including activities such as planning, monitoring, and evaluating thinking during learning and problem solving (Flavell, 1979; Schraw & Moshman, 1995). Within this framework, reflection can be understood as a metacognitive process that focuses particularly on the evaluation and reinterpretation of experiences, actions, and underlying assumptions. While metacognition broadly concerns the regulation of cognition, reflection emphasizes a deeper interpretive examination of practice and experience. For reflection to effectively improve practice, it must therefore involve fostering explicit metacognitive awareness, making students' thinking visible and available for reflection, discussion, and evaluation (Klapwijk, 2018; Ragonis & Hazzan, 2010; 2025; Zohar & Barzilai, 2015).

Thus, reflection serves as both a learning mechanism and an assessment lens, enabling instructors and researchers to trace the development of students' thinking over time.

2.3 *Reflections in Action in the M.Ed. program*

Throughout the M.Ed. In the program, reflection is intentionally embedded across courses to support meaning-making, integration of concepts, and professional identity development. Students engage in multiple forms of reflection, addressing conceptual learning, interdisciplinary connections, pedagogical practices, and managing challenges within their educational contexts.

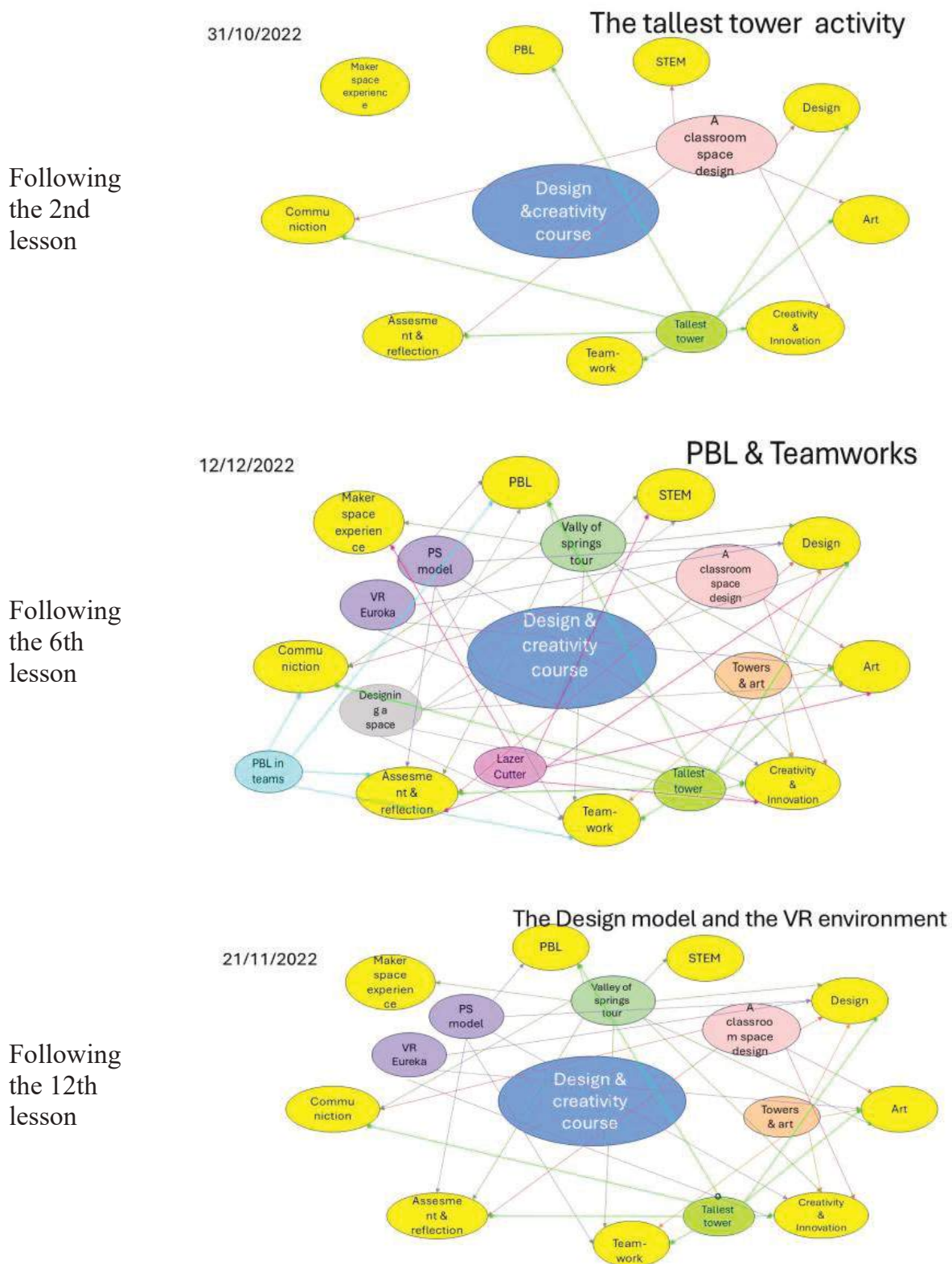
Within the four core courses of the program, students complete various types of reflective assignments, as presented in Table 1.

Table 1*Type of reflections*

Course	Reflection assignment
Creativity and innovation in development and design	Students are asked to present, at different stages of the course, <i>a concept map</i> illustrating the key concepts learned and the relationships between them. For example, Figure 2 illustrates three stages of reflection organized via concept maps from weeks 2, 7, and 13.
Analysis of projects from academia, industry, and education	Students are asked to articulate their educational worldview on implementing interdisciplinary STEM education, with particular attention to skills development, real-world relevance, and the barriers that may arise.
Development of an integrative STEM project via PBL approach	As part of the reflection, students <i>addressed each of the seven PBL components</i> by considering: a) Challenges they encountered b) How they experienced and managed those challenges c) Lessons learned for future teaching practice
Developing and implementing an integrative STEM-PBL educational unit	As the program's final course, the reflection focused on <i>key concepts in interdisciplinary STEM-PBL and their application in teaching</i> . Students addressed challenges in implementation, the teacher's role in teaching via the STEM-PBL approach, and their confidence in leading such learning processes.

Figure 2

Illustrations of the dynamic evolution of reflective concept maps



3 THE RESEARCH

3.1 *Aim and questions*

This study aimed to analyze how students' reflections correspond with the intended learning outcomes of selected courses and the extent to which these reflections indicate the attainment of the overarching aims of the program. To this end, we posed three research questions:

- (i) What themes emerged from the students' final reflective tasks in the two project courses?
- (ii) To what extent do these reflections indicate the achievement of the courses' intended learning outcomes?
- (iii) How do the reflections demonstrate alignment between course goals and the program's overarching aims?

3.2 *Methodology*

Research approach. This study employed a qualitative research design using inductive content analysis, allowing for a systematic yet interpretive examination of textual data and identification of recurring ideas, leading to the development of meaningful thematic categories.

Participants. The participants comprised 15 active teachers from various STEM subjects: Mathematics, Computer Science, Life Science, Geography, Mechatronics, Physics, Product Design. All participants except one are secondary school teachers (7-12 grades). The participants are multicultural including: Jewish-secular, religious, and ultra-orthodox, and Arab-Muslim and Christian. Two were males and 13 females.

Data sources. The dataset comprised final written reflections completed individually by each student. Students received structured guidelines for the two reflective assignments analyzed in this study. The reflections were collected at the end of the two advanced project-based courses (Courses 3 and 4; Table 1) from three consecutive M.Ed. cohorts (2021–2025).

Data analysis. Inductive content analysis was used to identify themes and categories emerging from the reflections, which were then mapped onto the predefined course outcomes. To assist in analysing the corpus of students' written reflections, a generative artificial intelligence (GenAI) tool (ChatGPT) was used as an analytical support for preliminary categorization. Structured prompts guided the tool to associate reflection excerpts with the predefined analytical categories and sub-categories. The GenAI output served as an initial classification and was subsequently reviewed and validated by the researchers to ensure alignment with the operational definitions of the coding scheme. The resulting categories were subsequently aligned with the program's overarching aims to examine the extent to which students achieved the program-level competencies.

4 FINDINGS

The findings section details the mapping used to answer the research questions.

4.1 *Reflections of the course: Development of an interdisciplinary STEM project via PBL approach*

The thematic analysis of the reflections revealed five major themes, each with three categories (for the full classification, see Appendix A):

- A. Farming and project initialization: identification, formulation, and relevance
This theme focuses on the initial stage of PBL, which is often challenging, requiring a necessary shift from broad thinking to a practical focus.
- B. The dynamics of the problem-solving process and integrative STEM
This theme examines how the PBL process was executed, how different knowledge domains were integrated, and the complexity involved in implementing the solution.
- C. Autonomous project management and taking responsibility
This theme addresses administrative and metacognitive aspects of learning, where responsibility for management was transferred to the students.
- D. Learning environment: collaborations and external involvement
This theme refers to the interactions of the students with their teammates, faculty (co-teaching) and other stakeholders.
- E. Personal growth and pedagogical insights for implementation
This theme summarizes the metacognitive and emotional learning and the pedagogical practical tools that the students intend to implement in their future work as teachers.

In line with the objective of understanding how learning outcomes manifest in students' reflections, we mapped the categories identified in our analysis according to course learning outcomes. Table 2 presents the specific categories of students' reflections for each learning outcome. The capital letter indicates the main theme (e.g., A1 is category 1 of theme A).

Table 2

Mapping the categories according to the pre-defined course outcomes

Learning outcomes related to knowledge domain	Categories
To cope with problem-solving using the PBL approach – from defining the problem to presenting and evaluating the solution	A1. Finding the topic and formulating the problem; A2. The impact of personal connections; A3. Dealing with knowledge and resource constraints; B1. The iterative/dynamic nature of the solution; B3. Sustainability and relevance as an organizing axis;

	C1. Time management; C2. Transferring responsibility and autonomy; D1. Internal teamwork; D3. Co-teaching; E1. Soft skills and personal growth; E2. Application insights in teaching field
To identify analogies and connections between knowledge domains	B2. Integration of fields of knowledge in STEM
To construct criteria for evaluating solutions and assess based on them	C3. Self-assessment and fairness
To locate, organize, and represent knowledge in a comprehensive and grounded manner	D2. Involvement of stakeholders and experts
To systematically document a project	E3. Expanding professional identity
Learning outcomes related to skills	Categories
To work in a team, to contribute and to benefit from the group effort	D1. Internal teamwork
To collectively define working methods	A1. Finding the topic and formulating the problem; C2. Transferring responsibility and autonomy
To give feedback and to receive feedback	D2. Involvement of stakeholders and experts
To cope with constraints	A2. The impact of personal connections; A3. Dealing with knowledge and resource constraints; B1. The iterative/dynamic nature of the solution; B2. Integration of fields of knowledge in STEM; B3. Sustainability and relevance as an organizing axis; D3. Co-teaching
To manage a schedule	C1. Time management
To cope with disagreements	D1. Internal teamwork

To reflectively observe personal work and teamwork	C3. Self-assessment and fairness; E1. Soft skills and personal growth; E2. Application insights in teaching field; E3. Expanding professional identity

As shown in Table 2, all learning outcomes were represented in the students' reflections, indicating that the core elements of the learning goals were understood, practiced, and internalized by the students. The students not only enacted these components in practice but also conceptualized them and articulated their emerging knowledge and skills in their written reflections. The findings indicate that certain outcomes appeared more frequently than others (greater number of categories aligning with outcome), suggesting areas of the student's strength as well as outcome components that may require greater instructional emphasis in developing these capacities. The most achieved learning outcome was implementing the PBL approach in problem-solving.

4.2 *Reflections of the course: Developing and implementing an integrative STEM-PBL learning unit*

The thematic analysis of the reflections revealed five major themes, each with three categories (for the full classification, see Appendix B).

- A. Interdisciplinary Curricular Design (The "What")
This theme deals with how students planned the content, selected the disciplines, and structured the "Driving Question" to create an integrative learning experience.
- B. Pedagogical Facilitation & Classroom Dynamics (The "How")
This theme reflects on the shift in teaching methods—moving from frontal teaching to guiding active, collaborative learning.
- C. Assessment and Evaluation Strategies (The "Measurement")
This theme covers the specific tools and philosophies used to evaluate student success, often contrasting them with traditional testing.
- D. Systemic Implementation & Logistics (The "Context")
This theme highlights the "real-world" tension surrounding implementing innovation within the rigid school system.
- E. Impact on the Learners (The "Result")
This theme reflects how the pupils (the school children) reacted to the intervention.

We also aligned each stated learning outcome with the themes derived from our analysis. Table 3 displays the categories corresponding to each course outcome. Overall, the higher number of categories aligning with each stated learning outcome in the course oriented around developing an educational intervention (Table 3) compared to the course oriented around developing a technological solution to a problem (Table 2) seems to indicate the educational orientation of these students in comparison to their technological orientation.

Table 3*Mapping course outcomes onto the thematic categories*

Learning outcomes related to knowledge domain	Categories
Present theories, principles, and methodologies in the field of STEM-PBL.	A1. Integration of STEM disciplines; A2. Driving question & authenticity; A3. Use of Technology & Digital Tools
Adapt curriculum content to the integrative learning approach in STEM-PBL.	A1. Integration of STEM disciplines; A2. Driving question & authenticity; B3. Active inquiry & autonomy
Develop and implement relevant assessment, feedback, and reflection processes.	C1. Alternative assessment tools; C2. Reflection & feedback; C3. Challenges & traditional validation
Integrate digital tools in teaching content in the field of STEM-PBL.	A3. Use of technology & digital tools
Learning outcomes related to skills	Categories
Identify, lead, and collaborate with school colleagues in the development and integration of integrative STEM-PBL learning.	D1. Logistics & resources; D2. Staff collaboration (co-teaching); D3. Management support
Guide and accompany student teams	B1. Teacher as facilitator; B2. Teamwork & collaboration (students); B3. Active inquiry & autonomy
Develop students' self-directed learning skills, teamwork skills, and reflective abilities.	B2. Teamwork & collaboration; B3. Active inquiry & autonomy; C2. Reflection & feedback; E2. Skill acquisition
Provide and receive feedback.	C2. Reflection & feedback
Develop collaborative relationships with the educational field (schools, communities, stakeholders).	D1. Logistics & resources; D2. Staff collaboration (co-teaching); D3. Management support

Learning outcomes related to affective aspects	Categories
Cope with challenges and obstacles in implementing innovation within educational settings.	C3. Challenges & traditional validation; D1. Logistics & resources; D2. Staff collaboration; D3. Management support; E3. Resistance
Foster among students a sense of empowerment, self-efficacy, and self-worth in leading change within the educational environment through the development and implementation of a STEM-PBL educational project.	E1. Engagement & motivation; E2. Skill acquisition; B3. Active Inquiry & autonomy

4.3 *Aligning reflections of the two courses with the overall aims of the program*

To address the third research question, which examines the extent to which the program's objectives were achieved, we mapped the categories derived from students' reflections in the two project-based courses to the overarching aims of the M.Ed. program. This alignment enabled us to examine how students' reported learning experiences correspond to the intended program outcomes (Table 4).

Table 4

Aligning the reflection-based learning categories in the project-based courses to the program's overarching aims

Program aims	Course 3: 'Development of an interdisciplinary STEM project via PBL approach'	Course 4: 'Developing and implementing an integrative STEM-PBL learning unit'
1. STEM disciplinary and interdisciplinary knowledge		
1.1. Deepening knowledge in the STEM disciplines	B3. sustainability and relevance as organizing axis	A3. use of technology & digital tools
1.2. Developing advanced thinking skills such as problem solving, critical and creative thinking, inquiry, and synthesis across domains	B1. iterative nature of problem-solving; B2. integration of knowledge domains; C2. transfer of responsibility and autonomy	B3. active inquiry & autonomy; B1. teacher as facilitator (supports inquiry)

1.3.	Building interdisciplinary understanding of the nature and value of integrating STEM fields	B2. integration of knowledge domains in STEM; A2. influence of context and personal connection	A1. integration of STEM disciplines; A2. driving question & authenticity
2. Pedagogical Content Knowledge (PCK) for STEM-PBL instruction			
2.1.	Building pedagogical and practical skills for implementing interdisciplinary PBL	A1. finding the topic & formulating the problem; B1. iterative problem-solving; E2. insights for implementation	B1. teacher as facilitator; B2. teamwork & collaboration; B3. active inquiry & autonomy
2.2.	Developing competencies for guiding students through inquiry, experimentation, and problem-solving processes	B1. iterative nature of problem-solving; C2. autonomy; E1. soft skills & personal growth	B3. active inquiry & autonomy; E2. skill acquisition
2.3.	Learning to design and apply diverse assessment methods suited to PBL	C3. self-assessment & fairness; D2. involvement of stakeholders & experts	C1. alternative assessment tools; C2. reflection & feedback; C3. challenges & traditional validation
3. Leadership and management of STEM initiatives			
3.1.	Developing capacity to plan, lead, and manage school-based STEM projects and educational innovation	C1. schedule management; C2. transfer of responsibility & autonomy; D1. internal teamwork	D1. logistics & resources; D2. staff collaboration; D3. management support
3.2.	Gaining experience in leading applied STEM-PBL projects in collaboration with educators, communities, scientific institutions, and industry	D2. involvement of stakeholders & experts; E3. expansion of professional identity	D2. staff collaboration; D3. management support; E1. engagement & motivation

3.3.	Promoting participation of diverse learner populations in STEM fields	A2. influence of context & personal connection; E1. soft skills & personal growth	E1. engagement & motivation; E3. resistance (barriers and inclusion)
4. Research literacy and reflective practice			
4.1.	Building foundational research skills for examining STEM teaching and learning in PBL contexts	C3. self-assessment & fairness; E2. insights for implementation	C2. reflection & feedback; C3. challenges & traditional validation
4.2.	Conducting action research to inform instructional improvement and address learner diversity	C3. self-assessment; E2. insights for implementation; E3. expansion of professional identity	C1. alternative assessment tools; C2. reflection & feedback; E3. resistance (reveals diversity-based challenges)

The students' reflections in these two advanced project development-oriented courses provide concrete evidence that the MEd program's objectives across the domains of content, pedagogy, and skills were realized. Extending the mapping to additional courses would further deepen and enrich the overall picture.

5 DISCUSSION AND CONCLUSIONS

This study aimed to examine how students' reflective accounts provide evidence of achieving learning outcomes in two project-based courses within the M.Ed. program Integrative STEM Education, and how these outcomes align with the program-level objectives. The findings indicate that structured reflection functions both as an indicator of conceptual, practical, and affective learning and as a metacognitive learning tool (Dewey, 1933; Loughran, 2002; Mezirow, 1990; Ragonis & Hazzan, 2010; Schön, 2017). This discussion synthesizes the findings from both courses and considers their collective contributions to achieving the program's aims.

5.1 *Achievement of courses outcomes and areas for strengthening*

In the development of a socially oriented technological product course, reflections demonstrated students' broad engagement with the conceptual and procedural elements of PBL through the design process. They articulated challenges related to framing authentic problems, integrating disciplinary knowledge, managing constraints and engaging stakeholders. Reflections also revealed growth in metacognitive skills, including self-assessment and collaboration within teams and with external partners, indicating strengthened reflective competence and professional awareness of the students.

In the education-oriented course, students demonstrated achievement across all learning outcomes, with particularly strong alignment in pedagogical facilitation, classroom dynamics and assessment for learning. Reflections highlighted a shift from traditional teaching roles toward facilitation, emphasizing active inquiry and extensive engagement with alternative assessment and reflective practices.

Students also grappled with the systemic challenges of implementing innovation in schools. Frequent references to logistics, staff collaboration, management support, and resistance underscore their understanding of the organizational and cultural contexts that shape educational change. Additionally, students demonstrated sensitivity to affective dimensions such as pupil motivation, engagement, and autonomy.

Overall, the findings suggest productive pedagogical progression: the technological project course builds foundational PBL competencies, whereas the educational implementation course deepens pedagogical, systemic, and leadership capacities.

5.2 *Alignment with program-level objectives*

Mapping reflections from both courses to program-level aims revealed a strong alignment across content knowledge, pedagogy, leadership, and reflective practice. Students demonstrated meaningful interdisciplinary STEM integration, iterative inquiry, and authentic problem framing, aligning with the goals of complex problem-solving and critical and creative thinking. Pedagogical content knowledge for STEM-PBL was not only understood but also enacted through concrete instructional, facilitation, and assessment practices. Leadership capacity emerged particularly in the education-oriented course, as students reflected on collaboration, navigating constraints, and leading changes. Finally, reflective practice matured across courses, evolving from descriptive to critical and strategic reflection, consistent with the program's vision of cultivating reflective practitioners.

The analysis demonstrates that the program's intended outcomes are being achieved meaningfully. Students articulated rich learning experiences encompassing the cognitive, practical, and affective dimensions of integrative STEM education. Together, these two courses form a coherent developmental trajectory aligned with the program's goal of preparing reflective, knowledgeable, and innovative STEM education leaders. Thus, reflection serves both as a mirror of learning and as a powerful diagnostic tool for program evaluation and refinement.

Limitations. The study relies on students' written reflections as the sole data source. Reflections provide insight into learners' perceptions, metacognitive processes, and professional awareness, they cannot fully represent actual learning achievements or the internalization of competencies. Students' accounts reflect their interpretations of learning rather than direct evidence of practice. Although the reflections revealed challenges such as logistical constraints and institutional resistance when implementing innovation in schools, future research could triangulate reflections with additional data sources (e.g., classroom observations or project artifacts) to strengthen the evidence of learning outcomes.

Contribution. The study contributes to the field of STEM teacher education by illustrating how structured reflection can be used to examine the alignment between course-level learning

experiences and program-level objectives. More broadly, the study suggests that reflection can serve not only as a learning tool but also as an informative mechanism for evaluating programs aims.

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APPENDIX A

Full categorization of reflections of the course: Development of an interdisciplinary STEM project via PBL approach

- A. Framing and project initialization: identification, formulation, and relevance
 - A1. Finding the topic and formulating the problem
 - A2. The influence of context and personal connection
 - A3. Coping with knowledge and resource constraints
- B. The dynamic of problem-solving process and integrative STEM
 - B1. The iterative nature of the problem-solving process
 - B2. Integration of knowledge domains in STEM
 - B3. Sustainability and relevance as an organizing axis
- C. Autonomous project management and taking responsibility
 - C1. Schedule management
 - C2. Transfer of responsibility and autonomy
 - C3. Self-assessment and fairness
- D. Learning Environment: collaborations and external involvement
 - D1. Internal Teamwork
 - D2. Involvement of Stakeholders and Experts
 - D3. Faculty - co-teaching
- E. Personal growth and pedagogical insights for implementation.
 - E1. Soft skills and personal growth
 - E2. Insights for implementation
 - E3. Expansion of professional identity.

APPENDIX B

Full categorization of reflections of the course: Developing an integrative STEM-PBL learning unit focusing on implementation of the educational projects within the school system.

- A. Interdisciplinary curricular design (the "what")
 - A1. Integration of STEM Disciplines
 - A2. Driving question & authenticity
 - A3. Use of technology & digital tools
- B. Pedagogical facilitation & classroom dynamics (the "how")
 - B1. Teacher as Facilitator
 - B2. Teamwork & collaboration (students)
 - B3. Active inquiry & autonomy (choice)
- C. Assessment and evaluation strategies (the "measurement")
 - C1. Alternative assessment tools
 - C2. Reflection & Feedback
 - C3. Challenges & traditional validation
- D. Systemic implementation & logistics (the "context")
 - D1. Logistics & resources
 - D2. Staff collaboration (co-teaching)
 - D3. Management support
- E. Impact on the learners (the "result")
 - E1. Engagement & motivation
 - E2. Skill acquisition
 - E3. Resistance

The Relationship Between Computational Thinking and Design: Insights from the Implementation of the 4P4CT Pedagogical Framework

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Abstract

Computational thinking (CT) is widely recognized as a set of essential cognitive and social skills that support complex reasoning across disciplinary domains. This study adopts a broad view of CT as a transferable thinking paradigm and introduces an analytical perspective that examines how CT skills can be theoretically connected and pedagogically applied to the design process. The study is grounded in the Four Pedagogies for Developing Computational Thinking framework, which is inspired by constructivist and constructionist learning theories and integrates active, project-based, product-based, and context-based learning. The framework was implemented in an academic course for preservice K–12 teachers from diverse disciplines and in a course for the general public, in which learners applied core CT skills—decomposition, abstraction, and generalization—while developing computerized simulations of computational processes. Computational processes were defined as dynamic representations of domain-specific concepts and the relationships and interactions between them, realized through animated scripts in environments such as Scratch. The research question examines the extent and manner in which students' reflections while applying CT skills correspond to different components of the design process. Analysis of students' reflective responses, mapped onto the design process, revealed that although the design process was not explicitly taught, students implicitly produced reflective language consistent with all six dimensions: problem understanding, idea generation, planning, building, testing, and improvement. The findings suggest that CT-based simulation development naturally elicits design thinking. Articulating these connections explicitly may further strengthen both design learning and computer science education within technology education, as well as teacher education in these domains.

Key Words: Computational thinking, Problem solving, Design process, Preservice teachers, Simulations

1 INTRODUCTION: REFRAMING COMPUTATIONAL THINKING FOR DESIGN

Computational thinking (CT) is increasingly recognized as a collection of cognitive and social skills essential for effective participation in 21st-century societies. Beyond its association with computer science, CT has been conceptualized as a transferable thinking paradigm that supports the analysis, modeling, and design of solutions to complex problems across disciplines. Within technology education, this broader view positions CT as a foundational component of technological literacy, closely aligned with how learners conceptualize systems, reason about processes, and develop purposeful technological solutions.

To operationalize this perspective, the present study builds on the Four Pedagogies for Developing Computational Thinking (4P4CT) framework (Ragonis et al., 2025), which integrates active learning, project-based learning, product-based learning, and context-based learning. These pedagogies are central to technology education, which emphasizes engagement with authentic problems and construction of meaningful products as solutions to those problems. From a design-oriented standpoint, core CT principles, specifically, abstraction, decomposition, and generalization, are fundamental to the design process (DP), supporting problem framing, system modeling, and solution development.

Although CT and the DP are both central to technology education, they are typically addressed in parallel rather than as mutually reinforcing constructs. CT is often taught as a cognitive toolkit, while the DP is framed as a professional methodology for technological problem solving. Explicit curricular connections between these domains remain under-theorized. This gap raises an important pedagogical question: can structured engagement with CT skills implicitly cultivate design-oriented reasoning, even when the DP is not explicitly taught?

The present study examines whether structured engagement with core CT skills within the 4P4CT framework leads learners to implicitly enact components of the DP. Rather than evaluating CT instruction per se, the study investigates how design reasoning emerges through CT-based computerized simulation development. The study was conducted in a computational thinking course in which product development was a central component, specifically, the creation of computerized simulations. This simulation development closely parallels design practices and provides a rich context for developing computational thinking skills. Particular attention was paid to how prospective teachers translate complex technological or scientific concepts into computational models. Accordingly, the study analyses students' reflective narratives generated while developing CT simulations in Scratch, mapping the expressed experiences onto the DP components. In doing so, the study explores how design-oriented thinking emerges through CT practice, even when the DP is not explicitly taught.

2 BACKGROUND

2.1 *Design in Technology Education: Conceptual Foundations*

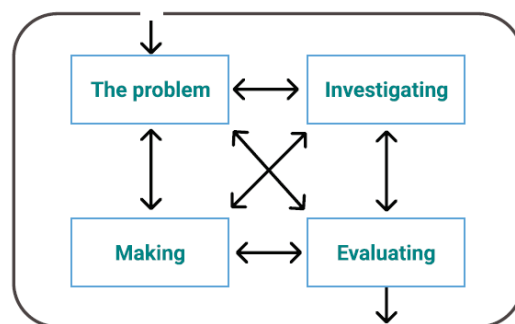
Problem solving is a foundational competence in technology education and across STEM domains. A problem is commonly defined as a situation in which a gap or conflict exists between

a desired state and the current state, and where no ready-made procedure is available for reaching a solution, requiring the solver to select and construct an appropriate solution path (Mioduser, 1998). Problem solving involves high-level cognitive processes, including analysis, synthesis, evaluation, and decision making, and therefore constitutes a central educational goal throughout learners' lives. In technology education, problem solving is predominantly taught and learned through the DP (De Vries, 1996; Mioduser & Dagan, 2007). Over time, this process has evolved from a linear, structured, stage-based model toward a more iterative and flexible model, reflecting authentic design practices (Stables & Kimbell, 2006).

The DP is understood as a creative yet systematic methodology for developing technological solutions, integrating both thinking and making. It typically begins with problem definition and progresses through research, ideation, construction, and evaluation, culminating in a functional solution—a product. Engaging effectively in design requires a set of skills, each representing a cluster of abilities that must be explicitly addressed through teaching, learning, and assessment (Bloom & Canty, 2022; McLain, 2022; Stables, 2020). Importantly, the DP is inherently iterative, with repeated movement between components as ideas are refined and evaluated, as presented for example in Figure 1 (Mioduser, 1998).

Figure 1

The Design Tool Model (Mioduser, 1998)



Project-based learning is acknowledged as meaningfully strengthening the DP by connecting theory with authentic, industry-relevant design practice, thereby enhancing problem solving, collaboration, and design competence when supported by structured models and appropriate assessment frameworks (Dagan, 2023; Zhang & Ramli, 2025). Pedagogical approaches to design therefore emphasize problem framing, investigating relevant topics, idea generation, construction, and evaluation, highlighting the dynamic interplay between cognition, action, and reflection within technology education.

2.2 Computational Thinking

As mentioned, computational thinking (CT) is widely acknowledged as a vital set of cognitive and social skills essential for functioning effectively in the technology-driven 21st century. While the concept originated in computer science and was pioneered by Papert (1980), the contemporary

discourse was significantly advanced by Wing (2006, 2011, 2014), who framed CT as a universal problem-solving skill rather than merely a programming competency.

Computational thinking is defined as a thought process involved in formulating problems and designing solutions that can be executed by humans or computers. The key cognitive components of CT include decomposition (breaking problems into sub-problems), abstraction (focusing on essential details), generalization (pattern recognition), and algorithmic thinking (Shute et al, 2017; Cuny et al., 2010). Beyond cognitive abilities, CT also encompasses social skills such as teamwork. Educational systems worldwide are increasingly integrating CT across all disciplines—not just STEM—viewing it as a transferable mindset necessary for all citizens to analyze, model, and design solutions to complex real-world challenges (Barr et al., 2011; Denning & Tedre, 2021; Tedre & Denning, 2021; Yadav et al., 2014; 2017).

2.3 *Linking Computational Thinking to Design and Design Thinking*

Prior research has examined the relationship between CT and design-oriented learning, positioning CT as a form of reasoning that supports complex problem framing, modeling, and solution development. Within this growing body of work, two related yet conceptually distinct research traditions are identified: (a) design process (DP)-oriented studies and (b) design thinking (DT)-oriented studies.

Design process-oriented research demonstrates that learners naturally enact CT competencies while engaging in design-based activities, even without explicit CT instruction (e.g., Ehsan et al., 2021; Wang et al. 2022). In contrast, the present study adopts a complementary but reversed analytical perspective, examining how adults, specifically preservice teachers, implicitly enact design-related competencies while engaging in CT-based activities. Together, these strands reveal a curricular gap in how CT and design can be intentionally connected and mutually reinforced in educational settings to promote student learning.

Design thinking-oriented research frames CT as part of broader creative and human-centered design processes, emphasizing DT ideation, iteration, and innovation (Kelly & Gero, 2021; Wu et al., 2022). While DT-oriented work highlights important connections to CT, it differs from the present study in its focus on open-ended design practices rather than the structured DP components, on which the present analysis focuses. Future research can analyze these interconnections to develop a more comprehensive framework.

2.4 *Design-Oriented Computational Thinking Dimensions in Simulation-Based Developing*

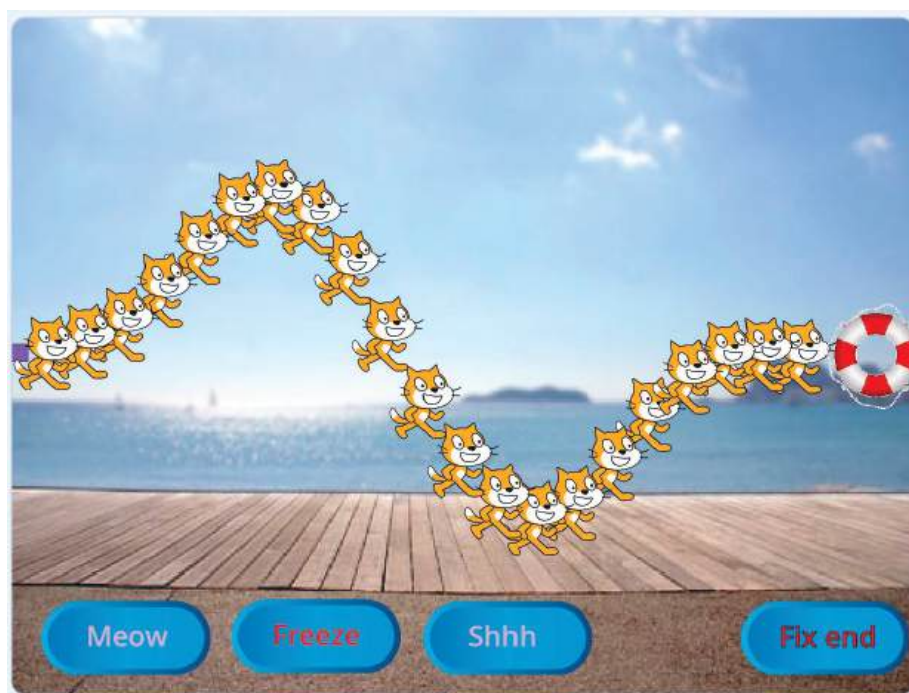
Computational thinking can be conceptualized as a problem-solving capability and a form of design-oriented thinking that supports the planning, development, and implementation of technological solutions.

Developing a computerized simulation provides a useful analogy for understanding how CT supports the DP, since the process resembles designing and creating a technological prototype.

Initially, learners must decompose the function of the intended product by identifying its essential components and relationships. They then engage in abstraction, selecting core concepts while deliberately omitting non-essential details, and in general, enabling the model to represent broader patterns or behaviors. These modeling decisions are subsequently translated into a functional design through algorithmic and programming structures. For examples of simulations, see Hazzan et al. (2026) and Ragonis & Hazzan (2026). Figure 2 presents an original simulation developed by a team of preservice physics teachers¹. The simulation illustrates the motion of a one-dimensional wave and operates according to the laws of wave propagation in space, allowing a choice between wave motion with a fixed or free end.

Figure 2

Simulation of wave propagation in space



As in technological design, the quality and functionality of the final product, the simulation, directly reflect the depth and coherence of the modeling decisions and CT skills applied. In particular:

- (i) *Social skills*: Collaboration, communication, and shared problem framing during design activities.
- (ii) *Cognitive skills*: Problem decomposition, abstraction, and generalization are primarily enacted during the disciplinary analysis phase, in which learners define and structure a

¹ Created by Israel Ofek and Ofer Calderon (with their permission)

computational process, which is a dynamic representation of concepts from any domain of knowledge illustrating relationships and interactions between those concepts, and are reflected in the simulation.

- (iii) *Modeling skills*: Bridging conceptual understanding and design practice, encompassing activities such as system representation, reverse engineering, and alignment with real-world phenomena. Making skills, exemplified through coding, involve enhancing design decisions during implementation, including debugging, integration, and iterative refinement.

The presented interpretations position CT as a comprehensive design-supporting competence that underpins both conceptual and practical aspects of technological design. This approach is further, and naturally, supported by present findings.

2.5 *The 4P4CT Pedagogical Model*

The Four Pedagogies for Developing Computational Thinking (4P4CT) model was used to develop a MOOC on CT, targeted at the general public, in which three main CT skills are taught and practiced: problem decomposition, abstraction and generalization (Ragonis & Hazzan, 2022; Ragonis et al., 2025; Ragonis & Hazzan, 2026). See Section 3.2.

The 4P4CT model is a holistic conceptual framework designed to teach CT across all educational levels and disciplines. Grounded in constructivism and constructionism learning theories, this framework asserts that learning is most effective when students actively construct knowledge by creating meaningful products (Ragonis et al., 2025; Ragonis & Hazzan, 2026). The framework integrates four specific learner-centered pedagogies:

- (i) *Active Learning*: Involves learners through problem solving and collaborative discussions rather than passive listening.
- (ii) *Project-Based Learning*: Engages learners in teamwork to address authentic problems and develop comprehensive solutions.
- (iii) *Product-Based Learning*: Enables learners to demonstrate understanding by building a concrete product.
- (iv) *Context-Based Learning*: Ensures that learners develop CT skills within a relevant domain, i.e., specific subject matter, such as biology or history, rather than as an isolated theoretical skill.

While the 4P4CT framework was originally developed to strengthen CT competencies, its implementation, presented in this study, enabled to explore a complementary question: how CT practice may cultivate design-oriented thinking?

3 THE RESEARCH

3.1 *Rational, Aim and Research Questions*

This study aimed to determine whether learners who apply CT skills in computerized simulation development also apply the different DP components. Accordingly, the following research question was formulated.

RQ: How, and to what extent, do students who apply CT skills in computerized simulation development apply the different components of the DP?

3.2 *Methods and Tools*

Environment. The study was conducted in a CT course, the foundational structure of which is presented in Figure 3. As part of the summative task, learners developed simulations of computational processes identified within their specific disciplines. Within this framework, a computational process is defined as a dynamic visual representation of concepts from any domain of knowledge that illustrates the relationships and interactions between those concepts.

Figure 3

The CT course design foundations

Computational Thinking MOOC		
Content: CT Knowledge & Skills	Pedagogy: 4P4CT (1) Active learning (2) Project-based learning (3) Product-based learning (4) In context Constructivism & Constructionism	Population: All (1) Teachers (2) School students (3) General public In all subjects

Methods. The study employed a mixed-methods approach. Students' open-ended responses from the reflection form in Course Chapter 6, which focused on simulation development, were analyzed qualitatively through thematic categorization using the rubric described in Table 1. Category frequencies were calculated for a complementary quantitative perspective.

Tools. The reflective course assignments were designed to support the consolidation of thinking skills and encourage learners to articulate their learning experiences and challenges. A reflective form was submitted at the end of each course chapter. Each form consisted of two components.

The first was a uniform section aligned with the core CT concepts addressed in the chapter, intended to help learners monitor their progress and understanding over time. The second was a guided personal reflection section, in which learners were required to complete at least two reflective statements. This section employed a sentence-completion format, prompting students to select verbs expressing the cognitive or emotional dimensions of their learning experience (e.g., “I found interest in...”, “I was afraid of...”, “I was curious about...”). All reflections were submitted anonymously to encourage open, authentic responses.

To reflect the study’s design-oriented perspective on CT in simulation-based learning, we developed the following rubric based on an analysis of the customized DP components, adapted to the context of computational simulation development (see Table 1). These components were used to map the reflective narratives onto the DP components.

The rubric was constructed deductively based on canonical representations of the engineering design process (Mioduser, 1998; Bloom & Canty, 2022). Each DP component was operationalized specifically for simulation development to ensure contextual alignment. The rubric was not intended to measure mastery of the design process but to serve as an interpretive framework for identifying design-related reasoning embedded in students’ reflections.

Table 1

Rubric for mapping CT reflections onto DP components

DP component	Reflection in simulation development
a. Identify/define the problem	Recognizing needs, goals, and essence of the computational process.
b. Ideate/explore possible solutions	Generating ideas, considering alternatives, conceptualizing the simulation.
c. Plan the design	Structuring the algorithm, planning components and interactions.
d. Create a solution	Coding, assembling Scratch blocks, building the simulation’s logic and interface.
e. Test the solution	Testing/Running/Evaluating the simulation, identifying bugs, malfunctions or unexpected behavior.
f. Improve/reflect	Revising the design, acknowledging difficulties, and articulating what was learned.

Importantly, the reflection prompts addressed CT-related learning experiences without explicitly invoking the design process framework. Therefore, the alignment between reflections and the DP rubric was analytically derived rather than structurally induced by the reflection format.

Population. The analyzed reflections were provided by 120 learners who completed the Chapter 6 reflective assignment on developing a simulation of a computational process. Reflections were collected between January 2022 and August 2025. The questionnaire was anonymous, so, no demographic or descriptive statistics about the responding population are available.

Data analysis. The analysis procedure in three stages:

1. Reflections were organized and anonymized in a structured dataset.
2. Deductive coding was conducted using the DP rubric as a predefined analytical framework. GenAI tools (ChatGPT and NotebookLM) were used to map reflections deductively onto the DP rubric and to generate preliminary frequency distributions. Each reflection served as the unit of analysis and could be associated with multiple DP components. When a reflection reflected more than one DP stage, it was coded accordingly in each relevant category.
3. The research team independently reviewed categorizations resolved discrepancies through discussion, and refined category assignments to ensure conceptual coherence, analytical consistency, and alignment with the theoretical framework. This triangulated process combined AI-supported pattern recognition with human theoretical judgment.

Although the sentence-completion format may have shaped the initial framing of students' responses, only two opening words were provided, and the substantive content of each reflection was entirely open-ended. This structure balanced guided reflection with opportunities for authentic expression.

3.3 *Disclosure Statement*

GenAI tools (ChatGPT and NotebookLM) were employed solely as supportive instruments for organizing data, facilitating deductive mapping, and generating preliminary frequency distributions; the analysis is sole responsibility of the research team.

4 FINDINGS – MAPPING REFLECTIONS ON CT TO DP

In the following, we present illustrative quotes from students' reflective statements corresponding to the six DP components alongside the frequency of each category as identified by the two GenAI tools (see Table 2).

The data suggest structural and epistemic alignment between CT and the DP, i.e., CT and the DP support knowledge construction in similar ways. In both cases, understanding develops through

planning, experimentation, problem decomposition, encountering errors, iterative refinement, and abstraction. This alignment extends beyond the use of similar terminology or components; CT and the DP are similar not only in *what* learners do but also in *how* they learn and understand ideas through action. Table 2 specifies the roles of CT and the DP in this learning process.

Table 2

Original reflection excerpts illustrating implicit engagement with the DP and their frequencies, N=120

DP component	Original reflection excerpts [Student file number]	Frequency
a. Identify/define the problem	How to identify a problem, [and] plan solution steps up to the final solution. [10]	21
CT provides the cognitive tools for precise problem framing; the DP provides the process context in which this framing is necessary and meaningful.	It is important to plan in advance exactly what you want to create, what problem you want to solve, and to plan the solution method in general. [33] The process includes not only executing the calculation itself but also organizing and precisely defining the problem. [43]	
b. Ideate/explore possible solutions	I found great interest in thinking about how to transfer the project to a simulation, which characters to choose, and how to distribute roles [22]	29
CT supports reasoning about alternatives, while the DP frames this as a design decision-making process.	I had to consider different solutions options, and I enjoyed seeing that there always are [some]. [57] [It was a joy to experience...] the need to find original solutions and invent ways to overcome challenges. [89]	
c. Plan the design	It is important to plan in advance exactly what you want to create, what problem you want to solve, and to plan the solution method in general. [33]	30
CT operationalizes how to plan; the DP legitimizes planning as an essential professional practice.	Now I understand... how I must weigh the project planning, the planning stages... and how to choose characters that will reflect the idea for the simulation itself. [34] The main idea I learned in this chapter is that solving problems with the help of a computer requires organized thinking, advance planning, and decomposing the problem into small parts. [50] It surprised me how important it is to plan in advance the characters and the connections between them, even for a process that appears simple at first glance. [95]	

d. Create the solution	To build stage by stage until all the parts are connected into a single creation. [3]	86
In both CT and the DP, building is a way of thinking, not just a means of production.	I struggled with the frustrations of failing in my first attempts. [29] The code development process is complex, involving steps back and forth, but also fulfilling. [93]	
e. Test the solution	Checking the process during development of the sprite code, allows problems to be fixed as early in the process. [15]	20
CT interprets errors as diagnostic tools; the DP normalizes iteration as both expected and productive.	In my eyes, this is a very important tool because I could perform error control [self-check] and understand if there were things I hadn't done correctly. [59] It challenged me and I was happy I succeeded in finding errors and fixing [them]. [83]	
f. Improve / reflect	Every step in the project requires attention to small details but can also lead to changes that improve precision in the final result. [44]	69
CT explains how refinement works cognitively; the DP situates it within real-world <i>practice</i> .	I understood that sometimes errors specifically provide an opportunity to better understand my thinking and to improve my precision. [54] It is important to plan in advance exactly what you want to create... and then be flexible, adapting as needed during the implementation. [83] There is always room and reason for more... one can continue to develop additional ideas for implementing additional generalization and abstraction. [87] Developing the simulation completely changed my understanding of the subject from my perspective. Now I have a clearer sense of what a computational process is. [18]	

Overall, CT and the DP appear to be mutually reinforcing, with CT providing the thinking patterns (problem formulation, decomposition, abstraction, and debugging) and the DP providing the process structure (design, implementation, testing, and iteration).

5 DISCUSSION

Analysis of students' reflections indicates that, while engaging in computational simulation development, preservice teachers implicitly articulated all six dimensions of the DP, even though they were neither explicitly taught this framework nor explicitly asked about its components. As

students practiced computational thinking through modeling, iteration, and refinement, their reflections naturally referenced design-related activities such as problem understanding, idea generation, planning, building, testing, and improvement. Mapping these reflections onto the DP demonstrates that CT-based simulation work can elicit core design thinking processes without direct instruction in design models.

Conceptual mapping further revealed that students' reflections aligned with central CT practices. This trajectory—from initial conceptualization through iterative refinement to metacognitive reflection—highlights the close interplay between computational thinking and design in simulation-based learning. Enhancing prompts for reflective writing may further reveal students' engagement with early DP components, particularly problem framing and planning, thereby making CT's contribution to learning the design process more explicit and effective.

Although participant characteristics were not available due to the anonymous design, the emergence of consistent DP-related language across a diverse and non-specialized cohort was not predetermined. The findings were therefore analytically derived rather than assumed, strengthening the interpretive contribution of the study.

6 SUMMARY

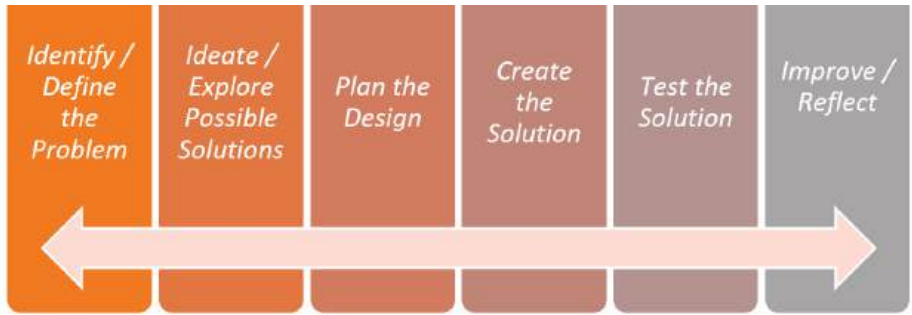
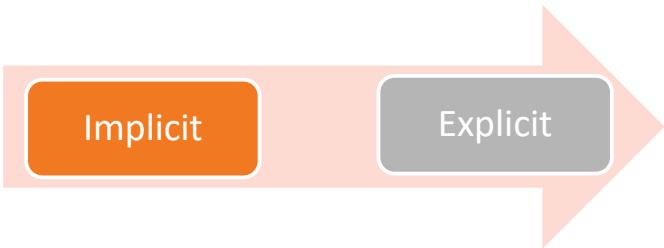
The application of CT skills within a product-development context, as enacted through the 4P4CT pedagogical model, inherently cultivates competencies aligned with the key components of the DP, even without an explicit instructional focus on design. In particular, engaging students in computational simulations appears to strengthen modeling skills that require higher levels of abstraction, which are central to design thinking. Mapping students' reflections onto the DP further uncovers rich layers of learning, demonstrating how CT-oriented simulation courses can simultaneously cultivate CT and design reasoning.

These findings underscore the pedagogical potential of CT as a foundational lens for design learning and support the argument for explicitly anchoring the teaching of design components in CT skills. This proposed integration can also be interpreted in light of Mioduser's (2025) assertion regarding the shortage of structured curricula in technology education. The growing prominence of CT in curriculum design may therefore serve as a catalyst for strengthening technology education by providing a coherent conceptual framework that enriches existing programs and supports the development of sustainable and well-articulated curricular models. Future work could extend this analysis by systematically relating CT competencies to established design frameworks, such as the MDLD Design Skills Framework (Klapwijk, 2018) and frameworks supporting preservice teachers' acquisition of the design process (Bloom & Canty, 2022).

Figure 4 summarizes what the CT course gains when examined from the DP perspective and outlines the next steps for course development. We suggest that this approach be applied bidirectionally, to enable the development of a more holistic set of skills for technological education.

Figure 4

Leveraging CT pedagogies to make design explicit

Pedagogies	• Active Learning • Project-Based Learning • Project-Based Learning • Product-Based Learning
CT skills Explicit	• Decomposition • Abstraction • Generalization
Design Process throughout a simulation development Implicit	
Design skills ² From implicit to explicit	

Contribution. *Theoretical contribution:* This study advances the understanding of how explicitly taught CT competencies contribute to students' execution and implementation of the DP. *Practical contribution:* The study proposes a conceptual framework for examining and interpreting how the DP emerges within CT-oriented learning environments.

Recommendations. The DP is a valuable analytical lens for making students' CT development visible and, therefore, should be intentionally employed in the design, analysis, and assessment of CT-based learning experiences. Based on this research, in the upcoming course cycles, we plan to explicitly ask students to reflect on the design process components upon completing simulation development and indicate whether they believe they applied them. We intend to present these preliminary findings at the conference.

² Such as, Think in all directions; Make productive mistakes; Bring ideas to live (Klapwijk, 2018).

The message. CT can improve the DP, and the DP can serve as an environment for developing CT competencies. Shall we call these ideas CT4DP and DP4CT respectively?

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Balancing Generative AI Use in Creative Processes: How Teachers and Students Adopt Emerging Technology in an Educational Context

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Abstract

Artificial intelligence (AI) text-to-image generators have quickly become influential in art, design, and media education. While some view it as a fruitful supplement to their creative processes, as it can stimulate idea generation and make image creation quicker and more accessible, others fear that the generators will replace the human creator and eradicate creativity. Furthermore, AI generators are known to reproduce stereotypes, and it can be challenging to control their output. Due to the emergent nature of the technology, there are many studies where the authors themselves or participants have explored using generative technology in specific tasks given by the researchers or in researcher-led educational interventions. Teachers, designers, and artists' perceptions of text-to-image generators are also well studied, but there is less research on how they actually use generative AI in their everyday professional lives. As the technology now has been in common use for a few years, it is time to explore how early adopters have integrated text-to-image generators in their professional practice. We have conducted semi-structured interviews with teachers in Norwegian upper secondary art, design, and media education, strategically chosen due to their advanced use of generative AI. In the interviews, we have asked how they use the technology in their work, both in educational projects with students and in their professional development. We have also asked them to reflect on how they understand and seek to develop their students' AI literacy, as well as the technology's limitations, practical and ethical challenges of educational use of AI. This paper provides insights into how generative AI is used in art, design, and media education, including innovative practices and how the teachers seek to balance its positive and negative aspects in an educational context.

Key Words: Artificial intelligence, Text-to-image generation, Art and design education, AI literacy, Emerging technology

1 INTRODUCTION

As society and technology evolve, education adapts and develops in response. For art, design, and media education to remain relevant, these subjects must equip students with the skills necessary to navigate a changing world. Artificial intelligence is already reshaping society, and educators must engage with its implications, as it stands to redefine how we create, work, and teach. Text-to-image generative technologies have evolved steadily since 2014, gaining widespread attention after the introduction of DALL-E in 2021 (Cetinic & She, 2022). Since then, numerous providers have emerged, supplying an array of standalone services—whether subscription-based or funded through advertising—alongside enhanced functionalities integrated into established software platforms. Such rapid technological progression demands a critical examination of its capabilities and the ways it should be employed in practice.

1.1 *Artificial intelligence literacy in education*

As AI technologies become increasingly integrated into schools, both teachers and students need to develop a critical awareness of when and how these tools should—and should not—be used. In Norway, county authorities differ in their policies regarding which AI tools are permitted. Approved tools are usually modified chatbot models with strengthened privacy controls. Text-to-image models are not addressed in existing guidelines. Bringing AI into education raises important questions about how teachers make decisions and maintain control over its use. With AI technology advancing rapidly, educators must be prepared to navigate its complexities.

AI literacy (Kong et al., 2024; Chiu, 2025; OECD, 2025) prepares students to critically understand when and how to use AI, knowing its advantages and limitations. It encompasses teaching students to critically engage with AI, including its foundational principles and its practical applications in both educational settings and daily life for problem-solving (Kong et al., 2024). Chiu (2025) argues that AI literacy is interdisciplinary, tightly woven into ten other literacies. In this paper, visual literacy and design literacy are particularly relevant. Students in art, design, and media education learn to interpret and communicate through visual language. The ability to critically assess visual outcomes from AI generators is therefore essential. The connection to design literacy concerns its iterative and human-centred approach as well as a focus on critical thinking and problem solving. In the Norwegian curricula, digital skills are defined as a basic skill. Most subject specific curricula have at least one competency aim including the use of digital technology.

The study has been guided by the overarching research question: *How do teachers balance the challenges and opportunities of using AI text-to-image generators in upper secondary art, design, and media education?*

This has been divided into four sub-questions, where (i-iii) focuses on opportunities and (iv) on challenges:

- (i) How do the teachers use generative AI in their teaching?
- (ii) How do the teachers seek to develop their students' AI literacy?

- (iii) What value do the teachers see in the use of AI text-to-image generators?
- (iv) Which challenges and hindrances exist to the use of generative AI?

2 LITERATURE REVIEW

The research on AI text-to-image generators in art, design, and media is characterised by the technology's emergent nature. Several studies draw on researchers' own experimentation (Abdallah & Estévez, 2023; Mikkonen, 2023; Ringvold et al., 2023, 2024), while others involve participants using such tools in various design and artistic processes, including product design (Chen et al., 2019; Liu et al., 2023), furniture design (Chandrasekera et al., 2024), and visual arts (Ko et al., 2023; Lyu et al., 2022). Oppenlaender, Linder, and Silvennoinen (2025) examined participants' ability to assess and develop quality prompts, arguing that prompt engineering constitutes a creative skill.

Within educational research, Vartiainen and Tedre (2023) explored pre-service craft teachers' and teacher educators' understandings and attitudes towards AI text-to-image generators. Participants acknowledged the new opportunities enabled by AI but raised concerns about bias, copyright violations, and lack of transparency. Vartiainen, Tedre, and Jormanainen (2023) arranged hands-on workshops with youth aged 14-16, including exploring and experimenting with the text-to-image generator Midjourney. The students engaged in a free-flowing ideation process but expressed divergent views regarding image ownership. Hutson and Lang (2023) used text-to-image generators into their own digital media course. The students stated that it helped them to structure and visualise ideas but felt that their images shared the same postcard-like expression. Heaton, Low, and Chen (2024) included text-to-image generators in the ideation phase of a painting project with students aged 14–15. Although the students initially expressed concerns related to artistic autonomy and the creative process, they later found that their processes were enriched and that visual exploration with generated images allowed them to engage more deeply with the topic.

Overall, few studies examine how text-to-image generators are used in educational contexts, indicating a research gap. Oppenlaender (2022) conducted an online ethnography focused on prompt-writing. Kalving et al. (2024) investigated how designers use and perceive generative AI, where several participants described using text-to-image generators for ideation, yet also viewed AI use as laziness or as a potential threat to their jobs. In a study on Design and Technology-teachers' adoption of generative AI, McLain, Barrow, and Ndiaye (2024) found that although teachers generally held positive views of the technology, few employed it in innovative pedagogical ways.

3 METHODOLOGY

In this section, we present the methods used for collecting and analysing data, as well as the ethical considerations we have made in planning, conducting, and disseminating the study.

3.1 *Semi-structured interviews with teachers*

Four informants were purposively sampled (Bryman, 2016). They were identified through inquiries within our professional network, which sought teachers in upper secondary art, design, or media education who could be considered early adopters of AI text-to-image technology. *Early adopters* are defined as those who are among the first to use a new technology (Rogers, 2003). We contacted four teachers meeting these criteria, and all agreed to participate. The informants have diverse backgrounds, with most having professional experience in art, design, or media. All hold pedagogical qualification or teacher education and are currently teaching in upper secondary schools.

Semi-structured interviews were chosen to ensure coverage of predetermined themes while also allowing for follow-up questions (Brinkmann & Kvale, 2015; Bryman, 2016). The interviews were conducted individually and lasted 45-60 minutes. Three to four researchers participated in each, with two researchers present at all sessions. Three interviews were held face-to-face and one via video conference between December 2025 and January 2026.

The teachers were asked about how they use the technology in their professional practice. This included how they aim to develop their students' AI literacy and how they integrate generative AI into creative processes, as well as the technology's limitations, practical and ethical challenges. Finally, they were invited to reflect on text-to-image generators' contribution to educational projects and imagine how the technology could be used in new ways.

3.2 *Thematic analysis*

The empirical material was analysed through a thematic analysis (Braun & Clarke, 2022). Each author first read the interview transcripts and independently made In Vivo codes (Saldaña, 2016) separately. The subsequent stages of the analysis were conducted collaboratively. Using Microsoft Whiteboard—a digital workspace enabling real-time collaboration—we placed each code on a digital sticky note. In the next step, we grouped similar codes together. Through a process of defining, renaming, and merging (Braun & Clarke, 2022), the codes were developed into themes that characterised how the teachers used AI text-to-image generators, the challenges and hindrances they encounter, how they sought to develop their students' AI literacy, and their understanding of the value of using AI in education.

3.3 *Ethical considerations*

Before contacting the informants, our plan for handling personal data was approved by Sikt – Norwegian Agency for Shared Services in Education and Research. This approval required us to obtain informed consent from all informants, minimise privacy risks by collecting only necessary data, secure identifiable information through two-factor authentication, and describe informants in a manner that reduces the likelihood of identification (Sikt, undated).

3.4 *Disclosure on the use of Generative AI*

The authors have conducted the analysis and text production for this paper without the use of Generative AI. The GenAI-tool Microsoft 365 Copilot has been used in copy editing the final version of the text.

4 RESULTS

The structure of this section is guided by the four sub-questions presented in the introduction, where we present a total of 21 themes identified through the analysis.

4.1 *The teacher's use of generative AI in their teaching*

4.1.1 *Getting to know the technology*

The teachers wished to introduce students to AI text-to-image generation, aiming to develop an understanding that the technology exists and how it works. In one exercise, students were asked to formulate a prompt describing the teacher. This was followed by a discussion of the generated images and how closely they resembled the teacher.

4.1.2 *Inspiration and idea generation*

AI text-to-image generators were used to support students' creative processes. Students used AI to generate inspiration images for their projects, rather than searching online, and to explore and refine ideas by experimenting with AI generators.

4.1.3 *Producing raw material used as elements in final products*

AI-images was not wanted as finished outcomes. Instead, students used AI-generated elements as components within larger compositions, for example by inserting AI-created elements into photographs, modifying specific parts of an image, or assembling multiple AI-generated image or video components into a cohesive whole.

4.1.4 *Creating complex or impossible visualisations*

The teachers described how students used generative AI to create images that would otherwise be inaccessible or impossible to make—either because existing image databases lacked the necessary material, or because students did not have the equipment, time, or opportunity to access specific locations. One example was a project titled *Under the Surface*, where students created images depicting underwater or underground environments.

4.1.5 *Visualising ideas*

AI generators were also used to visualise the students' ideas for communication. This included generating visual material to articulate prefigurative thoughts, as well as producing moodboards or storyboards.

4.1.6 *Develop critical understanding of images*

The teachers also addressed that visual material encountered daily can be misleading and AI-generated, and they aimed to help students develop critical awareness of this. One teacher, for instance, asked students to use AI to fabricate news articles and then challenged them to distinguish them from authentic news articles.

4.2 *How the teachers seek to develop their students' AI literacy*

4.2.1 *Developing a critical understanding of visual outputs*

The teachers were concerned with helping students develop a critical understanding of visual outputs, and to distinguish between what is authentic or not, as described above. Informant 1 described spending considerable time with the students reflecting on 'how they are getting tricked'.

4.2.2 *Authorships and transparent use of AI*

Generative AI actualises a discussion on authorship. Our informants required a transparent use of AI, asking that the students could describe how AI has been used in the process and which elements are generated and which is their own work.

4.2.3 *Mastering generative AI and developing skills in prompt engineering*

Some of the teachers described teaching students how to master the AI technology, emphasising how the quality of the output is dependent on a clear vision and description, as well as the ability to generate multiple images and evaluate which ones to develop further. Some teachers guided students in using subject-specific terminology and collaboratively developing and assessing their prompts. Taking a different approach, one teacher used the AI-generator Leonardo to upload images and see which prompt could be used to produce a similar result.

4.2.4 *Devaluing AI literacy, emphasising visual literacy*

Other informants placed less emphasis on AI literacy, with Informant 3 asking, 'is AI literacy really necessary?'. Rather than teaching prompt-engineering, one teacher instructed the students to use Chat GPT to generate prompts. These teachers instead prioritised the development of visual literacy.

4.3 *How the teachers value the use of generative AI in teaching*

4.3.1 *Preparing the students for a future with AI*

The teachers regarded the use of generative AI in education as essential for preparing students for the future and preventing them from lagging behind. Informant 3 described his first understanding of text-to-image technology as ‘revolutionary in the field’. The media teachers stated that they expect generative AI to be used increasingly in the industry, which requires them to use the technology in education.

4.3.2 *Improving the creative process and outcome*

Several informants described how text-to-image technology enhanced students’ creative outcomes. Generating their own images for ideation or moodboards can increase sense of ownership and improve the communication of design ideas. The teachers also stated that generative AI can enable new artistic expressions and creating “impossible” images.

4.3.3 *Making the creative process more efficient*

Some teachers also emphasised how AI technology is far more efficient than traditional techniques, allowing for ‘a whole sketching process in a few minutes’, as Informant 3 stated.

4.3.4 *Having fun experiencing the technology*

One informant also mentioned that the students enjoy using text-to-image technology and have fun with the experience, as an important value of using the technology.

4.4 *Challenges and hindrances to the use of generative AI*

4.4.1 *Limitations in available tools*

The text-to-image generators available to the teachers had limited functionality and poor quality, limiting the students’ actions and results. Their choice of AI-generators was restricted by economy and privacy regulations. All the teachers stated that without these limitations, they would use more advanced and more costly alternatives.

4.4.2 *Students' capabilities in using AI*

The informants described limitations in students’ prompting abilities and in their persistence when working toward a desired outcome. One teacher emphasised the importance of encouraging AI use primarily in the second or third year, expressing concern that first-year students should first develop foundational skills in image making and design before incorporating text-to-image generators into their creative processes

4.4.3 *Resistance from the students*

Among the informants, clear differences emerged between the educational programmes in which the students were enrolled and their views on the use of generative AI. Students in art and design programmes were strongly critical of its use on ethical and moral grounds, citing sustainability and copyright concerns as key motivations. These students expressed a preference for working more analogically. One teacher noted that the students seemed fatigued by screen-based work, having grown up with constant digital exposure both at home and in school. According to the informants, students in technology and media programmes were generally more positively inclined towards generative AI. However, even within these groups, several students preferred to maintain full control over all aspects of the creative process.

4.4.4 *Challenges in evaluating student work*

The teachers' assessment practices have been affected by the introduction of text-to-image generative AI. Some informants described clear instances of attempted misconduct, such as students presenting AI-generated material as their own photographs, as well as uncertainty among assessors regarding what constitutes acceptable and unacceptable use of text-to-image generation. There also appeared to be variation in experiences related to examinations and in perspectives on future priorities—whether greater emphasis should be placed on assessing the final product or the underlying creative process.

4.4.5 *Strict regulations from the school*

Three of the teachers work in schools where the county municipality has implemented strict regulations on which generative tools may be used, limiting access to a single language model that performs poorly and is not designed for image generation. One teacher described these restrictions as contradictory to the official curriculum and subject framework, which emphasise the importance of engaging with new technologies and developing technological understanding as part of the subject's learning outcomes.

4.4.6 *Lack of guidelines and information*

The teachers reported receiving limited information from their employer or public authorities and described spending significant personal time familiarising themselves with new technologies. One teacher called for clearer guidelines regarding their use.

4.4.7 *Lack of knowledge and understanding from peers and leadership*

The teachers agreed that school leadership lacks understanding and knowledge about the use of text-to-image generative AI within their subject areas and professional fields. As stated in the word of one informant:

So it becomes a kind of general talk where everything related to AI is basically a no. [...] there is an understanding that AI is just ChatGPT and that it basically has to do with text, so they don't know that it both exists within our software and that it is used for creative

processes—because I don’t think they themselves engage in very many creative processes. (Informant 2).

One teacher also emphasizes a lack of interest from colleagues.

5 DISCUSSION

Our informants primarily used text-to-image generators during the ideation phase and early stages of student projects. Previous studies have shown that such tools can positively influence idea variation and help avoiding design fixation (Chen et al., 2019; Hutson & Lang, 2023; Ko et al., 2023; Liu et al., 2023; Vartiainen & Tedre, 2023). Furthermore, the teachers in our study described generating raw materials to be edited and incorporated into final outcomes, which we have not found in previous studies.

The teachers were conscious to develop the students’ critical understanding of AI and how visual outputs in society is affected by it, much in line with what is described as AI literacy (Kong et al., 2024; Chiu, 2025; OECD, 2025). However, they were divided on whether students need to master the technology itself. Some considered prompt engineering a skill worth cultivating, echoing Oppenlaender et al. (2025), while others regarded visual literacy as sufficient. Taken together, the teachers’ perspectives suggest that visual literacy is viewed as a component of AI literacy—consistent with Chiu’s (2025) argument—particularly in relation to evaluating generated images.

The study also illustrates how teachers are balancing between demands to prepare the students for a future with AI, with hindrances in form of negative perceptions and limited access to functional technology. The teachers experience either overly restrictive or entirely absent guidelines, both attributed to an unfamiliarity with generative technology within art, design, and media contexts. Some also encountered student resistance to using the tools. Similar ambivalence has been reported in previous studies (Heaton et al., 2024; Vartiainen & Tedre, 2023; Vartiainen et al., 2023).

Recognising the importance of the emerging technology, the teachers are caught between several conflicting considerations in their efforts to prepare students accordingly. If schools and teachers are to be able to prepare students for contemporary and future working life and fulfil the requirements of the curriculum, they must have access to functional tools and up-to-date knowledge. It is the responsibility of schools and public authorities to facilitate this.

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Reframing Engineering Literacy: A Comparative Synthesis of International Competence Frameworks

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Abstract

Based on a systematic literature review of international competence frameworks that aim to integrate engineering-related practices into general school education in STE(A)M contexts, this paper examines how central ways of working and thinking in engineering can be located and operationalised within school-based technology education. Using a comparative synthesis, the analysis identifies recurring dimensions across a heterogeneous body of models and classifies the identified approaches into three overarching framework types: (1) *design- and problem-solving-oriented frameworks*, (2) *competency-oriented frameworks*, and (3) *curricular or domain-specific frameworks*. Across these types, a patterned asymmetry becomes visible: procedural elements (engineering design cycles) and cognitive elements (engineering habits of mind) are typically described in teachable terms, whereas the normative dimension (explicit evaluation and responsibility in relation to societal, ecological, and economic consequences) remains underdeveloped and is often treated merely as contextual “constraints”. Rather than proposing yet another national model, the paper develops a synthesis that consolidates distinctive features of existing approaches, discusses their compatibility with the Common Reference Framework for Technology (GeRRT), and argues for a hybrid perspective that links iterative process structures with transferable habits of mind while making normative evaluation an explicit educational outcome.

Key Words: Engineering Literacy, Competence Frameworks, STEAM Education.

1 INTRODUCTION

Beyond being just a professional field, engineering is establishing itself as an important approach of modern education; and while it is taking root at varying speeds across the globe, many nations are already leading the way in integrating it into their curricula (e.g., Lai & Cheng, 2023; Purzer et al., 2021). Within the context of STE(A)M, there is a growing emphasis that learners should not only understand scientific concepts or mathematical models but also become familiar with the specific ways of thinking and approaching problems, or: “prototypical engineering practices”, used to design, test, improve, and integrate technical solutions into societal contexts. Under terms such as *engineering literacy* or *engineering practices*, a perspective emerges that views

technology education not merely as the transmission of knowledge about artefacts and the use of tools, but as a learning space for tackling complex problems, balancing competing requirements, and developing solutions in a structured manner (Srikoon et al., 2024; Wan & Lee, 2023).

At the same time, educational research reveals a certain lack of conceptual clarity. While international competency frameworks and models exist (e.g., Purzer et al., 2021; Srikoon et al., 2024), their terminologies, priorities, and underlying dimensions vary considerably. Some studies place *User-Centred Design* at the forefront, while others focus on the iterative *Design-Build-Test* cycle. Still others view *Engineering Thinking* as the essential hallmark of engineering theory and practice that needs to be translated into the school environment. Furthermore, problem-oriented pedagogical approaches, such as *Problem-Based Learning*, are frequently used as a bridge to make engineering practices accessible within school settings (Halawa et al., 2024). This diversity is productive yet complicates the question of how central dimensions of engineering can be systematically located and designed within technology education, especially when ensuring compatibility with German-speaking reference frameworks.

Against this background, the present article pursues a clear objective: based on a systematic literature review (SLR) of international framework models, it investigates which recurring dimensions of prototypical engineering ways thinking and approaches are described in key studies. It examines how these dimensions relate to one another and identifies unique approaches that may not be found across all models. Specifically, we distinguish between three levels:

- (i) *procedural* (Engineering Design),
- (ii) *cognitive* (Habits of Mind),
- (iii) *and normative* (Evaluation and Responsibility).

The goal is not to draft another isolated national model, but to propose a comparative synthesis that international approaches, highlights distinct characteristics, and assesses their transferability to German-speaking educational contexts. In doing so, we demonstrate how engineering practices already present in technology education can be systematized and structured for adaptation across various curricular contexts. Ultimately, this contribution serves as an impetus to firmly ground *Engineering Literacy* in curricular and conceptual debates and to support the further development of technology education in coherent alignment with international discourse.

2 METHODOLOGY

This study employed a systematic literature review based on the methodology of Nordhausen and Hirt (2022). To maximize the retrieval of relevant literature, the investigation followed a sensitive search strategy. The operationalization of the research question involved thematic clustering instead of traditional schemas like PICO or SPIDER. Methodological and pragmatic considerations led to the selection of three key databases: EBSCO, SCOPUS and Web of Science. After identifying the necessary terms and descriptors, the research team constructed and piloted

an initial search string. While the primary search was executed during the summer of 2025, the data collection includes all records identified up to the cut-off date of April 15, 2025.

The search terms were organized into four thematic clusters to refine the focus of the results while accounting for terminological variations within the international discourse. In each cluster, synonyms and related terms (e.g., “competency framework” vs. “educational standards”) were linked using the “OR” operator to capture diverse nomenclature. Subsequently, these clusters were combined using the “AND” operator. This ensured that the final selection only included publications that simultaneously addressed a school-based target group, provided a framework-like description of competencies, related to engineering or technology education, and maintained a specific focus on competency or literacy. Table 1 provides a summary of the thematic clusters and search strings.

Table 1

Search terms and thematic clustering

Thematic Cluster	Search Terms	Explanation
Target Group	("K-12" OR "school students" OR "students" OR "learners" OR "pre-college" OR "primary education" OR "secondary education" OR "elementary school" OR "high school")	Definition of the educational level and delimitation of the search to the school sector (K-12 or primary/secondary level and equivalent terms); exclusion of higher education or vocational training
Content	("competency framework" OR "competence framework" OR "skills framework" OR "competency model" OR "framework of competencies" OR "educational standards" OR "learning outcomes" OR "curriculum framework")	Types of text or artifacts being searched for
Framework / Context	("engineering" OR "engineering education" OR "engineering skills" OR "technical education" OR "STEM" OR "technology education" OR "design-based learning" OR "maker education")	Definition of the subject area and related pedagogical approaches
Context / Domain	("competence" OR "competency" OR "skills" OR "literacy" OR "capabilities" OR "problem-solving" OR "design thinking" OR "21st century skills")	Specification focusing on contributions to competence, ability, or literacy concepts

A total of 2,132 articles were identified across the Web of Science, EBSCO and Scopus databases. The records, including their abstracts, were subsequently uploaded to Rayyan, a web-based application designed for conducting systematic literature reviews. Following the removal of 496

duplicates and 23 non-English or non-German records, an additional 1,524 datasets were excluded after title and abstract screening. This cleaning process resulted in 89 records remaining for full-text analysis. To ensure the reliability and credibility of the selection, the full-text screening was conducted using a double-blind procedure (Covidence, 2024). The inclusion and exclusion criteria were aligned with the research question and the previously developed thematic clusters. Both the double-blind approach and the specific criteria served to maintain methodological rigor and ensure a transparent documentation of the selection process (Covidence, 2024; Higgins et al., 2024).

The final corpus of selected frameworks served as the basis for the comparative synthesis. For the analysis, we used the paper's conceptual distinction between procedural (Engineering Design), cognitive (Habits of Mind), and normative (Evaluation and Responsibility) dimensions as a cross-cutting analytical lens. For each framework, we examined (a) whether and how design processes are operationalized as learnable classroom practices (procedural), (b) which transferable ways of thinking are foregrounded (cognitive), and (c) whether evaluative judgement and responsibility are articulated as explicit competencies with concrete decision criteria (normative), rather than being mentioned only as contextual "constraints". This dimension-based reading allowed us to align diverse terminologies and structures and, importantly, to identify not only what is present across frameworks but also what tends to remain implicit or underdeveloped.

3 RESULTS

Following the full-text screening, data extraction was conducted using a standardized protocol. Of the 89 records assessed, 61 were excluded because they did not meet the inclusion criteria. Studies were excluded when they did not present a framework, when they addressed non-school educational settings, or when they were situated in subject domains other than technology education (e.g., biology education). The review specifically focused on approaches that seek to integrate engineering competencies into technology education through framework-based approaches. In addition, a considerable number of records proved difficult to classify during the initial screening because they addressed school engineering but specified content or activities, not competencies. This highlights an underlying challenge in the literature, namely the lack of consistent terminology and clear distinctions between competence-oriented frameworks and other types of educational frameworks. For the remaining 28 cases in which initial disagreement occurred between the researchers, a structured consensus procedure was employed, involving re-analysis and joint alignment with the exclusion criteria. Ultimately, 7 articles met all inclusion criteria and were selected for final analysis. The core data extracted included bibliographic information (author, year, title), the thematic domains, and central research findings.

Based on this, the engineering-related frameworks identified in the literature are categorized by their thematic domains within the context of general technology education. These domains are systematically detailed in Table 2 (here exemplified by the Purzer et al. Framework due to space constraints), which specifies the (1) author, (2) year of publication, (3) specific domains, and (4) a brief contextualization for the school setting.

Table 2

Identified domains, exemplified through the 'Honeycomb of Engineering' framework (Purzer et al., 2021)

Author	Pub	Domains	Explanation
Purzer et al.	2021	User-Centred Design	Students work with real or simulated users or contexts, identify their needs, and develop solutions that are guided by those needs.
		Design-Build-Test	Students are given clear criteria, generate different solutions, build prototypes, and test them to demonstrate functionality.
		Engineering Science	Students conduct controlled experiments, deliberately vary one variable, and thereby gain technical knowledge.
		Engineering Optimization	Students analyse existing systems, compare key criteria, and improve their performance using calculations or practical tests.
		Engineering Analysis	Students use data, models, or calculations to draw conclusions about technical systems without having to build a prototype.
		Reverse Engineering	Students examine an existing product, systematically take it apart, document its structure and how it works, and develop ideas for improvements or redesigns.

4 CONCLUSION

4.1 *Engineering as a Discipline vs. a Practice*

The present analysis reveals that the term “engineering” is too narrow to characterize general educational competencies in a school context, as it predominantly evokes associations with purely academic bodies of knowledge. As noted by the European Commission (2024):

"Technology and engineering are firmly grounded in applied knowledge, which often presents challenges in school settings due to its highly contextual and specific nature (Feenberg, 2002; Dasgupta, 1996; Pacey, 1999; Skolimowski, 1966). [...] Technology and engineering are often regarded as domains focused on preparing students for specific careers, thus making it a vocational subject at the collegiate level where its curriculum is tailored to meet the needs of particular occupational fields (Oaks, Leone & Gunn, 2001)."

A significant conceptual challenge lies in the translation of the term itself: While the English term 'engineering' seamlessly functions as both a noun for the discipline and a verb describing the prototypical ways of acting and thinking, the German equivalent 'Ingenieurwissenschaften' remains linguistically tied to its academic and theoretical roots ('science of engineering'). In German, there is no direct verbal equivalent that captures the dynamic, iterative process of 'doing engineering' in a classroom context.

Table 3

Conceptual Nuances of 'Engineering' in English and German Contexts

English Term	German Equivalent	Nuance / Limitation
Engineering (as a discipline)	Ingenieurwissenschaften	Very academic, implies higher education
Engineering (as an activity)	No direct equivalent	Often translated as "Technisches Gestalten" or "Konstruieren," but these lack the professional "engineering" scope
Engineering thinking Habits of mind	Ingenieurwissenschaftliche Denkweise(n)	Accurate, but lacks the "hands-on" active component of the verb
"doing" Engineering	Ingenieurmäßiges Handeln	The closest pedagogical term, emphasizing the way things are done

This conceptual ambiguity is reflected in the empirical findings of Moriyama et al., who encountered similar difficulties in reaching a consensus on the term 'Engineering' within their framework:

"However, the concept of the term 'Engineering (2.78) had a mean value of less than 3.00 and a larger SD than the others. Therefore, in the last version the concept of the term 'Engineering' was revised, and the framework was completed." (Moriyama et al. 2024)

To align with the pedagogical objectives of general technology education, and in accordance with the frameworks identified, the term '*engineering-typical*' (*ingenieurtypisch*) is preferred hereafter. This deliberate shift in terminology marks a crucial distinction: while 'engineering' primarily addresses the academic discipline and its theoretical foundations, 'engineering-typical' targets the specific methodological identity and the characteristic ways of thinking and acting inherent to engineering. The adjective 'typical' emphasizes transferable core practices (e.g., iteration, systems thinking, optimization under constraints) that serve as viable problem-solving strategies for non-engineers in a technologized world. Consequently, the transfer from specialized science to general schooling is understood not as a mere reduction of content, but as the extraction of a technological logic of action. This approach transcends mere curricular simplification. Instead, it represents a functional transposition: rather than diluting engineering science, it isolates

the discipline's core cognitive and procedural architecture. By focusing on this technological logic of action, students engage with authentic engineering challenges, such as navigating uncertainty and optimizing under constraints, at an appropriate level of complexity. Consequently, the integrity of the engineering mindset is preserved, shifting the pedagogical focus from static knowledge acquisition to iterative process proficiency.

4.2 *Categorization of identified Frameworks*

Although the seven frameworks vary considerably in their pedagogical entry points, they can be systematically compared by tracing how each model makes engineering-typical action teachable (procedural), how it frames transferable engineering thinking (cognitive), and how it connects design decisions to evaluative judgement and responsibility (normative). Using this lens, our results not only map common ground across models but also reveal a patterned asymmetry: normative aspects are frequently acknowledged in principle yet rarely operationalized as an independent competency dimension with explicit criteria.

The literature review demonstrates that while the international discourse encompasses a broad range of work on engineering education, only a small subset develops or systematically describes explicit frameworks for the school context (Lai & Cheng, 2023; Moriyama et al., 2023; Srikoorn et al., 2024; Wan & Lee, 2023; Halawa et al., 2024; Reynante et al., 2020; Purzer et al., 2021). The identified contributions can be classified into three overarching categories:

- (i) Design- and problem-solving-oriented frameworks
- (ii) Competency-oriented frameworks
- (iii) Curricular or domain-specific frameworks

The works of Lai & Cheng (2023), Wan & Lee (2023), Reynante et al. (2020) and Purzer et al. (2021) fall into the first category. These frameworks typically describe phases such as *problem definition*, *idea generation*, *modelling*, *construction*, *prototyping*, *testing*, *reflection* and *optimization*. They define general technology education as empowering learners to tackle open-ended, authentic problems through *engineering-typical* procedures. Characteristically, they emphasize iterative processes, work with prototypes, and the integration of scientific knowledge into technical solution strategies.

Articles by Srikoorn et al. (2024) and Halawa et al. (2024) focus on engineering habits of mind rather than concrete iterative steps. This includes systems thinking, linking cognitive models, a scientific understanding of technology and developing the capacity to participate in technological innovation and societal solutions. Here, general technology education is understood as building a cluster of subject-specific, methodological, social and reflexive competencies that enable learners to understand, evaluate, and actively shape technical phenomena.

Moriyama et al. (2023) fall into the third category. Their NGTE ("New Framework of Technology and Engineering Education") is explicitly developed as a curriculum-standard-like reference for

Japan's upcoming national curriculum revision. In contrast to generic process or competency models, the paper anchors its framework in the concrete national subject structure of Japanese secondary education while also being designed as a bridge for transdisciplinary STEAM learning across subjects. Regardless of whether these frameworks are process-oriented or competency-centred, they share the goal of making *engineering-typical* patterns tangible for learners. They transform highly contextualized engineering knowledge into structured learning pathways.

4.3 *Identifying the Normative Gap*

Despite this diversity, the analysis reveals a significant gap: while the procedural dimension (*Engineering Design*) and the cognitive dimension (*Habits of Mind*) are well-developed, the normative dimension (the explicit link to *Evaluation and Responsibility*) remains underexposed. Although the theoretical definition of the engineer as a "cultural profession" places ethical responsibility at its centre, the analysed frameworks often neglect this in favour of technocratic processes. For true 'Engineering Literacy' aimed at societal participation, closing this gap is essential.

Engineering-typical actions are often portrayed as methodologically neutral. The fact that every technical solution is embedded in a complex web of social, ecological, and economic interactions is occasionally mentioned as a 'constraint' but is rarely operationalized as an independent, critical competency area for general education. Without this, frameworks risk promoting a functionalist understanding of technology where functionality eclipses appropriateness and consequences.

Across all three categories of frameworks, a consistent pattern emerges when reading the models through the procedural–cognitive–normative lens: while procedural components (e.g., iterative design cycles) and cognitive components (e.g., systems thinking and other habits of mind) are described in comparatively rich and teachable terms, the normative dimension—i.e., the explicit linkage between design decisions, evaluation, and responsibility—remains underexposed. Even when frameworks acknowledge that engineering solutions are embedded in social, ecological, and economic contexts, such considerations are most often framed as external constraints on an otherwise methodologically “neutral” process rather than as a core educational outcome that requires explicit criteria, deliberation, and justification.

This imbalance matters for the very goal many frameworks claim to serve: enabling learners to participate in and shape a technologized world. If evaluation is reduced to functionality and efficiency, learners are left with a functionalist view in which “what works” risks overshadowing “what is appropriate” and “at what cost”. Therefore, the normative dimension should be treated not as an optional add-on but as a constitutive component of engineering literacy in school contexts.

The identified normative gap is not an isolated weakness of individual models but a systematic outcome of approaches that privilege either process descriptions or mindset taxonomies without explicitly anchoring evaluative responsibility as a teachable practice. This motivates the

following proposal of a hybrid approach that links procedural structure and cognitive transfer while making normative evaluation visible within engineering-typical action.

4.4 *The Necessity of a Hybrid Approach*

The analysis clarifies that focusing on a single category is insufficient for general technology education. Instead, we suggest a hybrid approach that inseparably links the process-oriented logic of *Engineering Design* (the *how* of making) with the competency-oriented development of *Habits of Mind* (the *how* of thinking). This hybridization resolves the challenges posed by the "highly contextual nature" of technical knowledge (European Commission, 2024, p. 9). While pure engineering science remains tied to specialized contexts, the combination of iterative processes and transferable mindsets provides a pedagogical scaffolding manageable in everyday school life:

- *Process orientation* establishes the necessary structure for the classroom, providing a "common thread" that guides learners through complex projects
- *Competency orientation* ensures long-term transfer value, transforming specialized technical knowledge into versatile strategies for real-world problem-solving
- *Action-oriented integration* serves as the vital link between *process* and *competency*: it is through the rigorous application of the iterative process that students internalize the transferable mindsets necessary to actively navigate and shape their environment

An *engineering-typical* pedagogy based on this hybrid model presents technology not as a static canon of knowledge, but as a dynamic, methodologically guided form of world-shaping. Thus, school does not serve as a mere precursor to university but as a place where students learn to master the complexity of a technologized world through systemic thinking and iterative problem-solving strategies.

4.5 *What lessons can Germany draw from this?*

While the Common Reference Framework for Technology (GeRRT)¹ outlines a clear vision for "technological literacy", ranging from elementary use (Level A) to complex development (Level C), the reality of schooling in Germany presents a more nuanced picture: In federal states such as Lower Saxony, technology education is firmly anchored in the core curriculum (KC), yet it often

¹ The Common Reference Framework for Technology (GeRRT) is a German reference framework developed in the VDI (Verein Deutscher Ingenieure) context to describe and differentiate technological competencies across educational settings. Structured into three levels (A: elementary, B: extended, C: complex) and five domains – understanding, using, developing, evaluating, and communicating technology – it provides a conceptual framework for discussing technological literacy. In this article, we use GeRRT as an analytical reference point because it offers a systematic language for examining the extent to which school-based technology education addresses not only the safe use of technology, but also processes of technological development.

aligns with traditional competency areas: *subject knowledge, inquiry/acquisition of knowledge, and evaluation/assessment* (Gerste et al., 2021; N-KM, 2010). For example, there is a heavy emphasis on "safe operation" of machinery and the correct use of tools. While this is essential for safety and provides a solid vocational foundation, it falls short of true engineering. What is frequently missing in German classrooms is the iterative process, a defining element of engineering often portrayed in the cycle of *design-build-test-redesign*, exemplifying the discipline's approach to problem-solving. In current everyday schooling, the focus is often on achieving a "perfect" final product, rather than embracing failure as a necessary step for gaining insight within the development process.

In comparison to the identified approaches, POD (*Process of Design*), which organizes learning in a much more granular and process-oriented manner, is a more dedicated path that incorporates a *positive failure culture*. Internationally, "failure" is often more actively integrated into the learning process. There, the iterative cycle is not merely a side note but the pedagogical backbone. The same can be said about *Engineering Thinking*: While technology education in Germany often resembles traditional "shop class" under a modern guise, other countries are more consistent in translating engineering mindsets, such as systems thinking and problem solving, into the classroom. However, true procedural competence (engineering-based action), which requires high error tolerance and constant iteration, often remains reserved for university education, a gap that must be closed to provide a comprehensive general education.

5 DISCLOSURE

The authors utilized ChatGPT and Google Gemini to assist in translating the manuscript from German to English and to refine the linguistic flow. AI tools were not employed for data analysis, the generation of original research content, or the formulation of the core scientific arguments. All AI-generated suggestions were critically evaluated for accuracy and edited by the authors to ensure the integrity of the scientific argument.

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The Problem Space: A Tool for Teaching and Learning Programming

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Abstract

Studies show that novice programmer use a range of self-made strategies when problem solving. They step through code, insert print statements, and test incrementally. Yet their debugging skills are often unsystematic. This is partly due to cognitive overload and reliance on habitual practices. Teachers also struggle to interpret students' questions when prior actions remain hidden in what has been written in the code. Consequently, teachers require a didactical tool that support the reconstruction and interpretation of what made the students' question important in the first place. In the paper, we draw from *pragmatism* and a student case where novice programmers are solving syntactical, contextual and semantical problems simultaneously, to argue for a *problem space*. The concept serves as a didactic tool to support teaching and learning problem-solving in programming, as teacher and students become aware of the different problems, when the problematic situations translate into inquiries. The concept does so without disclosing the solutions to students' problems and opportunities to gain valuable insights.

Key Words: Programming, Teaching Instructions, Problem-Solving, Problematic Situations, Pragmatism

1 INTRODUCTION

In upper-secondary programming courses, teachers spend a great deal of time teaching the syntax of a programming language—that is, the language's formal rules—because syntax errors are the easiest to identify and correct. Today, with artificial intelligence (AI), that kind of instruction is redundant, since tasks can be solved with a chatbot (Jonsson & Tholander, 2022): it writes the code, interprets the code, and explains the code. There are also studies (Robins et al., 2003; Grover & Pea, 2013) showing that learners of programming must be offered a meaningful context in order to develop these skills, and therefore programming education needs to be carefully designed, since AI can generate code with little effort, while students have to thoroughly understand, and use the basic concepts in computer science (e.g., variable). The present paper addresses the intersection of AI in programming education and the didactical imperative for meaningful learning experiences in pragmatism, both of which are developed more fully in the subsequent subsections.

1.1 *A problem space for teaching and learning about problem-solving*

According to researchers (Murphy et al., 2008), it does not matter very much which debugging strategies one teaches in programming education, since students typically debug randomly regardless of the error and use different methods as they occur to them. They argue that this behavior stems from students' lack of ability to recognize when their cognitive capacity is overloaded. In addition, they tend to remain in established habits. Instead, the researchers suggest students should ask themselves reflective questions: "What else could I try?", "Is this too much to keep track of in my head?", and "What are other possible sources of the bug?". However, learning and teaching programming can be dynamic, especially as many of the programmer at upper-secondary are novices and not reasoning logically with computer science concepts, making it difficult for teachers to discern how far students have progressed from a problematic situation toward an understanding of how to tackle the problem. Additionally, we find these reflective questions challenging to formulate as a novice, when occupied with multiple problems.

In the following, we propose a didactic tool, *problem space* as a shared reference of understanding, to unpack problematic situations while depicting the complexity of how one or many problems are co-existent in problem-solving. The notion of a *problem space* was established by Middleton (2002), where a chess player moves from an initial configuration (the problem state), explores a solution space or search space containing multiple possible continuations, and ultimately reaches a resolution (the goal state). As Middleton notes, a problem space may permit numerous moves, yet only a subset of these will be about problem-solving. Over time, progress is achieved by selecting the most appropriate move within the search space; importantly, what counts as the "best" move is not value-neutral but shaped by contextual norms and priorities. In the paper, we expand on Middleton's problem space making it suitable for the teaching of novice programmers when learning about problem-solving.

1.2 *The theoretical and analytical framework*

The language and discourse about problems when programming is deeply embedded in teachers' and students' actions when problem-solving, often framed as inevitable or beneficial — and it is precisely this naturalization of concepts that Wittgenstein addresses in his later work (1953). Therefore, in the following we *deconstruct* and *reconstruct* what is naturalized in students' problem-solving processes, and made to appear among us all as inevitable or universal. However, problems are in fact contingent and particular in many ways, and we would like to pinpoint that with a problem space.

In fact, Wittgenstein argued that words in a language game do not need to be clearly defined to be meaningful (Jago, 2007), a statement that is crucial when coding and discovering the logical solution when programming. According to Pinto (2024), the later Wittgenstein conceived language based on its different uses, in a language game, abandoning the essence of language and the limits imposed by the logical world. Instead, he suggested an account of otherness (Zarębski, 2023) shifting perspective from finding the one right answer to understanding the differences behind how students arrive at various conclusions. In the paper reconstruction is an act of

expanding our understanding problem-solving processes, creating space for non-expected language games, recognizing that the person who speaks differently is not speaking *wrongly*, but playing a different game, one with its own internal coherence and dignity. After all, many of Wittgenstein's examples are from his teaching experiences and he pursued that logical thinking is not always about words and symbols (Maruyama, 2000; Stickney, 2017). In the following we draw from these principles and ideas of otherness and language game, to unfold the very process of learning when programming.

For the deconstruction, we deploy an analytical framework (Östman et al., 2019) to move beyond our prior assumptions and interpretations of students' learning when programming. It is a framework that goes into detail when students deepen their understanding of the problems with multiple possible paths to move forward. Researchers (Östman & Wickman, 2014; Östman & Öhman, 2022) argue that students have an opportunity either to deepen old habits or to acquire new habits as a result of the experiences they gain when they choose to engage with in the problematic situation and initiate an inquiry. In this text, we use this analytical framework to unravel students' actions when *encountering*, *standing fast*, *creating gap*, and *relations*. Four actions that describe, in detail, what students draw on in their immediate surroundings, as they work through and make sense of what is actually at the core of their communication. The first action (*encountering*) concerns the meeting with something new or unexpected; the second (*standing fast*) concerns prior knowledge; the third (*creating a gap*) concerns the uncertainty they display when they hesitate and ask questions to themselves and others; and the fourth (*creating relations*) concerns the meaning they create in relation to one another, the task description, the programming environment, the structure of the code, and what they already know about the code. In addition, students are encountering code instructions, the computer's error messages, and one another's utterances in an ongoing conversation, in order to create relations to what is happening, something that we consider to be transactional (Dewey & Bentley, 1949) by nature.

Central when analyzing the transcripts are Dewey's ideas about the learning that emerges when "the living creature undergoes, suffers, the consequences of its own behavior" (Dewey, 1920, p. 129) — precisely what happens when students are encountering a problematic situation, initiate an inquiry, and resolve the problems that arise in the inquiry process. The latter — resolving the problems — can be observed in whether students gain a valuable experience or insight: what Dewey describes as a consummatory experience (valuable insight).

2 METHODOLOGY

The paper is grounded in a relational and transactional perspective when learning. In this chapter we describe the specific task and the importance of students' environment, focusing on students' relationships with their immediate surroundings—such as the computer, keyboard, screen, and peers — and how a problematic situation can be analysed with the theoretical framework described above.

2.1 *The setting, the data collection and the analysis*

To support our research, we situated our study in a setting and a task that requires students to draw on their previous experiences of problem-solving. To carry out the data collection, we used a screen-recording tool to capture students' actions, including mouse movements, keystrokes, and the conversation between the students S1, S2 and computer (C). The two students are novice programmer, and we twisted the task somewhat to unravel how they decide to move forward when the context is not clear to them. The task given to them was as follows:

```
1 # Pelle has been given a few lines of code; he doesn't understand
  what the program is supposed to do.
2 # Can you explain the program to Pelle and then make sure it
  works as intended
3
4  user_input = input("Knorglf florpa slorf: ")
5  ADJUSTMENT = (9/5)
6  OFFSET = 32
7  result = ADJUSTMENT * user_input + OFFSET
8  print("Blorflengor ", user_input, "p å florf elg: ", result)
```

The code, in the task, will produce a common syntax error in line 7: a text string (`user_input`) is multiplied by a decimal number (`ADJUSTMENT`). Therefore, the setting is prepared with something that become problematic in different ways, among the students (See chapter 3).

In the following chapter, students' actions have been *deconstructed* as far as we consider necessary in order to *reconstruct* a narrative. In practice, this means that the author of the paper worked closely together with the upper-secondary teachers (acknowledged) in a strictly empirical manner to unravel the problematic situations in the transcripts, with many cycles, so that students' actions became visible and the narrative became trustworthy. Initially, we searched for the gaps and insights (See Chapter 1.2), when students used signs, actions (the mouse cursor to focus and communicate), the computer environment and error messages to revise the code. Later on, we searched for how the students conducted the language game. Some situations (next chapter) may initially appear unproblematic, but the analysis unravels how students' questions, hesitations and insights are analytical windows for us to study what is actually problematic, and how they decided to initiate inquiry. For that reason, you as a reader may need to examine the whole transcript before going into the details.

2.2 *Disclosure Statement*

Generative AI tools were employed solely for assistance with translation and phrasing

3 RESULTS AND ANALYSIS

In the following transcripts we explore how the problematic situations evolve and the two students (S1 and S2) initiate inquiry with two types of problems (syntax and context, Table 3.1 and 3.2), and end with a third type of problem, a semantic problemⁱ (Table 3.3).

Table 3.1

The students move into two types of problems (syntax and context)

Line	Agent	Utterance	Action
121	S1	I still don't know what "knorg florpa slorf" is.	
122	S2	But it doesn't matter what it is.	gestures
123	S2	It's some kind of question.	
124	S1	They <i>are</i> asking.	
125	S2	They're asking for something.	
126	S1	They must... yeah	talk over each other
127	S2	We don't give a damn what they're asking.	gestures
127b	S1	—	laughs and leans back
128	S2	Ignore it.	
129	S2	With the answer they get, they're supposed to do something.	points at the screen
...	...	...	...
132	S2	What do they want to do?	
133	S2	Adjustment multiplied —	
133b	S1	—	moves closer to the screen
134	S2	User input times.	
135	S2	Plus offset.	
136	S1	What?	grins and looks down at the table
137	S2	I'm trying to put it into a context and see if it makes sense here, but...	rubs his eyes
138	S1	Noo—	

139	S2	Adjustment times user_input plus offset	reads line 7 silently; hands in hair
140	S2	Is user input supposed to be a number?	
141	S2	No, it's still a string.	
143	S1	A florf is in there too.	laughs; puts a hand to his forehead; mutters
144	S1	It's florf and slorf.	
145	S1	No, God—my brain.	
146	S1	I feel like I'm overthinking...	
147	S2	I think you're focusing on the wrong thing.	grins
148	S1	—	laughs
150	S1	I'm really confused	

Deconstruction: A gap emerges: S1 does not understand “...what Knorg florpa slorf is” (121). S2 tries to fill the gap with, “But it doesn’t matter what it is ... it’s some kind of question ... they’re asking for something” (122, 123, and 125). S1 notes that “they are asking” (124). S2 says, “We don’t give a damn what they’re asking. Ignore it” (127 and 128). S1 encounter S2’s statement with laughs as he leans back. S2 relates to the code as he continues: “With the answer they get, they’re supposed to do something” (129). Then S2 opens a new gap with another question: “What do they want to do?” (132). S1 leans forward (133) and listens as S2 reads aloud (132 to 135). S1 encounter S2 with a question as the gap is deepened: “What?” (136). S2 explains what he recently did: “I’m trying to put it into a context and see if it makes sense” (137), and we witness in real-time how they are using words and actions to bridge a gap. S2 then reads line 7 silently—“Adjustment times user input plus offset” (139)—and another gap is opened with a new question: “Is user input supposed to be a number?” (140). S2 immediately respond to his own question and fills the gap with, “No, it’s still a string” (141). At the same time, S1 works with the initial gap: “A florf is in there too ... I feel like I’m overthinking ... I’m really confused” (143, 146, and 150). S2 thinks S1 is “focusing on the wrong thing” (147), and we witness how they are aware of their differences.

Reconstruction: The students express uncertainty about “something” in a language game. S2 argues that they should “not give a damn what they’re asking” (127) because they know the code is supposed to “do something” (129) with the input. A problematic situation emerges, and the deconstructive analysis reveals that the students are, in fact, engaged with different problems. Their divergent orientations become particularly visible when S2 encounters difficulties with *user_input* (line 4 and 7), where two different data types are in play, while S1 tries to understand the meaning of “Knorg florpa slorf” on line 4, which contributes to the student’s confusion (136, 143, 146, and 150). They initiate the inquiry with different problems in mind.

Table 3.2*The context problem is solved*

Line	Agent	Utterance	Action
152	S1	But are they trying to ask, like, in some way, how—how much you want... how many of those adjustment-things you want to do?	
153	S2	How many adjustments you want to do?	
154	S1	That that's kind of what they're trying to ask for.	points at the screen
155	S1	So that you have...	takes the mouse and closes the terminal window
156	S1	—	execution for the 3rd time
156b	C	—	prints: "Knorglf knorpa slorf"
157	S1	Because you <i>will</i> get a result.	places the mouse cursor in the terminal window
158	S2	No...	
159	S1	But, hypothetically.	gestures broadly with both arms
160	S2	You <i>do</i> want a result.	emphasize "result", while taking the keyboard to type
161	S1	Exactly.	laughing
162	S1	But— so, yeah—	
163	S2	But if we type a number here now, it's still a string.	leans forward, Submits 6
164	S1	But it won't work.	Puts his hand to his forehead
165	C	—	computer displays an error message: "TypeError: Can't multiply sequence by non-int of type 'float'"
166	S1	Exactly! ... but—	

Deconstruction: S2 opens a gap as he hesitates: “how many of those adjustment-things do you want to do?” (153). In order to fill the gap, S1 points to line 4 and reply, “That’s kind of what they’re trying to ask for,” (154). S1 takes the mouse and keyboard to run the code (156). They encounter the computer’s prompt on the screen together: “Knorglf knorpa slorf.” The students have different views of the “result”: S1 says, “Because you *will* get a result ... hypothetically” (157 and 159) and S2 states with emphasis “No ... you *do* want a result” (158 and 160), something S1 agree with “Exactly” (161) while laughing. S2 moves closer to the screen submitting the number 6 (163). S1 puts his hand to his forehead. The computer (C) returns an error message (165), and S1 reply “Exactly!” (166).

Reconstruction: As the transaction is explicit, we can see how “result” is still not decided in the language game, but takes shape through the participants’ overlapping actions (including the computer) in the course of the inquiry. S2 submit a number, and S1 closes the transaction with his final “Exactly!” (166) — an expression suggesting that S1 gained a valuable insight (*consummatory experience*) because of the error message (165), and the word “hypothetically” (159) is used to move forward, and they finally agree on how the “result” could be used to communicate different things (the code outcome and result on line 7), in the inquiry.

Table 3.3

The syntax problem is solved and semantic problem emerges

Line	Agent	Utterance	Action
175	S1	The reason why it is there	adds a parenthesis on line 7 around user_input
176	S1	You want to multiply, with that, and then it must be an integer	adds an “int” before the parenthesis
177	S2	—	runs the program for the 4th time
178	S1	But then you also need something that says it has to be written in numbers, too.	hides face in both hands
179	S2	—	Submit 7
180	C	—	program runs; prints: “Blorfengor 7 p å florf elg: 44.6”
181	S2	I’m thinking that’s what “knorgl glorpa slorf” means.	points at the screen (the output) and laughs
182	S1	Mmm.	
183	S2	Okay, then we get [a] number.	

184	S1	Yes.	
185	S2	Blorfengor seven. p å florf elg, 44.6	gazes upward toward the ceiling and rolls his eyes

Deconstruction: S1 explains the reasons why he revises the code in line 7 (175 and 176), to `result = ADJUSTMENT * int(user_input) + OFFSET`. The code is a profound statement, in the inquiry, as they execute the code for the fourth time (177). S1 says, “But then you also need something that says it has to be written in numbers” (178). S2 submit the number 7 (179). The computer responds and they encounter “Blorfengor 7 p å florf elg: 44.6” (180) on the screen, and S2 expresses a feeling by laughing. S2 says, “Okay, then we get [a] number” (183), and S1 responds, “Yes” (184). The S2 gazes upward toward the ceiling while rolling his eyes (186).

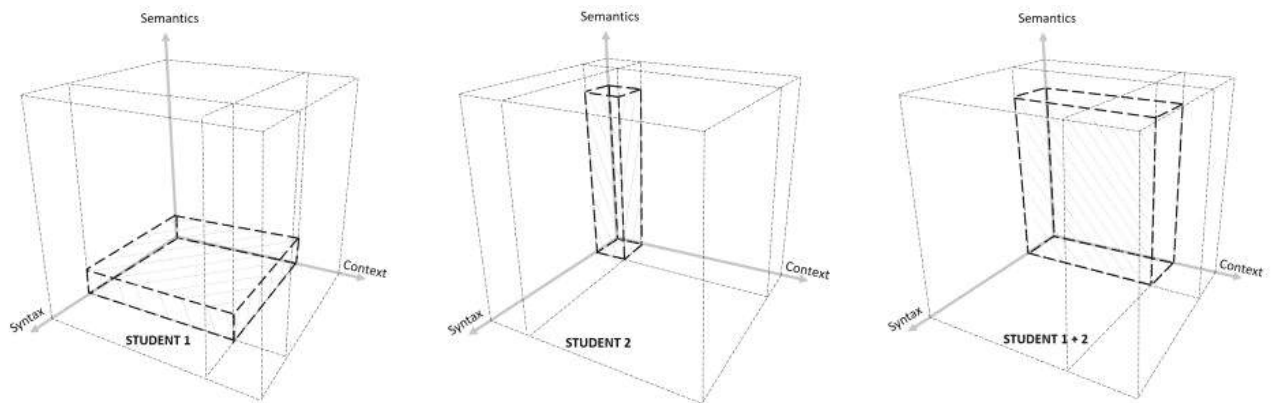
Reconstruction: S1 changes the data type from string to integer and executes the code. The previous error message is no more, and we understand a bit more of S1’s insight (see previous transcript) and the reasons for correcting the code. S2 does not comment on that change, and we can therefore infer that knowledge of different data types *stands fast* to them both. In other words, the students have done similar things (switching data types) before, in order to continue and move forward in the inquiry. However, the informational texts (on lines 4 and 8) are at foci while expressing “something that says [to the user] it has to be written in numbers” (178) and we can tell they are working within the dimension of semantics, to understand what the code actually imply for a user. S2 goes from laughter to eye-rolling in a couple of seconds, telling us he is frustrated.

3.1 Summary

In the three transcripts describe above, the students’ responded differently when problems appear, i.e., a syntax error planted in the code, did not imply a syntax- or context problem in any straightforward sense. This is described eloquently in the first transcript where one of the students (S1) experience a cognitive overloaded, and the other student (S2) want to move forward. This is because of different problem spaces (Figure 1a and 1b respectively). However, in the third and the last transcript, the students expanded, focusing on the semantic problem, and we can imagine how the syntactical problem is solved. In short, the two students enter into one or more problems simultaneously trying to solve the problematic situation. The two students worked in two dimensional spaces — initially syntax in relation to context (Figure 1a) and later semantics in relation to context (Figure 1c). In contrast with the rest of our data, we found no problematic situation in which students oriented exclusively to the semantics-syntax dimensions. One possible explanation for this absence is that students were typically able to easily detect syntactic errors, thus preventing the relevant situations from occurring in our data. Addressing such inquiries would most likely require students to engage in more complex structures.

Figure 1a, 1b and 1c

The problem spaces experienced by the two students.



4 DISCUSSION

There are computer scientists arguing that “coding is to programming what typing is to writing” (Lamport, 2015), meaning the code serves as a tool for thinking, and Hazzan et al. (2026) suggest alternative conceptions as a way for teaching problem-solving in programming, moving away from the discourse of misconceptions where one perspective is the standard and everything else is a “mistake”. However, our upper-secondary students are novice programmer, and there is a distinction between what computer scientists and novice programmer think, and what the computer interprets, a distinction that emerges as the code is malfunctioning, and we are interested in what novice programmers are actually thinking when problematic situations occur and transform into inquiries. This distinction proved significant in our data, where a considerable number of novice programmers continued their inquiry beyond the point at which the problematic situation had been resolved, indicating that the sense of what counted as a problem was not fixed in advance but was continuously negotiated in use. In short, we are interested in the students’ language game (presented by Wittgenstein) and how novice programmers are negotiating alternative courses of action (not alternative conceptions) to move forward, while teachers need to preserve students’ prerogative to remain in charge of their work. In short, a problematic situation is commonly a complex web of problems and with a better understanding of the existent problems among students, we as teachers can assist them better than AI. Besides many of our students, as novice programmers talk about “this” and “down there” etc., instead of using the names of the computer science structures involved.ⁱⁱ This is also a language game that most likely stems from poor experiences or missing opportunities of having a valuable insight. A contributing source of this lack of experiences may be located in teachers' lack of clarity concerning both the appropriate timing and approach to offer students the insights. In response, we propose the problem space designed to render visible students' original epistemic values in the thinking process, as a complementary concept to the prevailing emphasis on (mis)conceptions, strategies, and industrially inflected values — such as efficiency and logical reasoning — that characterize many programming practices today.

5 ACKNOWLEDGMENTS

This paper builds on a practice-based research project in collaboration with Jens Andreasson, Stefan Folkesson, Martin Lundqvist, and Gustav Wiberg, all of whom are teachers in programming at upper secondary schools.

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ⁱ Context refers to what the task is asking and how students understand it. Syntax refers to the rules and structure of the code that allow the computer to read and run it. Semantics refers to what the code actually *means* – what happens and why the computer executes it.

ⁱⁱ It is extremely hard for a student to recount a sequence of events, when the s/he is a novice, missing the conceptual understanding. Students' narratives easily become a reconstruction after the fact—based on the outcome rather than on the choices available when the problematic situation initially appeared.

Early Robotics: A Case Study of Technology Education in Pre-Primary Education

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Abstract

The Finnish National Core Curriculum for pre-primary education emphasizes fostering children's interest in science and technology, creative designing and making, problem-solving, exploration and experimentation with structures and materials, and reflection on the processes and products, with all competences approached in an integrated way. The study illustrates a learning process in which technology education and arts activities are integrated into the joint objective of exploring and interacting with the environment. During the learning process, children created a robot that was inspired by nature and artistic activities in an outdoor environment. The study was conducted with a pre-primary group in Western Finland in the spring of 2022. The group included 19 children, 12 boys and 7 girls, all aged 5-6. The primary data consists of children's outcomes – photographs of land art pieces serving as sketches for the robots, robot designs and ready-made robots– and the secondary data consists of children's written documents of their oral stories about the robots. The findings reveal that integrating technology education to artistic activities and outdoor learning inspired children to create detailed and individual robots as well as concentrate on designing and building their robots. The robot's implementation was motivating for the children and supported the learning of technological details. Furthermore, these findings suggest that careful pedagogical planning and multisensory experiences can support the implementation of diverse STEAM projects and deepen children's involvement.

Key Words: Technology Education, STEAM Education, Robotics, Pre-primary Education

1 INTRODUCTION

Technology significantly impacts children's lives, leading early childhood education curricula to increasingly emphasize technology education (Sundqvist & Nilsson, 2018). The aim of technology education is to help children understand the role of technology and spark interest through practical, hands-on experiences (EU, 2019; Turja et al., 2009). As its core, technology education centres on innovative solutions, and inquiry-based, experimental learning, rather than on the technical devices themselves (Kilbrink et al., 2014).

The Finnish National Core Curriculum for pre-primary education (FNPE, 2018) emphasizes fostering children's interest in science and technology, creative designing and making, problem-solving, exploration and experimentation with structures and materials, and reflection on the processes and products. Technology education is integrated into the joint objective of *exploring and interacting with my environment*, supporting children's development as thinkers and learners by building on their observations, experiences, and understanding of both natural and man-made surroundings (FNPE, 2018). A recent report from the Ministry of Education in Finland (Sintonen et al., 2025) emphasized the integration of digital content into children's life worlds. The report also showed that research-based development of technology education is critical for supporting the equal growth and education of Finnish children: there is significant variation in the quality of technology education across different groups of children, linked to teachers' professional skills and municipal resources.

Previous research (Ijanjek et al., 2021) shows that electric circuits are often introduced to students early in their school years and remain an important part of technology education through the university level. However, many students struggle to grasp simple electric circuits, especially voltage, making it essential to develop pedagogical approaches to technology that would suit young children's abilities and be grounded in familiar, child-friendly elements. Regarding children at the ages of 5–11, pedagogical solutions and studies on electricity are more limited and often concentrated on 1) children's ability to appropriate the idea of electric current, 2) to become aware of connections between light bulb and battery and of polarity, 3) to recognise what has to do with electricity and describe its operation and properties, and 4) to understand the relationship between battery and circuit. (Colletti et al., 2024) This article describes an educational intervention carried out in pre-primary education. During the intervention, children learned about eccentric motors and simple electric circuits by building their own insect-shaped robot. The aim is to describe how playfulness and child-centeredness, which are a part of early childhood education, can be integrated into technology education. Two research questions were set:

- (i) What kinds of robots did the children create during the long-lasting learning process?
- (ii) How did art-based education support the implementation of technology education?

2 HOLISTIC LEARNING IN FINNISH PRE-PRIMARY EDUCATION

The learning process presented in this paper follows the NaCra (Narratives and Crafts) approach, which emphasizes narratives and crafts alongside artistic approaches and transversal contents (Aerila & Rönkkö, 2023). In the intervention illustrated in this article, all activities were designed according to NaCra's cyclical structure, including phases of motivation, orientation, hands-on core assignments, and reflection. Motivation activates existing schemas, whereas orientation launches engaging activities, often sparked by imagination and a shared context. Like a picture book, environment or an interesting theme. Core tasks are art-mediated, and the aim of these artistic approaches is to make learning visible to oneself and others. Reflection typically takes the form of storytelling and discussion, strengthening child-centred and peer learning; oral storying suits this well because it aligns with children's natural ways of expressing their inner worlds. (Aerila et al., 2019; Aerila & Rönkkö, 2023; Rönkkö & Aerila, 2024). NaCra approach has been

tested and refined across multiple contexts and learning processes, primarily in pre-primary settings and within the tradition of design research (see Rönkkö & Aerila, 2024).

The theoretical foundation of NaCra is closely connected to the basic principles of the Finnish National Curriculum for Pre-primary Education (2018), which holds that children generally learn new knowledge and skills more effectively when learning content is connected to their everyday lives and experiences. They learn by playing, moving, exploring, working on various assignments, and expressing themselves through a range of activities (FNPE, 2018). Further, facing and solving problems align well with children's natural inclination towards imagination and creativity in finding their own solutions (Kiewra & Veselack, 2016). Children typically show keen interest in small-scale observations and investigations, especially of natural phenomena such as animals, plants, and water, while also displaying curiosity about everyday technological solutions (Kiviranta et al., 2023). These explorations often inspire them to create artefacts based on their experiences (Rönkkö et al., 2021). Playful exploration is an inherent part of children's activity, allowing them to naturally discover and make sense of the world and of themselves (Stylianidou et al., 2018). Such exploratory play is a central means by which children gather information about their surroundings and their own abilities (Bodrova & Leong, 2015).

3 METHODS

3.1 *Starting point for the study*

This study was carried out in a pre-primary group in a city in Western Finland during the spring of 2022, from late April to the end of May. The group included 19 children, 12 boys and 7 girls, all aged 5-6. A consent form and General Data Protection Regulation (GDPR) sheet were provided to the children and their guardians. Participants were given the opportunity to withdraw from the study at any time.

The intervention was executed jointly by the teacher, the two researchers, three student teachers (one specializing in early childhood education and two in craft, design, and technology education), and an assistant who regularly worked in the group. This assistant also helped the children with tool usage and ensured safety during outdoor activities.

3.2 *Intervention in pre-primary education*

The intervention was planned with the group's teacher, considering the children's interests, learning objectives, and the available learning environment. Following shared consultation, nature was selected as the theme for the intervention, and the nearby garden was designated as the learning environment alongside the traditional classroom. This way, the eccentric motor and circuit experiments were naturally combined with the insect-like robot. The eccentric motor was selected for the intervention to illustrate the circuit's function; the motor and its associated materials (battery, wires, and decorations) were low-cost and easy to obtain. The technology was also considered suitable for an insect-themed bristlebot, as a product built around an eccentric motor would move in an insect-like manner. The insect robot was also considered a good alternative due to its toy-like appeal. To make each child's designed character visible, we selected

plywood and engraved the figures into the material. The laser-engraving process was recorded and shown to the children, after which we discussed material processing.

It was also agreed that STEAM (Science, Technology, Engineering, Arts, and Mathematics) education would be a suitable pedagogical framework for implementing the intervention. Integrating STEM with artistic activities in a supportive environment has been shown to make learning more experiential, foster personal connections, and shift the learning experience from teacher-oriented to more child-centred (Peppler & Wohlwend, 2018). It is worth noting that some STEAM activities did not focus directly on technology but emphasized other content. However, activities such as planting and observing plant growth or creating nature-themed drawings, also supported engagement with the technology tasks. The activities included in the technology process are presented in detail below, and many of these exercises incorporate other STEAM elements alongside technological learning. Overall, the intervention consisted of eight activity sessions, in which art-based activities and learning in nature formed the framework for the technological content. (See Aerila & Rönkkö, 2023).

At the beginning of the technology process, the children were asked to design their own insect characters. To spark ideas, they first visited a nearby garden where they made multisensory observations of the environment. For example, they collaboratively constructed an artwork from natural materials and created soundscapes based on what they heard in the garden. The designing of each robot character began with creating an individual insect from natural materials in the garden. These artworks were photographed and later scaled down to fit the robot's motor. Before assembling the actual robot, the children familiarized themselves with electric circuits and eccentric motors in the classroom. The assembly started by making an electric circuit to the eccentric motor and attaching it to an insect figure, cut from the plywood. Children painted and decorated the robot using natural materials and other items such as beads. At the end of the intervention, the insect robots were taken back to the garden, where the children tested and played with them. Throughout the process, individual storytelling (Aerila et al., 2019) was used to support reflection on the different phases.

3.3 *Data and data analysis*

The dataset comprised photos of children's drawings, robots, stories, recordings of the learning sessions, and the researchers' field notes. We conducted a qualitative content analysis using a data-driven approach (Hsieh & Shannon, 2005). The study has ethnographic features, as the researchers were present throughout the process and took field notes and photographs. In addition, they helped guide the children's activities. Research Question 1 was examined by studying each child's work and paying particular attention to the children's robot stories and the information they contained. Research Question 2 was examined by analyzing the entire learning process from the perspective of the group's activities as a whole. In this analysis, special attention was paid to the details of technology education and to the significance of arts-based approaches in it.

GenAI was used as a support tool to check translations.

4 RESULTS

Insect robots became meaningful to the children

The insect robot project described in the study was successful from the perspective of an individual child. All the children were able to build their own robot, and they were happy with their robot toys. Further, all the robots had several individual features, and they reflected their ideas about insects and were clearly connected to the land art project carried out in the garden. When examining individual children's learning processes, it can be concluded that art-based and child-centred activities supported the learning of technological content, and technological content motivated children to work with commitment in art-based activities. The reciprocal relationship between technology and art-based activities was particularly evident during the garden visit at the end, where the children proudly presented their jumping insect robots and began to play with them. One popular game, for example, was to put the robots in wheelbarrows, where they rattled against the bottom and bumped into each other. The significance of technology in general and of robot manufacturing for children became apparent at various stages of the process, as the idea of a robot motivated them from the very beginning and was raised several times throughout. The children talked among themselves about robots and asked questions about their completion. The robot's movement seemed particularly significant. The meaningfulness of the intervention and the toylike robot were also apparent in the reflective stories, which described their empathy and positive feelings towards robots.

In general, the long learning process encouraged the children to focus and appreciate their own work. In figure 1, the children are testing their robots on various surfaces and the individual characteristics, such as the colouring, size, and various protrusions of the characters, are visible.

Figure 1

Testing bristlebots and how they move on different surfaces



Figure 2 presents one of the robots and the land artwork that inspired it. In the robot, the plywood is combined with found natural elements, such as leaves and a flower, and PLA which creates the legs for the bird. It is also apparent, how the child has implemented the character from the land

art when developing the robot's appearance and considering the materials do add details. In the reflective story, the child describes the robot as a bird that can drink juice, go shopping, and spin the Wheel of Fortune:

It's a bird. It's at a party and drinking juice. It's playing. It's watching TV. It's watching a Mickey Mouse movie. It's eating chips and drinking Coca-Cola. It goes to buy a cupcake and a hamburger. Then it spins the wheel of fortune. It gets the best number on the Wheel of Fortune, number one. He took a gooseberry cap and went to play with the birds because it was a bird party. Dogs and cats came to the party. He liked them and played with everyone. Then he bought cupcakes for everyone and they ate them.

Figure 2

One child's land art and a bristlebot decorated with a leaf as the beak, a flower as the tail and a plant part as the crest



Connecting the circuit to an eccentric motor and a toy-like robot proved effective, as the robot's insect-like movement gave children a concrete understanding of how both the circuit and the motor work. The robot's toy-like nature also kept them engaged even after construction was complete. Unlike the ready-made kits used by many groups, this project allowed children to create individual toys to take home, deepening their learning and helping them remember what they had learned.

Art-based and child-centred learning process as part of technology education

Below, we present observations regarding the pedagogical process tested in the study and outline some pedagogical decisions made during its implementation. From the perspective of technology education, some activities focused directly on building a robot with an eccentric motor and an electrical circuit, while others supported children's engagement and aligned with broader pre-primary learning objectives. This holistic and long-term approach was considered important for sustaining motivation. It is also worth noting that most activities in the technology process, such as designing a robot, function as independent activities with their own learning goals. For

example, creating an insect figure from natural materials was an independent land art task that enabled children to explore natural materials in a multisensory way and express their creativity. Similarly, scaling down the land art figure to fit the eccentric motor incorporated mathematical learning objectives.

During the process, we recognized the importance of concretizing and clearly presenting technological details, given the learners' age and natural learning styles. For example, we designed a dramatized, collaborative play to demonstrate how an electric circuit works and to identify conductive materials. In this circuit play, each child took turns embodying a component of the circuit, and the circuit's operation was illustrated through movement. These multisensory learning methods appeared well-suited to teaching technology to young children, helping them remember concepts through physical movements and enabling learning to continue in their own play.

The study also indicates that playfulness might have reduced children's prejudices and fears about learning technology, as new, slightly abstract phenomena can sometimes elicit such reactions. Safety is a key factor in technology education for young children, and the challenge is greater when groups include many children. For example, the attachments of the motor and foot to the plywood were implemented by a low-temperature hot glue. However, because some children were wary of it, double-sided tape might have made this step easier. Further, laser cutting a plywood figure proved too demanding for the whole group to handle. Therefore, we decided that the teacher would perform the laser cutting and record the process for the children. Although video can generally be an abstract teaching method for young learners, seeing their own designs being created on screen motivated them. Moreover, even though the teacher completed this stage, the children were still able to explore how the device operates.

At many stages of the intervention, children's individual developmental levels required special attention. This means that in technology education, individualized approaches and teacher-provided support are essential. In this study, most children needed assistance with soldering, and teacher guidance was critical to ensure safe working practices. Even so, the diverse, hands-on activities supported the understanding of key concepts. It is safe to say, that during the intervention the children took their first steps toward programming thinking as procedures were explained and observed together. Some of the challenges described above were related to the motor development of the children. At this age, children are typically developing fine motor control and increasingly able to perform tasks that require a refined grasp and precise hand-eye coordination.

5 DISCUSSION

Throughout the learning process, the children reflected together on their observations and possible solutions. They developed several key competences, especially practical skills and the responsible and safe use of tools. They invented and built robots, which encouraged them to share their ideas. Furthermore, children were enthusiastic about inquiry into everyday technological phenomena and problems. The learning process culminated in constructing their own devices, bristlebots, during which children were encouraged to develop their own ideas, which strengthened their

understanding of technological systems as they investigated the operating principles of the circuit. Blending STEAM education with outdoor learning inspired children to design detailed, individual bristlebots and to remain focused on their creation.

In this study, NaCra approach was applied within an integrative STEAM learning process for 5- to 6-year-old pre-primary children. The results showed that the NaCra approach fitted well with STEAM-based learning and enhanced children's engagement, creativity, and sense of inclusion. Overall, the integrative STEAM–NaCra process fostered meaningful learning, social interaction, and positive learning experiences for all children involved. The cyclical structure of the learning process, varied activities, and strong emphasis on arts-based methods helped children emotionally connect with the learning process and express their ideas in personal ways. Children carried out all learning tasks successfully, often connecting the work to their own interests, experiences, and imagination. The combination of classroom, outdoor, and STORIED environments enriched learning and encouraged participation among diverse learners. The study also found that the continuity across cycles via child-centred activities provided motivation and supported deeper understanding. (See e.g., Aerila & Rönkkö, 2023; Rönkkö & Aerila 2023).

This study aligns with the findings of Kiviranta et al. (2025), who argue that supporting children's active participation and planning skills throughout the learning process, situating technology-related learning goals in familiar contexts and adapting content to children's age and skill levels all help to strengthen the implementation of technology education. In this study, the theme of nature and an insect-shaped bristlebot was inspiring, but children do not necessarily expect a robot to resemble any familiar character. They can be just as receptive to other types of robots, but we wanted to emphasize the children's own creating process, which brings together materials and possibilities, the maker's skills and knowledge and the ability to invent. In this kind of learning, the goal was not to invent a completely new solution but rather to practice imaginative thinking and build confidence in problem-solving. In addition, we highlighted the robots' lives through storytelling. By inviting children to narrate who the robot was, what it could do, what it likes and where it might go, the robots became characters rather than mere technical objects (Aerila et al., 2019). The robot began to “come alive” in the children's imagination, strengthening their attachment to the project.

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Structured Making in Technology Education: Conceptual Foundations and Initial Insights from a Maker Task

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Abstract

Structured making is proposed as a pedagogical approach in which making activities are deliberately designed rather than assumed to be educationally effective. Prior discussions within Maker Education often attribute learning outcomes to creative activity itself, while empirical evidence on the actual learning processes involved remains limited (Wiemer & Rothe 2024). Similarly, existing competence models and frameworks associated with the Maker Movement provide descriptive structures but offer only tentative indications of their relevance for technology education, as systematic evaluations are still lacking. In response, a maker task was developed to operationalise structured making through five core principles: iteration, materiality, structured openness, technical functionality and reflection. The task is intended to create learning situations in which learners engage with open problem spaces, encounter material constraints and articulate reasons for technical decisions

Initial empirical insights are based on learning journals produced by prospective technology teachers. The journals document decision-making processes, perceived challenges and developing lines of reasoning during the task. The analysis suggests several preliminary tendencies: iterative redesign cycles are experienced as demanding but potentially conducive to deeper engagement; material behaviour is frequently identified as a catalyst for problem analysis; structured openness leads to varied solution pathways but also to uncertainty regarding appropriate justification; and reflective entries indicate emerging attempts to relate technical, aesthetic and occasionally ecological considerations. These tendencies should be interpreted cautiously, as they do not yet provide evidence of task effectiveness, but they highlight aspects of the learning process that merit further examination.

The contribution outlines the conceptual grounding of structured making and presents exploratory empirical findings from the maker task. The aim is not to validate the approach, but to identify promising directions and open questions for future research.

Key Words: Structured Making, Maker Task, Learning Process, Technology Education

1 INTRODUCTION

In recent years, making and maker spaces have increasingly been integrated into technical education at schools and universities. In particular, in the training of prospective technology teachers, maker spaces are being explored as environments that foster action-oriented approaches to technical content and enable new forms of design (Wiemer & Degen, 2025). At the same time, a discourse has emerged that highlights the congruence between making and the aims of technology education and emphasises its potential benefits (Wiemer & Rothe, 2024).

However, critical perspectives point out that the educational assumptions underlying making often remain implicit. Rothe et al (2025) shows that although numerous competence models and frameworks in maker education provide descriptive classifications, their relevance for technology education has rarely been examined empirically. This raises the question under which didactic conditions making actually leads to engagement with technological contexts, justification processes and decision-making.

Against this background, technology education increasingly conceptualises making not merely as a method, but as a pedagogical space that requires deliberate design. This perspective draws on design-oriented approaches that understand technology as the result of human decision-making processes (Röben, 2023).

The present article contributes to this discourse by conceptualising structured making as a didactically pre-designed educational approach. The development of a maker task operationalises five structural principles that address learning processes beyond mere product manufacturing. In addition, exploratory empirical insights from learning diaries of prospective technology teachers are presented. Rather than evaluating effectiveness, the study aims to identify learning-related aspects relevant for further research on making in technology education.

2 MAKING IN TECHNOLOGY EDUCATION: CONCEPTUAL AND EMPIRICAL PERSPECTIVES

The maker movement has been described in the literature as a heterogeneous phenomenon shaped by social, technological and cultural developments, including accessible digital manufacturing technologies, open-source practices and new forms of collaborative workshops (Wiemer & Rothe, 2024). In this context, key concepts such as making, maker and maker education remain conceptually vague. Many definitions focus less on specific learning processes and instead emphasise a postulated maker mindset associated with creativity, experimentation and self-reliance (Rothe et al, 2025; Dougherty, 2012, 2016). Making is also described as a social practice characterised by collaborative problem solving and shared learning (Halverson & Sheridan, 2014).

From a technology education perspective, this conceptual openness poses significant challenges. Numerous competence models and frameworks emerging from the maker discourse address creativity, problem-solving skills and digital competencies, yet their relationship to established goals of technology education often remains unclear and largely descriptive (Rothe et al, 2025).

In particular, the production of an artefact is frequently treated as a sufficient indicator of learning, reflecting an implicit concept of learning in maker education (Wiemer & Rothe, 2024). Such an understanding, however, does not adequately address the core concerns of technology education, which include analysing functions and operating principles, considering alternatives, and evaluating the consequences of technical decisions (Röben, 2023). Technical learning, therefore, cannot be reduced to successful implementation but must be understood as the development of informed judgement.

Against this background, several authors argue that making should not be legitimised retrospectively as a learning activity, but rather conceptualised *ex ante* as a didactically designed learning architecture (Rothe et al, 2025). Whether making contributes to technical learning depends on how tasks structure openness, material resistance and functional requirements so that learners are compelled to engage in processes of analysis, reasoning and evaluation. In this context, productive failure in dealing with materials and technologies can have epistemic potential when it is embedded in an appropriate didactic framework (Blikstein, 2013). Empirical studies in teacher education further indicate that the educational value of maker spaces is contingent on task design and instructional framing (Wiemer & Degen, 2025).

3 STRUCTURED MAKING AS A PEDAGOGICAL APPROACH

Against the background of these conceptual and empirical gaps, the concept of structured making is introduced as a didactic response to the challenges identified in the maker discourse. The concept of structured making is not understood as a methodological format but as a didactic approach that designs school-based making *ex ante* in such a way that technical learning processes are not reduced to product manufacturing. Making is conceptualised as a learning architecture in which learners are required to make decisions, tolerate irritations, formulate reasons and weigh alternatives. In this sense, structured making is not positioned in opposition to technology education, but rather as a legitimate approach to fostering technical judgement and reflective action.

3.1 *Theoretical foundation: technical action, multiple perspectives and causes*

This approach can be clarified using Ropohl's action system theory. Technology is not regarded as a mere collection of artefacts but as a socio-technical system in which goals, means, information and execution interact systematically (Ropohl, 2009). Building on this perspective, Binder (2014) conceptualises technical action as the integration of the acting subject and the material system into socio-technical units. For didactic design, this implies that technical action cannot be adequately described by linear models of problem solving. Instead, it is characterised by recursive and branching processes in which feedback, evaluation and renewed decision-making play a central role.

The normative framework for structured making is provided by the multi-perspective approach developed by Schmayl (2021). Technology education is thus understood as an examination of technology from multiple perspectives, aiming at understanding technology and using it in a thoughtful and responsible manner. Multi-perspectivity functions as a structural principle that

systematically links making with questions of evaluation and responsibility, for example in ecological, social or aesthetic terms.

A further theoretical foundation is provided by Aristotle's theory of causes (aitiai). Aristotle defines understanding as knowledge of causes and distinguishes four modes of causality: the material cause (causa materialis), the formal cause (causa formalis), the efficient cause (causa efficiens) and the final cause (causa finalis) (Phys. II 3). Artefacts of technê can only be explained through the interaction of these causes (Phys. II 7) (Heinemann, 2021). For technical learning, this perspective is crucial because it shifts attention away from the finished product towards the analysis of conditional relationships that underlie technical action. If technical action is understood as socio-technical, multi-perspective and causally structured, specific didactic requirements for the design of making tasks can be derived.

3.2 *Five principles as didactic correspondences*

Table 1

Five principles of structured making

principle	aitia	function	implication
materiality	causa materialis	Material properties act as conditions and obstacles to technical action; they limit and enable design options (Phys. II 1–3).	Learning tasks must enable learners to experience material behaviour so that technical decisions cannot be made independently of the material.
iteration	causa efficiens	Technical development takes place as a process between an initial and a final state; action and experience of effects drive knowledge forward (Phys. II 3; III 1).	Iterative cycles are not a methodological addition, but rather a fundamental part of technical learning.
technical functionality	causa finalis	The purpose structures the scope of action without specifying concrete solutions; functionality has a normative effect, not a deterministic one (Phys. II 7).	Functional requirements must be binding, but at the same time allow for several technical solutions.
structured openness	ratio of causa finalis and causa formalis	Openness arises from the underdetermination of form given a specific purpose; artefacts are not unambiguously determined by their purpose (Phys. II 2, 7).	Tasks should clarify objectives and requirements without prescribing formal solutions.
reflection	causa formalis	Form is determined in technical activity not only materially, but also conceptually and argumentatively; understanding requires explication of shape and order (Phys. II 3).	Reflection makes implicit design assumptions explicit and accessible for analysis and justification.

As shown in Table 1, the five principles of structured making can be interpreted as didactic correspondences to the Aristotelian causes. They are not conceived as a sequence of steps but as mutually influencing structural principles within a learning architecture.

In structured making, materiality is not treated as a neutral resource but as a medium of resistance and knowledge. Feedback from material behaviour renders technical limitations tangible and necessitates decisions. From a didactic perspective, materiality establishes a connection to reality that makes functional assumptions testable and forces learners to relate design decisions to material properties.

Iteration is conceptualised as a constitutive feature of technical development rather than as a methodological addition. Technical action unfolds as a process in which actions produce effects, effects generate feedback and redesign follows from evaluation. Aristotle's conception of movement as a process oriented towards an end provides an ontological anchor for this understanding (Phys. III 1) (Heinemann, 2021). From a learning perspective, iterative cycles become productive when failure is framed as epistemically meaningful and integrated into the learning architecture (Kapur, 2025).

In structured making, functionality serves as a binding normative reference point for technical decisions. Purpose structures the scope of action without determining concrete solutions, thereby maintaining openness while ensuring technical viability (Phys. II 7) (Heinemann, 2021). Functional requirements thus organise decision-making processes without reducing making to mere optimisation.

Structured openness arises from the underdetermination of form given a specific purpose. While objectives and requirements are clearly defined, the concrete form of the artefact remains contingent (Phys. II 2, 7) (Heinemann, 2021). Didactically, this creates a productive tension: learners are free to develop different solutions, but they must justify their decisions with reference to functional and material constraints.

Reflection constitutes a central element of structured making, as it makes implicit design assumptions, criteria and justifications explicit. Form is not only realised materially but also conceptualised and argued. Reflection thus connects making with multi-perspective evaluation by enabling learners to articulate reasons, consider alternatives and assess consequences of technical decisions.

3.3 *Consequence: didactic architecture instead of a collection of methods*

Structured making can therefore be understood as a didactic architecture that organises the relationship between freedom, structure and responsibility. By coordinating material resistance, functional requirements, iterative development, openness and reflection, it provides a heuristic for designing maker tasks ex ante and for analysing learning processes in technology education. Learning relevance is determined not by the artefact itself but by the coordinated interplay of material, formal, efficient and final causes underlying technical action (Phys. II 3–7) (Heinemann, 2021).

4 DEVELOPMENT OF THE MAKER TASK AND RESEARCH DESIGN

Based on the conceptual framework developed in Chapter 3, a maker task was designed to operationalise the principles of structured making in an educational setting. The objective of the empirical study is to explore the learning processes initiated within the framework of a maker task in the sense of structured making (Chapter 3). The emphasis is not on the attainment of specific learning outcomes or the demonstration of tangible effectiveness; rather, it is on the processes of technical decision-making, reasoning, and reflection, as documented by the learners themselves. The research design is therefore qualitative, exploratory and process-oriented.

4.1 *The Maker task ‘Rotor X’ as a structured learning architecture*

The empirical basis of the study is the maker task Rotor X. The task required learners to independently design and iteratively refine the most efficient rotor possible, the performance of which could be tested during the project. Learners were free to work individually, in pairs or in groups. This openness regarding social organisation was deliberately chosen in order to allow different forms of coordination, decision-making and justification within the making process.

No specifications were provided with regard to form, material selection or concrete design solutions. The task structure thus deliberately followed the principle of structured openness: while the functional requirement of efficiency served as a binding reference point (*causa finalis*), the concrete form of the artefact remained underdetermined (*causa formalis*). This configuration required learners to formulate, justify and revise design decisions.

Materiality was established as a central structural element by encouraging systematic testing of material behaviour and adaptation of designs in response to material resistance (*causa materialis*). Iterative revisions were explicitly framed as an integral part of the task and not as failure (*causa efficiens*). In this sense, Rotor X is not to be understood as a method, but as a didactically designed learning architecture in which the five principles of structured making operate simultaneously.

4.2 *Implementation and sampling*

The maker task was executed by learners enrolled in a programme leading to qualifications in technology education. The project was conducted over an extended timeframe, during which the learners engaged in a process of design development, testing and refinement. The pedagogical role of the instructor was confined to the establishment of an organisational framework and the provision of safety instructions; no content-related solution ideas or evaluation criteria were furnished.

In order to facilitate the task, all learners were required to maintain learning diaries in which they recorded their approaches, decisions, difficulties and considerations. The learning diaries were an integral part of the task structure and were not introduced as an additional tool.

4.3 *Journals as a gateway to learning processes*

The use of learning diaries is grounded in concepts of self-regulated learning, understood as learners' active monitoring and regulation of their own learning processes (Perels et al., 2022). In this study, the diaries were not used for performance assessment but as a process-oriented data source providing insight into technical decision-making. By articulating assumptions, goals and evaluation criteria, the diaries support reflection as conceptualised in Chapter 3.

4.4 *Database*

The empirical database consists of the written learning diaries of all learners. Entries vary in scope and detail but consistently address perceived material behaviour, design decisions, functional considerations, iterative changes and reflective evaluations. The diaries thus provide a suitable basis for analysing the five principles of structured making derived in Chapter 3.

4.5 *Qualitative content analysis*

The learning diaries were analysed using qualitative content analysis according to Kuckartz (2018), which combines deductive and inductive procedures. Deductive main categories were derived from the five principles of structured making and used as an analytical framework. Within these categories, inductive subcategories were developed from the material. The analysis was conducted across cases and aimed at identifying typical patterns of reasoning and interpretation rather than frequencies.

4.6 *Methodological classification*

The present study is of an explicitly exploratory nature. The findings do not permit any conclusions to be drawn about the effectiveness of the maker task or about causal relationships. Nevertheless, they do provide indications of which learning processes become visible under the conditions of structured making and how learners deal with openness, materiality and functional requirements.

5 EXPLORATORY INSIGHTS INTO LEARNING PROCESSES

The evaluation of the learning diaries provides preliminary insights into the learning processes initiated as part of the Maker task 'Rotor X' under the conditions of structured making. The ensuing results must not be interpreted as substantiating evidence of efficacy; rather, they are to be regarded as exploratory reconstructions of the typical process sequences as documented by the learners themselves. The presentation adheres to the five principles of structured making, which also served as the primary deductive categories of the analysis (Chapters 3 and 4).

5.1 *Iteration as a challenge and learning opportunity*

The learning diaries demonstrate that iterative revision processes are often cognitively and emotionally demanding for many learners and required specific adjustments. These phases have

been described as both frustrating and productive. The entries reveal that iteration was not merely conceived as repetition, but rather as an opportunity to analyse one's own assumptions. Learners engaged in a process of reflection, examining the rationale behind specific design decisions that had not yielded the anticipated outcomes. This introspection led to the formulation of alternative solutions, which were then developed by the learners.

5.2 *Materiality as a trigger*

Material-related experiences are of central importance in the learning diaries. A significant proportion of the entries address unexpected material behaviour, including, but not limited to, instability, deformation and insufficient strength. Such experiences frequently prompted problem analysis by compelling learners to reconsider their original ideas. Materiality is described not only as a limitation, but explicitly as a source of knowledge. Learners refer to material properties in order to justify design decisions or to discuss alternatives.

5.3 *Structured openness and uncertainty of reasoning*

The openness of the task is assessed ambivalently in the learning diaries. On the one hand, learners report on the opportunity to implement their own ideas and pursue individual solutions. Conversely, uncertainty is repeatedly articulated, especially with regard to the question of when a solution can be considered 'well-founded'. This uncertainty about justification is particularly evident in cases where multiple functionally plausible solutions are possible. It is evident that learners recognise that efficiency alone is not sufficient to clearly justify decisions and begin to apply additional criteria, such as stability or material economy.

5.4 *Technical functionality as a frame of reference*

The technical functionality of the system is consistently referenced in the learning diaries, yet this does not result in a purely results-oriented approach. Learners repeatedly referred to efficiency, primarily as a basis for evaluating and revising their designs rather than as an isolated success criterion. Instead, it is related to other aspects, such as the use of materials or the complexity of design. These relational considerations suggest that functionality became effective as a structuring, rather than a determining, criterion. Design and material choices followed technical functionality and underlying physical laws only to a limited extent.

5.5 *Reflection and multi-perspective references*

The reflective entries in the learning diaries reveal approaches to multi-perspective consideration of technical decisions. In addition to functional considerations, occasional aesthetic, practical and even ecological references are observed. These are not systematically developed, but they do indicate that reflection can extend beyond mere practicality. The quality of reflection varies considerably. While some learners merely record decisions descriptively, others attempt to weigh up alternatives and make their own criteria explicit. The presentation draws attention to the fact that such reflective passages occur particularly where learners are repeatedly confronted with conflicting goals.

6 CONCLUSION

To summarise, a number of exploratory trends have been identified. Firstly, iterative processes are considered relevant to learning, albeit challenging. Secondly, materiality is identified as a central trigger for technical analysis. Thirdly, structured openness is shown to open up a variety of solutions, while simultaneously creating a need for justification. Fourthly, functionality acts as a normative frame of reference. Finally, reflection enables initial multi-perspective approaches.

Taken together, the analysis of the learning diaries suggests that making becomes educationally meaningful when learners are confronted with material resistance, functional conflicts and demands for justification. Under these conditions, learning is located less in the successful artefact than in the coordination of material, form, purpose and action. Iteration emerges as a response to functional irritations rather than as a methodological addition, while openness operates as a productive field of tension that invites evaluation beyond efficiency alone. From this perspective, the five principles of structured making function not as a checklist, but as a heuristic for analysing learning processes and designing maker tasks ex ante.

The study is exploratory, based on a limited sample of prospective technology teachers and on subjective data from learning diaries. Future research should examine structured making in other target groups and triangulate learning diaries with additional data sources, such as observations or artefact analyses. Comparative studies involving maker tasks with varying degrees of structure may further clarify how openness, materiality and functional requirements interact in technical learning processes.

7 DISCLOSURE

The author utilises [DeepL] to assist in translating the manuscript from [German] into English and to refine the linguistic flow. All AI-generated suggestions were critically reviewed for accuracy and revised to ensure the integrity of the scientific argumentation.

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Spiral Curricula for 21st-Century Technology Education: Fostering Digital and Mechanical Technology Problem-Solving

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Abstract

The increasing complexity of 21st-century society requires skills that enable handling technological, social, and economic changes. The need for 21st-century skills, like digital literacy, problem-solving and critical thinking, has grown since 1980, when the transformation to a knowledge- and information-based society began (Gervé, 2022; Van Laar et al., 2017).

New skills, known as 21st-century skills, became relevant in order to deal with changing situations. Computational thinking (CT) as a 21st-century skills integrates digital and mechanical problem-solving across disciplines and serves as a core competence for a digital society. Since schools prepare students to participate in society, CT should be integrated into technology education (Gervé, 2022; Wing, 2010). This includes mechanical and digital principles, artifacts, and their combinations. To develop targeted skills appropriately for the educational level, a spiral-curricular development could be helpful (Bruner, 1976).

Research indicate that children can solve various technological problems (e.g. Beimbrech, 2003; Eickelmann et al., 2024). It remains unclear, whether a spiral-curricular approach to promote mechanical- and digital-technological problem-solving can be successful. There's little evidence regarding the effectiveness of spiral-curricular approaches for solving technological problems. Therefore, this study aims to develop a spiral-curriculum promoting technological problem-solving and examine its ability to enhance problem-solving. The article presents the redesign of the intervention and test development based on qualitative and quantitative pilot results and provides an outlook on how the future study design will be structured.

Key Words: 21st-century skills, Computational Thinking, Problem-Solving, Spiral-Curriculum, Technology Learning

1 INITIAL SITUATION

Technology is considered an omnipresent element of the lifeworld. In a narrow sense, the concept refers solely to material technological artefacts (e.g. tools or microcontrollers) that are human-made and purposefully designed to satisfy human needs (DGTB, 2018; Graube & Mammes, 2013). In a broader sense, the concept of technology also encompasses technological procedures and actions, the conditions and purposes of technological processes, as well as the consequences and effects of technology (Möller, 2000). In the discourse of engineering and technology studies, developments of existing technologies are emerging, driven by new scientific insights and the resulting possibilities, such as increasingly advanced digital data processing (Duddeck, 2016). Graube (2024) refers to this as a digital revolution, which also leads to an acceleration of technological development (Duddeck, 2016). In this context, information and communication technologies (ICT) assume a central role (Van Laar et al., 2017).

These technological developments already affect children in preschool age, as, for example, programmable toys or smart home devices have become part of everyday use. Consequently, early educational processes that address mechanical technology and its digital extensions become increasingly important in order to foster comprehensive technological literacy (Schemel et al., 2025a). One way to establish relevant competencies is to orient educational approaches toward the 21st-century skills (Van Laar et al., 2017) without neglecting mechanical-technological aspects.

2 THE “WHAT” AND “WHEN” OF TECHNOLOGICAL EDUCATION IN THE CONTEXT OF THE 21ST-CENTURY

The everyday occurrence and use of mechanical and digital technology legitimizes early technological education (Finkbeiner & Eibl, 2023; Mammes et al., 2022). One possible approach could be a spiral-curricular structure for technological learning processes. In this structure, a technological subject is addressed at different points in an educational biography, along with the relevant subject-specific and interdisciplinary skills, as its complexity increases (Bruner, 1976).

Within technological education, competencies enabling learners to act purposefully in technology-related situations are to be developed (Mammes et al., 2022). This includes the acquisition of technological content knowledge (e.g., “stability in technological structures”) and the development of technological modes of thinking, working, and acting (e.g., “designing and manufacturing technological artefacts”) (GDSU, 2013, p. 64).

From a content-related and methodological perspective, technological learning often takes place by addressing technological problem-solving methodological or content-related (Tenberge, 2024). Whereas mechanical technology previously dominated technology education (e.g., Möller, 2000; Ullrich & Klante, 1980), digital technologies – and increasingly the combination of mechanical and digital technologies – have gained relevance in learning processes (Tenberge, 2024). These skills are also part of the 21st-century skillset.

21st-century skills are defined as the skills that determine future success (Lamb et al., 2017), as they are essential for education and professional life (Van Laar et al., 2020). Frameworks have been developed to define and organize these skills; differing in the number of skills and their categorization as 21st-century skills. For example, Binkley et al. (2012) identify ten skills: “[...] 1. Creativity and innovation; 2. Critical thinking, problem-solving, decision making; 3. Learning to learn, metacognition.[...] 4. Communication; 5. Collaboration (teamwork).[...] 6. Information literacy; 7. ICT literacy.[...] 8. Citizenship – local and global; 9. Life and career; 10. Personal and social responsibility – including cultural awareness and competence.” (Binkley et al., 2012, p. 18 f.). Voogt and Roblin (2012) highlight that many frameworks incorporate ICT-related skills within the areas of collaboration, communication, and social and cultural skills, and frequently also include creativity, critical thinking, and problem-solving skills (Van Laar et al., 2020). Van Laar et al. (2017, 2020) explicitly add a digital component to the 21st-century skills. This encompasses skills extending beyond the effective use of digital artefacts. They list seven competence areas – technological, information management, communication, collaboration, creativity, critical thinking and problem-solving – which include skills such as: “ICT knowledge: understand the characteristics of (mobile) devices or applications.” (Van Laar et al., 2017, p. 587) or “knowledge application: use ICT to apply implicit and/or explicit knowledge about the problem to find a solution.” (Van Laar et al., 2017, p. 587). Furthermore, Wing (2006) describes CT as “[...] a fundamental skill used by everyone worldwide by the middle of the 21st Century.” (Wing, 2006, p. 1).

CT has so far been defined in various ways. Kärcher et al. (2024) describe CT as an extended form of problem-solving grounded in computational approaches and highlight its importance as an educational goal in the digital world, noting that it contributes to the development of 21st-century skills. Similarly, Eickelmann (2017) characterizes CT as problem-solving thinking required for programming computers and algorithms, while encompassing programming-language-independent competencies. Goecke et al. (2021) further emphasize that CT extends beyond computer-based tasks to include everyday problem-solving strategies and non-computational actions. Wing (2006, 2008), who introduced CT into the school-relevant discourse, frames it as thinking across different levels of abstraction and defines it as an approach to solving problems, designing systems, and understanding human behaviour. She highlights its close relationship to other disciplinary modes of thought, such as mathematical, scientific, and technological thinking. In the context of this article, CT is specifically considered regarding technological problem-solving. Various sub-competencies of CT have been identified in the literature, with different authors emphasising different aspects and listing different components. This article focuses on the competencies that are particularly relevant to this study.

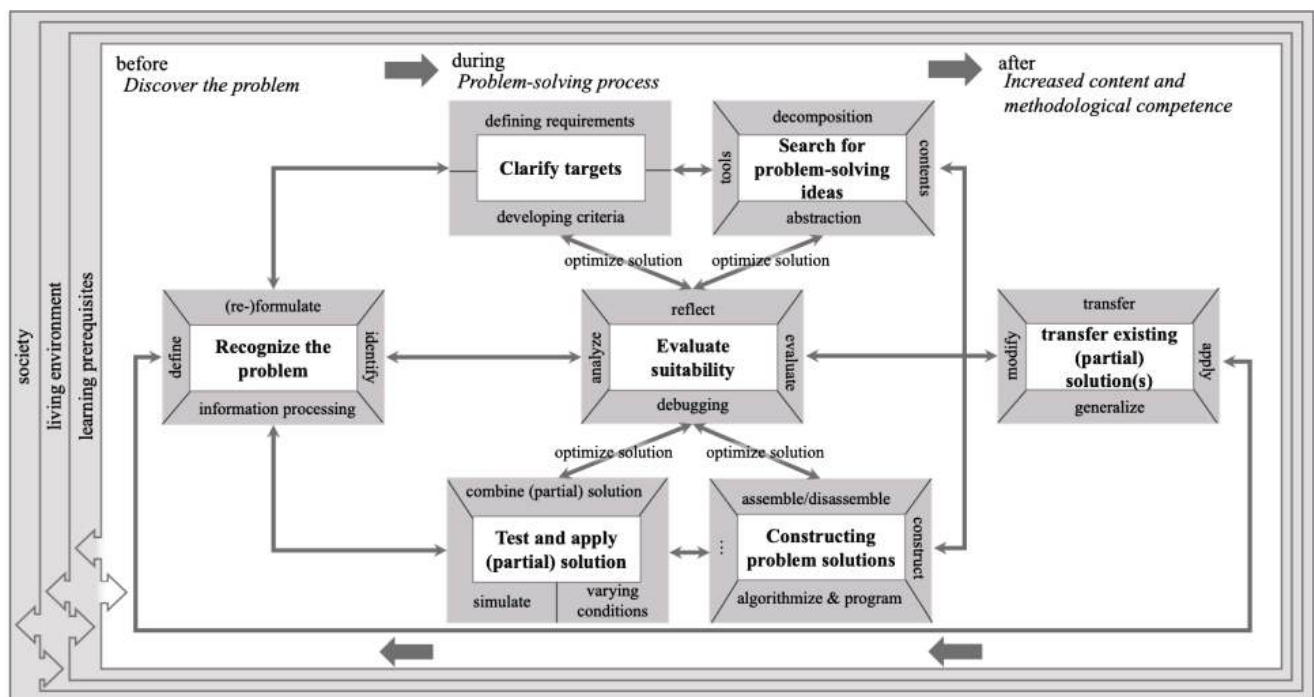
Like technological problem-solving, CT can be conceptualized through subprocesses and the competencies associated with them. These subprocesses originate from various disciplines, highlighting CT’s applicability across different domains (Eickelmann, 2017). Beginning with problem identification (Eickelmann, 2017) abstraction (systematically omitting irrelevant information) and decomposition (breaking the problem into subproblems) can be applied. Equally central is the ability to formally represent problems or solutions in a way that is understandable to humans and computers (Eickelmann, 2017). Goecke et al. (2021) emphasize algorithmic thinking and the ability to strategically employ algorithms for problem-solving as core CT competencies. Furthermore, testing solutions, debugging (identifying and correcting errors) and

evaluating solutions, for example in terms of efficiency, are essential subprocesses (Standl, 2017; Wing, 2006).

There are already individual models for technical problem-solving (Ahlgrimm et al., 2018; Mammes et al., 2022) and CT (Hong et al., 2021; Romeike, 2017; Tsarava et al., 2022). However, there does not yet appear to be a model combining technical problem-solving and CT which also models competencies for the entire educational continuum. For this reason, the PiCT model was deductive developed (Schemel et al., 2025a; Schemel & Tenberge, 2025) and then revised through an evidence-based redesign process. The redesign is based on an extended literature review, that incorporates not only concrete models of technological problem-solving and CT (Beinbrech, 2003; Mammes et al., 2022; Standl, 2017; Wing, 2006), but also aspects of technological action (e.g. Möller, 2000; Wiesenfarth, 1992). In addition, literature on general and cross-disciplinary problem-solving was considered (Bauer, 2009; Beinbrech, 2003). The resulting PiCT-A model (Schemel, 2026) is presented below.

Figure 1

Problem-solving integrating Computational Thinking-Adapted (PiCT-A)



The PiCT-A model (Schemel, 2026) can be applied to problem-solving contexts involving digital technology, mechanical technology, or combined technology. The problem-solving process is understood to be in reciprocal interaction with society, the surrounding environment and learners' prior knowledge.

The PiCT-A problem-solving process is divided into three phases: 'before', 'during' and 'after'. Different sub-competencies of the problem-solving process (represented by white boxes) are

applied within each phase. These sub-competencies are further specified by exemplary content, processes and methods (represented by grey boxes).

In the 'before' phase, identifying the problem is central. Problems are perceived and formulated here, and relevant information about them are processed. Following this, an existing (partial) solution may be applied to the problem, possibly after being adapted, allowing a direct transition to the 'after' phase. Alternatively, the process proceeds to the concrete problem-solving phase.

The first step in this phase is to clarify the requirements for the solution and establish evaluation criteria. Next, concrete problem-solving ideas are generated. During this stage, irrelevant information can be disregarded and the problem can be decomposed into sub-problems. The necessary content and tools can also be selected at this point. Potential solutions are then implemented, for example through construction, assembly or programming. Testing of (partial) solutions then follows, which may include simulating or modifying boundary conditions.

The evaluation phase is a central element of the process. Ongoing evaluation of the solution's adequacy occurs throughout all sub-processes, enabling error detection and correction, analysis and assessment, and subsequent optimisation. The model also allows connections to be made iteratively to previous sub-processes. For example, this could be done if evaluations identified weaknesses in the solution's adequacy.

3 PROBLEM OUTLINE

Empirical studies in the pre-school and school sectors also seem to consider technical problem-solving and CT separately.

Relkin and Bers (2021) warn against reducing CT-skills to programming knowledge alone. They developed the TechCheck-K multiple-choice test to assess CT-skills and administered it to 89 children aged five to six, who scored an average of 8.38 out of 15 (range: 0–14). At high school level, Standl (2017) examined students' (N=75) awareness of CT problem-solving strategies for real problems using a mixed-methods design with pre- and post-questionnaires and product analysis. Even after two CT-based interventions, abstraction, decomposition, and evaluation remained more challenging than problem description and solution design. Eickelmann et al. (2024) demonstrate that the competencies of German students are below the international average.

Regarding technological learning in general and problem-solving in particular, several studies provide further evidence. Baumert (1996) examined technological problem-solving skills in an international sample of fourth-grade students (N=532). The results show that students could partially solve problems independently but struggled with multi-parameter tasks and did not automatically transfer common knowledge to technological contexts; technological problem-solving was also related to competencies in other domains. Von Selasinsky (2023) analysed problem-solving phases and found frequent transitions between them (averaging 50 per process), a relationship between process duration and solution correctness, and that students spent most time on implementing and optimising solutions.

Although the importance of early technological education has increasingly become a focus of technology education research (Finkbeiner & Eibl, 2023) and linking CT with technological problem-solving appears plausible (Tenberge, 2024), the systematic and progressive integration of both constructs in preschool and school research remains a desideratum. Therefore, the present research project aims to answer the question: “How can an effective spiral-curriculum for solving technical problems involving mechanical, digital and mechanically-digitally connected technologies be designed?”. Initial pilot studies, incorporating both qualitative and quantitative research, have already been conducted. The results suggest that mechanically and digitally technological problem-solving can be implemented in preschool and school. However, the findings also emphasize the need to redesign the spiral-curricular interventions and the test instrument for evidence-based assessment (Schemel et al., 2025b; Schemel & Tenberge, 2025).

4 SPIRALCURRICULAR INTERVENTION DESIGN

Various theoretical descriptions of interventions in mechanical and digital problem-solving have already been developed (e.g. Möller, 2022; Tenberge, 2024; Tenberge et al., 2024). However, emerging concepts for technical learning only incorporate progressive learning development to a limited extent, and an explicit, spiral, curriculum-based approach to competence development appears to be lacking. For this reason, the following spiral-curriculum for mechanical- and digital-technical problem-solving was developed based on existing learning units (see Table 1).

The spiral-curriculum-based intervention design is structured across the educational continuum. Initial interventions begin at the early childhood level and are designed to connect seamlessly with class 1 and 2 of primary education. The competencies developed at this stage, in turn, provide the foundation for subsequent interventions in class 3 and 4, which are then followed by interventions at the lower secondary level.

Four learning areas are addressed at each stage of the curriculum. In the mechanical–technical problem-solving domain, children work on technical challenges using tools such as hammers and saws. For example, in Primary 1 and 2, they construct criteria-based artefacts from wood using hand tools, such as a vehicle that rolls as far and as straight as possible. Varying levels of task complexity enable competencies to be developed gradually in line with the principles of a spiral-curriculum. Additionally, repeatedly revisiting key aspects, such as fastening a screw with a screwdriver, ensures continuity and builds on previously acquired knowledge.

Table 1

Intervention structured by grade level and subject area, following a spiral-curriculum to competency development

	learning area	elementary level	primary level class 1 & 2	primary level class 3 & 4	secondary level I
	mechanical- technical problem solving	constructing and building a nail board with staggered nails	constructing and building a vehicle that rolls as far and straight as possible	constructing and building a tow truck	
	unplugged programming	unplugged navigating through a labyrinth	unplugged programming related to directions	unplugged programming related to multidimensional change of movement	
intervention	digital- technical problem solving	BlueBot™ in problem-solving contexts	BlueBot™ in more complex problem- solving contexts	programming a microcontroller with various sensors and actuator	Next Step
	mechanical- digital connected technical problem solving	constructing and building a labyrinth for the BlueBot™ using e.g. wood and programming the BlueBot™ in the labyrinth	taking various criteria into account, constructing and building a labyrinth for the BlueBot™ using e.g. wood and programming the BlueBot™ in the labyrinth	programming and building an attachment for the tow truck	

The digital problem-solving domain is introduced through unplugged programming, which highlights the importance of precise and unambiguous commands (Tenberge, 2024). Building on this foundation, children engage in age-appropriate digital problem-solving tasks at each stage of the curriculum using programmable tools such as Blue-Bots™ or microcontrollers. Increasingly complex criteria and different programming languages support the development of spiral-curricular competence, while the fundamental principle of input–processing–output remains consistent across all stages.

Finally, the intervention includes the learning domain of mechanical–digital connected technical problem-solving at all curricular stages. This domain addresses integrated problem situations that require consideration of both mechanical and digital aspects. Tasks draw on competencies from the respective stage, as well as skills developed in previous stages, such as the appropriate use of tools, thereby ensuring continuity and supporting spiral competence development.

5 ASSESSMENT OF LEARNING DEVELOPMENT

The study also aims to assess the improvement of students' abilities as a result of the intervention. This was considered when developing the “CleeveTechPRO” questionnaire. Following the pilotphase in elementary and primary education, areas for development were also identified in the test instrument (Schemel & Tenberge, 2025), resulting in a redesign of the test. The aims of this revision are (1) to achieve a stronger alignment between the competencies assessed by the test and those fostered through the intervention, and (2) to reduce the test length.

The test's content design is illustrated in Table 2. This design is divided into the learning areas and the curricular stages.

Table 2

Test's content design

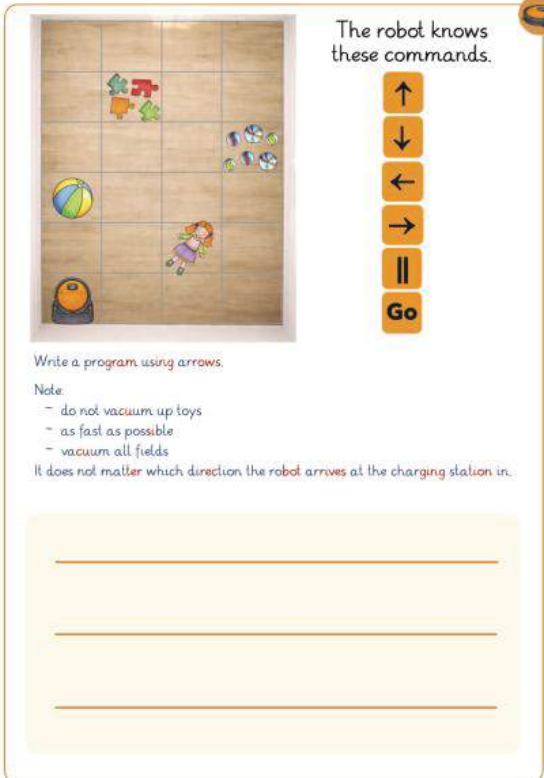
test instrument	learning area	elementary level	primary level class 1 & 2	primary level class 3 & 4	secondary level I
	mechanical-technical problem solving	criteria-based design stairs made of building blocks	criteria-based design of a marble run	criteria-based constructing a drawbridge	Later Step
	unplugged programming	finding and describing directions in problematic contexts	finding and describing complex directions in problematic contexts	finding and describing directions in multidimensional problematic contexts	
	digital-technical problem solving	programming a robot in a real-life context	programming a robot vacuum cleaner	developing a program with consideration of sensors and actuators	
	mechanical-digital connected technical problem solving	solving a mechanically and digitally connected problem in a real-life context	solving a mechanically and digitally connected problem in the context of a service robot in a supermarket	solving a mechanically and digitally connected problem in the context of a drawbridge	

A combined look at Table 1 and 2 illustrates the connections between the problem areas in the intervention and in the test. Each paired task addresses the same content and methodological aspects of competence development. The tools used are also identical in both the problem-based intervention and the test. This is illustrated clearly by one concrete example:

As part of the intervention, students programme the BlueBot™ learning robot using the robot's arrow-buttons (Janicki & Tenberge, 2023). The BlueBot™ is used to solve path problems in various contexts (Tenberge et al., 2024). As part of the test, the children programme a vacuum-robot using the same criteria as well as the same programming language (represented by arrows) and meaning of commands. Figure 2 provides an overview of the design of the intervention and test tasks. In addition to using the same programming language, the necessary problem-solving steps and the complexity of the problem-solving requirements are also comparable.

Figure 2

Insights into the Design of Test and Intervention Tasks in grades 1 and 2

Digital-technical problem solving – Primary level (class 1 & 2)	
Intervention	Test instrument
BlueBot™ in more complex problem-solving contexts	programming a robot vacuum cleaner*
	 The robot knows these commands. Write a program using arrows. Note: - do not vacuum up toys - as fast as possible - vacuum all fields It does not matter which direction the robot arrives at the charging station in.

*Translated: original version in German

A test instrument was developed for each stage of the curriculum. Each instrument includes one problem scenario for mechanical, digital, and mechanical-digital-connected problem-solving.

One item per sub-competency of the PiCT-A model is included in each problem scenario, resulting in a total of 21 items assessing technological problem-solving competencies. Additionally, one item addressing unplugged programming was included, bringing the total number of items in the test for each curricular stage to 22. These can be completed in about 60 minutes, and each section of the test can be taken independently. It is also possible to take a break between sections.

6 DISCUSSION AND OUTLOOK

This research project aims to promote problem-solving in the context of mechanical and digital technology using a spiral-curriculum. Despite increasing digitalisation, care was taken during the design phase to ensure that mechanical aspects were not neglected, but rather that all aspects of technology were considered together to ensure a future-proof education. While some studies have focused on mechanical-technological problem-solving, and initial spiral curricula have been developed, there is a need for more research on combining digital-technological aspects with a spiral-curriculum. In this respect, the design places increased relevance on 21st-century skills in general and CT in particular. The description of the planned spiral-curricular interventions, the model and the test demonstrate that some 21st-century skills are already incorporated into the research project. These include skills such as 'creativity and innovation', 'critical thinking, problem-solving and decision making', 'communication', 'collaboration', 'ICT literacy' and 'technology' (Binkley et al., 2012; Van Laar et al., 2020). However, some 21st-century skills, such as 'learning to learn' or 'information management', have not yet been considered. These now need to be meaningfully integrated into the project without displacing mechanical-technological aspects. Once finalised, a quasi-longitudinal study will be conducted using a control group design. Finally, using the test in a pre-post design will provide information on learning progressions throughout the spiral-curricular interventions.

The text was written as a German version and translated with generative AI tools (Deepl and Deepl Write) to English.

7 LITERATURE

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The Role of Teachers' Interest and Self-Efficacy in Implementing Technological Topics in Primary Education

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Abstract

The increasing societal pervasiveness of technology demands a solid foundation of technological literacy in primary education. In Germany, technological education is institutionally embedded within *Sachunterricht*, a multi-perspective subject unique to the German-speaking context (GDSU, 2013). Despite its curricular importance, empirical evidence indicates that technological topics remain significantly underrepresented in classroom practice, accounting for only 10.5% of instructional time (Möller et al., 1996; Steffensky et al., 2024). While structural explanations have been discussed (Möller et al., 1996), teacher-related dispositions – specifically individual interest and self-efficacy beliefs – require a systematic re-examination under contemporary conditions.

Building on the TeBiS study (Möller et al., 1996), this paper reports results from the third pilot phase of an extended replication (N=16) with pre-service teachers during their practical semester. The study differentiates rigorously between individual interest (Krapp, 1992), self-efficacy beliefs (Bandura, 1997), and implementation behaviour. Results indicate a slightly below-average individual interest ($M=2.39$) and moderately pronounced but highly heterogeneous self-efficacy expectations ($M=2.69$). Correlational analyses reveal a non-significant negative relationship between interest and implementation ($r=-0.33$) and a weak positive relationship for self-efficacy ($r=0.16$). Contrary to linear assumptions, the pilot data suggest that individual dispositions alone do not sufficiently explain implementation behaviour. These findings underline the necessity of modelling implementation as a multi-level phenomenon that integrates macro- (policy), meso- (school context), and micro-level (teacher) factors. Due to the small sample size, conclusions remain exploratory and primarily serve instrument refinement for the main study in 2026.

Key Words: Technology Education in Primary School, Sachunterricht, Teacher's Interest, Teacher's Self-Efficacy, Implementation

1 INTRODUCTION

Technology exerts a profound impact on contemporary society and has become an integral part of almost all areas of life (Ropohl, 2009). For children, this manifests through both digital media (Gervé, 2016) and the ubiquitous use of technological devices in their everyday environment (Möller & Wyssen, 2018). Consequently, technological education – defined here as the development of basic technological literacy – is essential for enabling primary school children to navigate and act competently within an increasingly complex world (Landwehr et al., 2021).

Importantly, this contribution does not equate ‘technology’ with digital media alone. In line with the system theory of technology (Ropohl, 2009), technological content refers to human-designed artefacts, processes, and systems – including but not limited to digital technologies. This terminological clarification responds to international concerns regarding the conflation of technological education with digital education.

Building on the premise, the primary school stage is critical for establishing a foundation for technology-related dispositions. However, the extent to which technological content is integrated into the classroom remains a subject of concern. To contextualise this for an international audience, it is necessary to examine the specificities of the German education system.

1.1 *Contextualising Technological Education within the German ‘Sachunterricht’*

The education system in Germany is structured into several successive stages, defined by a clear distinction between early childhood services and formal schooling. Contrary to international systems where formal education often begins earlier, the German model separates the ‘elementary sector’ from the primary stage. The elementary sector encompasses non-compulsory early childhood education in day nurseries for children aged zero to six. While providing foundational stimulation, it remains distinct from the compulsory school system, which commences with ‘primary education’ (KMK, 2023).

Building on this organisational premise, primary school constitutes the first stage of formal school education. It is typically attended by children aged six to ten and, in most federal states, comprises grades one to four (with the exception of Berlin and Brandenburg, where it extends to grade six). Crucially for the international reader, technological education is not institutionalised as a standalone subject within this framework. Instead, it is integrated into *Sachunterricht* (GDSU, 2013). During their university-based teacher training (primary teacher training), pre-service teachers receive instruction in all perspectives of this integrated subject, although the depth of technological training varies significantly between federal states and institutions.

Contrary to traditional mono-disciplinary assumptions in technological education, *Sachunterricht* follows a ‘multi-perspective approach’ (GDSU, 2013). It integrates historical, geographical, scientific, social, and technological perspectives. The technological

perspective aims to empower primary school pupils to navigate a technology-driven society, for example, by utilising tools, machines, and devices to solve technological problems.

However, the inherent ‘multi-perspectivity’ of the subject often leads to a marginalisation of the technological component in favour of more established scientific or social perspectives (Steffensky et al., 2024). The following section examines the role of teachers in *Sachunterricht*, focusing on the factors that influence the behaviours and conditions affecting the implementation of technological content.

2 THEORETICAL FRAMEWORK: COGNITIVE AND MOTIVATIONAL DETERMINANTS OF TECHNOLOGICAL EDUCATION

Contrary to traditional, mono-causal assumptions that curricular prescriptions directly dictate classroom practice, contemporary educational research conceptualises implementation as a complex, non-linear process mediated by systemic layers. Drawing on the foundational TeBiS study (Möller et al., 1996), we utilise a heuristic multi-level model to categorise the factors influencing the enactment of technological literacy in primary education.

Table 1

A heuristic multi-level model with key factors and determinants that influence the enactment of technological literacy in primary education

Level	Key Factors & Determinants
Macro Level	Encompasses socio-political frameworks and curricula, e.g. the Curriculum for primary schools in North Rhine-Westphalia (MSB, 2021)
Meso Level	Includes school-specific context characteristics, such as the availability of material resources (e.g., construction kits, digital labs), leadership support, and institutionalised professional development.
Micro Level	Focuses on teacher-related factors which, building on the premise that the teacher is the ultimate gatekeeper of the curriculum, represent the most critical nexus for instructional change.

2.1. Self-efficacy

The effective implementation of technology education in primary schools is fundamentally underpinned by a complex interplay of cognitive and motivational factors. Within this micro-level architecture, self-efficacy constitutes a pivotal cognitive mediator between pedagogical knowledge and actual classroom performance. Defined as the belief in one’s capability

to organise and execute the actions required to achieve specific goals (Bandura, 1997), self-efficacy is considered a key characteristic of professional teaching (Mietzel, 2017). It significantly influences cognitive, motivational, emotional, and behavioural processes, ultimately determining how challenges are tackled (Schwarzer & Jerusalem, 2002).

In the specific domain of primary technology education – where many teachers may feel ‘technologically under-prepared’ – high self-efficacy could act as a catalyst for innovation. Teachers with robust beliefs in their technological competence are not only more likely to adopt ambitious, technology-oriented teaching approaches but also tend to demonstrate greater resilience when facing the inherent unpredictability of hands-on technological topics. Furthermore, educators with high self-efficacy often set more ambitious goals, invest more time in preparation, and systematically use learner feedback to refine their practice (Ditton & Arnoldt, 2004).

As Schneider and Tenberge (2025) have indicated, empirical research into the specific relationship between self-efficacy beliefs and technological education remains limited. However, theoretical frameworks suggest that self-efficacy expectations might play a central role in the implementation of technological content, as teachers act not only in accordance with curricular requirements but also based on their internal expectations of their own abilities (Schwarzer & Jerusalem, 2002; Mietzel, 2017).

2.2. Individual Interest

In addition to self-efficacy, educational research identifies individual interest in technological topics and their pedagogical application as another key motivational factor that could significantly influence teaching behaviour and lesson design. From a theoretical perspective, interest is defined as a relatively stable person-object relationship (Krapp, 1992). In this context, the ‘object’ refers to specific technological content or topics that elicit a greater willingness to engage in depth.

While foundational research has primarily focused on primary school students (learners), showing that interest significantly dictates the intensity and quality of learning (Schiefele, 2009), there are few empirical approaches that extend these findings to educators. Nevertheless, extending this framework to teachers suggests that their individual interests could significantly influence lesson design (Straube et al., 2020). It is essential to differentiate between two types of interest:

- **Situational Interest:** A transient state triggered by specific external stimuli, such as a particular digital tool or a creative teaching sequence.
- **Individual Interest:** A long-term, stable motivational disposition characterised by high emotional and value-related valence toward a subject area.

In the field of technological education, conclusions can be drawn from related research in *Sachunterricht* (Straube et al., 2020). As a constant personality trait, individual interest influences long-term engagement and knowledge acquisition (Schiefele, 2009). Especially

in *Sachunterricht*, where teachers exercise high autonomy in topic selection, individual interest serves as a primary filter for curricular enactment. Teachers with a high personal affinity for technological topics are more likely to invest the effort required for complex technological units and seek subject-specific further training. Consequently, teachers' individual interests could emerge as a decisive factor in the implementation of technological topics in primary education.

3 PROBLEM OUTLINE: THE PERSISTENCE OF THE 'IMPLEMENTATION GAP'

The increasing societal pervasiveness of technology demands a foundation of technological literacy in primary education. Beyond functional usage, teaching technological content is a prerequisite for fostering 21st-century skills – specifically critical thinking, complex problem-solving, and creativity (SWK, 2021). In Germany, this educational mandate is institutionally embedded within *Sachunterricht*. However, a significant discrepancy exists between the curricular status of technology and its actual enactment in the classroom (Beutin et al., 2023). The TeBiS study (Möller et al., 1996) remains a seminal reference point, demonstrating that the implementation of technological topics depends on numerous factors. Crucially, Möller et al. (1996) revealed that less than half of the surveyed teachers (N= 535) integrated technology into their lessons, with only 25% feeling competent to do so.

Contrary to the assumption that the technological acceleration of the last three decades would instinctively lead to an increase in formal technological education, empirical data suggest a remarkable systemic stagnation. While the 'depth and immersiveness' of technology in everyday life have escalated since 1996, the school-based response remains fragmented. Current findings from the Trends in International Mathematics and Science Study (TIMSS, 2023) confirm this 'persistence of marginalisation': technological content accounts for a mere 10.5% of instructional time, lagging significantly behind the scientific and geographical perspectives (Steffensky et al., 2024). This is further corroborated by recent analyses of national framework plans, where the technological perspective is represented at only 9.8% (Beutin et al., 2023).

Building on the theoretical premises of Bandura (1997) and Krapp (1992), it becomes evident that the mere presence of technology in a child's environment does not translate into high-quality instruction. Instead, the teacher acts as the ultimate gatekeeper. Although the influence of individual interest and self-efficacy on general lesson design is well-documented in psychology, their specific impact on the enactment of the 'technological perspective' in *Sachunterricht* remains empirically under-researched under contemporary conditions. This study seeks to address this lacuna by re-examining these professional dispositions in the light of current curricular demands (e.g. *Curriculum for primary schools in North Rhine-Westphalia* (MSB, 2021)).

4 RESEARCH QUESTIONS

Building on the systemic framework, this study aims to identify and analyse specific teacher-related factors that act as predictors for the classroom enactment of technological topics in the

primary sector. This research prioritizes the internal dispositional landscape of educators, as these micro-level factors often act as the final gatekeepers of curricular innovation. To achieve this, the study focuses on the following research questions:

- (i) To what extent do pre-service teachers demonstrate an individual interest in technological topics?
- (ii) How pronounced are their self-efficacy expectations regarding technology-oriented instruction?
- (iii) How do these dispositions correlate with the actual implementation of technological content?

5 RESEARCH DESIGN AND METHODOLOGY

To provide an empirical basis for investigating the identified research questions, this study employs a quantitative design, framed as an extended replication of the TeBiS study. Contrary to the original 1996 design, the current questionnaire has been modernised to reflect contemporary standards of technological literacy and psychometric validation.

Building on the premise that an understanding of technology education requires a cross-sectional perspective on professionalisation, the research design expands the original scope of the sample. Specifically, the study is strategically structured to include both pre-service teachers (university students in their practical phase) and in-service teachers (practising professionals in primary schools). This expanded sampling strategy is designed to identify longitudinal shifts in individual interest and self-efficacy, thereby allowing for a more robust analysis of how professional experience moderates the implementation of technological content in *Sachunterricht*. By integrating these cohorts, the study moves beyond snapshot of teacher training.

5.1. Instrumentation and Operationalisation of Teacher Dispositions

The survey was conducted via a multidimensional questionnaire, which was refined through three consecutive pilot phases to ensure structural validity. Building on the premise that teacher dispositions are multi-faceted, we employed differentiated scales to capture individual interest and self-efficacy with high psychometric precision.

Individual Interest: This construct was operationalised using eight items based on the Interest Scale by Rakoczy et al. (2005). This scale assesses the stable, person – object relationship with technological topics on a four-point Likert scale (1 = strongly disagree to 4 = strongly agree). The decision to utilise a forced-choice format without a neutral midpoint was strategically made to minimise central tendency bias and ensure the emergence of clear dispositional profiles.

Self-Efficacy Expectations: This dimension was measured through 24 items across six subscales, adapted from Holtkemper (2022). These subscales represent the specific demands of technology-

oriented instruction, encompassing facets such as the design of technological solutions and the evaluation of technological impacts.

Implementation Frequency: This was captured through a self-reporting mechanism where respondents indicated whether they had already conducted or planned specific technological units during their professional practical training.

5.2. Sample Characteristics and Contextual Embedding

The present contribution reports on the third pilot phase, involving a cohort of N=16 pre-service teachers enrolled at Paderborn University. These participants were recruited during their mandatory practical semester, a pivotal stage in the North Rhine-Westphalian (Germany) teacher training programme. During this six-month period, students are actively engaged in teaching *Sachunterricht* in primary schools (Grades 1–4), providing a specific nexus between academic theory and classroom enactment.

This cohort was selected to evaluate the refined instrumentation within the context of early career professionalisation. Whilst the sample size reflects the exploratory nature of this pilot stage, it allows for a focused analysis of how initial teaching experiences interact with dispositional factors such as interest and self-efficacy. The data collected from this group serves to establish a baseline for the subsequent, large-scale investigation involving a broader range of both pre-service and in-service professionals.

To ensure high linguistic quality and clarity for an international audience, generative AI tools, specifically DeepL and DeepL Write, were utilized for the translation and stylistic refinement of this manuscript

6 RESULTS AND DISCUSSION

This article focuses on the results of the third pilot study; findings from previous cycles are not reiterated here (Schneider & Tenberge, 2025). While the quantitative results do not reach statistical significance, they provide important exploratory insights and raise critical questions regarding prevailing assumptions in the field. The quantitative analysis provides a insight into the dispositional profiles of pre-service teachers and their instructional engagement.

6.1 Descriptive Status of Teacher Dispositions

To assess individual interest, eight items were aggregated into a scale. As the instrument employed a four-point, positively worded Likert scale without a neutral point, the theoretical midpoint (2.5) serves as the conceptual boundary for interpretation. Mean values below this threshold indicate lower levels of interest, whilst values above signify higher interest. Analysis yielded a mean score of $M=2.39$ ($SD=0.81$), situated below the theoretical centre. This suggests that the sample generally demonstrated a low, albeit only marginally below-average, interest in technological topics. A look at the distribution reveals that eight students scored below the midpoint and seven above (with one exactly at the centre), reflecting heterogeneity.

Following the conceptualisation of interest as a stable person–object relationship by Krapp, this heterogeneity suggests that pre-service teachers differ in their prior experiences and motivational orientations towards technological content. In the context of *Sachunterricht*, this is particularly relevant, as the subject’s multi-perspective structure allows for considerable autonomy in content selection, thereby amplifying the potential impact of individual dispositions.

6.2 *Relation Analysis: The Interest, Self-Efficacy, and Implementation Nexus*

To explore the relationship between teacher dispositions and classroom practice, a point-biserial correlation analysis was conducted. This method was selected due to the dichotomous nature of the implementation variable (implemented vs. not implemented).

Table 2

Point-biserial Correlations between Teacher Dispositions and Technology Implementation (N=16)

Variable	Correlation (r)	Effect Size (Cohen's d)	Significance (p)
Individual Interest – Implementation	-0.33	Medium	.21
Self-Efficacy – Implementation	+0.16	Weak	>.05

Whilst these results do not reach statistical significance due to the pilot nature of the sample (N=16), several tendencies are noteworthy. The weak positive relationship between self-efficacy and implementation is broadly consistent with the theoretical framework of Albert Bandura, which posits self-efficacy as a determinant of action. However, the limited strength of this relationship indicates that self-efficacy alone is insufficient to account for observable teaching practices.

Most notably, the negative association between individual interest and implementation contradicts dominant assumptions in educational research. It suggests that, in this dataset, the implementation of technological content was associated with lower rather than higher levels of interest. Rather than interpreting this finding as an anomaly, it may be understood as an indicator of the specific conditions of early professionalisation.

During the practical semester, pre-service teachers operate within a constrained instructional environment shaped by curricular requirements, mentor expectations, and institutional routines. Consequently, instructional decisions may be less driven by personal motivational dispositions and more strongly influenced by external factors. In this sense, the findings point to a potential ‘suppression effect’, whereby contextual conditions temporarily override individual interest. This

interpretation aligns with a multi-level understanding of implementation, in which micro-level dispositions interact with meso- and macro-level structures.

6.3 *Synthesis of the Pilot Findings*

In summary, the pilot data reveals a ‘dispositional disconnect’. Pre-service teachers demonstrate a foundational level of self-efficacy, yet this does not consistently translate into the implementation of technological content, particularly in the presence of comparatively low or heterogeneous individual interest. The findings suggest that the relationship between teacher dispositions and instructional practice is neither linear nor straightforward. At the same time, these results must be interpreted with caution. The small sample size ($N = 16$) restricts the statistical power of the analysis and limits the generalisability of the findings. The reliance on self-reported data captures perceived rather than observed behaviour. Nevertheless, the pilot study serves an important function in refining the research design and generating hypotheses for further investigation. The expansion of the 2026 main study, including pre-service and in-service teachers, will allow for a more robust examination of whether the observed patterns persist as teachers gain professional autonomy. In this way, the present findings provide a necessary empirical and conceptual foundation for addressing the broader challenge of the persistent ‘implementation gap’ in primary technology education.

7 CONCLUSION AND OUTLOOK

The pervasive nature of technology in the 21st century necessitates a fundamental re-evaluation of its role within primary education. This pilot study, framed as an extended replication of the TeBiS study, contributes to the current discourse by identifying factors influencing the implementation of technological topics within *Sachunterricht*. Building on the empirical evidence presented, several key conclusions can be drawn of technology education:

The negative correlation ($r = -0.33$) between individual interest and classroom enactment suggests that in the early stages of professionalisation, personal motivational dispositions are often suppressed by external systemic factors. Contrary to the assumption that personal interest is the primary driver of innovation, the practical semester appears to be a phase where institutional mandates and mentor guidance exert a dominant influence. Whilst the sample size of the third pilot phase ($N=16$) precludes broad statistical generalisations, initial indicators have been identified regarding the relationship between teacher dispositions and the implementation of technological content. The findings confirm that the mere presence of technology in a child’s environment does not instinctively translate into high-quality instruction; the teacher remains the ultimate gatekeeper.

The inclusion of in-service teachers will allow for an analysis of how professional experience moderates the relationship between dispositions and practice. Future research will systematically record school-specific resources to evaluate how the availability of material tools interacts with teacher self-efficacy. In conclusion, fostering technological literacy in primary education remains a multifaceted challenge. This study provides the necessary empirical baseline to refine

professionalisation strategies, ensuring that the technological perspective in Sachunterricht moves from the periphery to the centre.

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“They Really Need to Handle, Inspect, and Experience Things”: On Teachers’ Practices and Strategies to Teach Technology Inclusively at Primary Level

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Abstract

Taking pupils’ diverse needs into account is considered a central requirement of inclusive education (Booth & Ainscow, 2016). These needs are—according to Ainscow’s (2007) *inclusive turn*—not primarily ‘special educational needs’, but diverse needs of all learners. For the rather segregated German educational system, this endeavour applies especially to primary education, where needs are still developing and pupils are not yet assigned to different types of schooling according to their needs and abilities.

Despite a substantial amount of research on pupils’ basic psychological needs for autonomy, competence and social relatedness (Ryan et al., 2022), strategies that technology education teachers apply in this regard are not yet well understood. Besides interventional studies on technology education, indicating effectiveness of self-directed and action-oriented teaching and learning, there is a dearth of research on how teachers address different needs as a routine.

The purpose of the presented study is therefore to investigate and systematize actions and strategies teachers apply, and to specify how pupils’ needs are considered when teaching technology education on a given topic.

The overall study used a mixed-methods approach to the question how pupils’ needs are characterized by themselves and by their teachers, and how they were taken into account in a lesson adapted and delivered by the teachers. In the sub-study presented here, participating primary school teachers were interviewed about their consideration of pupils’ needs whilst planning and conducting a technology education unit on the functionality of robots.

The results gained from qualitative content analysis of the interviews indicate that although the anticipation of different needs is considered challenging, teachers possess a substantiate amount of practices and strategies to take them into account.

The paper systematizes the practices teachers described in structured interviews within strategies and discusses the contribution of taking basic needs into account for inclusive technology education.

Key Words: Technology Education, Inclusion, Basic Needs, Robotics, Mixed-Methods, Teachers' Abilities

1 INTRODUCTION

Technology Education at primary level in most federal educational systems in Germany is included in the general studies subject '*Sachunterricht*'. Subject specific research has recently increasingly incorporated the developmental task of inclusion into its discourse (Pech et al., 2019). The necessity of developing and designing concepts and designs for inclusive technology education, as a part of '*Sachunterricht*', is therefore considered to be largely undisputed (Offen, 2014). However, underlying requirements to such a reform and their consequences for *established principles, teaching concepts, structural features and practices* are assessed indifferently so far.

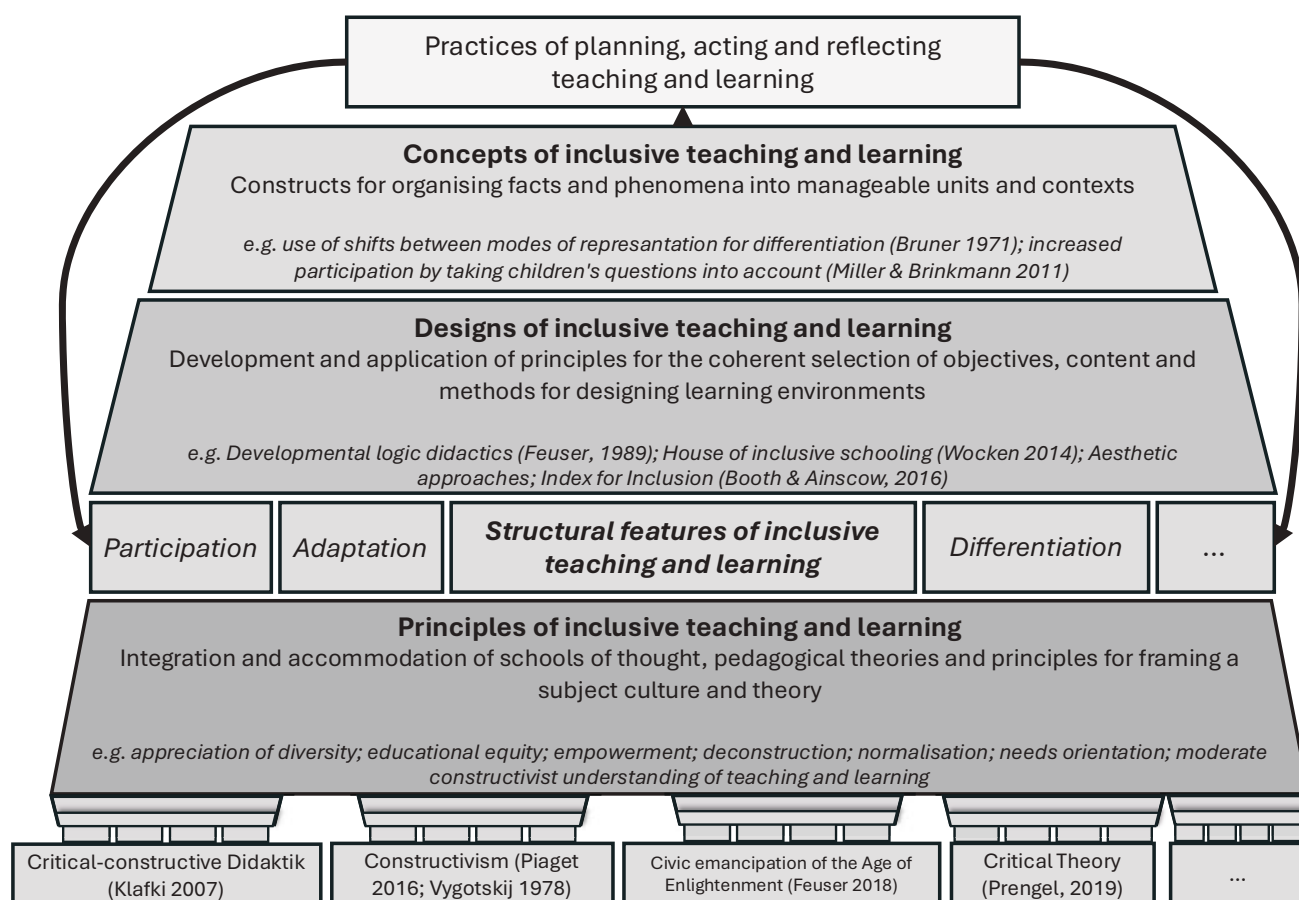
Within the collection of terms highlighted above, the consideration of different learning needs is assigned the status of a fundamental principle of inclusive teaching here. It is considered to not be limited to *practices* as it cannot be sufficiently described through a ritual or a sequence that usually proceeds in a "family-like" manner (Schäfer, 2020, p. 19). Taking needs into account is, under the assumption of their individuality, subjectivity and development a complex part of teaching inclusively (Albers & Lichtblau, 2014, p. 10; Sander, 2004, p. 243). As a teaching strategy it can be influenced by assumptions about the nature of students' needs as well as by value judgements and didactical approaches (e.g., teaching arrangements, use of materials).

Taking needs into account cannot be described exhaustively as an overarching educational design such as action-orientation either. It does not comprise a coherent draft that "develops fundamental principles for the selection of objectives, content and methods for the design of learning environments and, if necessary, applies and concretises them in an exemplary manner" (Kahlert, 2016, p. 153). Especially for the collection of learning objectives, content, and methods, the consideration of needs struggles in offering sufficient categories.

The role of a principle of inclusive teaching design remains for the consideration of learning needs. This is due to its fundamental character that gives the opportunity to frame a subject culture depending on the underlying understanding and the normative value assigned. It cannot yet be constituted as a structural feature in that it has not been sufficiently described in theory or differentiated and substantiated empirically. For illustrative purposes the hierarchy of the aforementioned *principles, conceptions, structural features, concepts and practices* adopted on the basis of Kahlert's work, Figure 1 provides a rather general theoretical model. In addition to a brief definition, there are short examples relating to inclusive teaching for each level of the model. The important connection shown between *practices* and *structural features* is based on the assumption of Seitz (2009) and Dixel (2020, p. 247) that theories on inclusive education cannot be further developed without taking school practice into account. Therefore, the model assumes that structural features are to be developed out of the reflection of practices.

Figure 1

Hierarchical arrangement of concepts, designs, structural features and principles of inclusive teaching and learning with reference to Kahlert (2016, p. 152)



This assumption is adopted for the purposes of this article, as taking diverse learning needs into account is considered a central principle of inclusive education. Earlier policy documents that advocate for inclusive education – like the Salamanca Statement (UNESCO, 1994) still referred to “special needs education”, which was specified as needs that “arise from disabilities or learning difficulties”. Education policy documents from the 2000s, such as the UN-CRPD (United Nations (UN), 2006) or the UNESCO report “Guidelines for Inclusion” (UNESCO, 2005), no longer make this distinction. Instead, they refer to the “needs of persons with disabilities” (UN, 2006, p. 6) or to needs related to diverse characteristics, such as age or gender.

Inclusion-related educational research has also taken up the concept of needs and integrated it into definitions of inclusive teaching (Grosche, 2015, p. 25; Nuding & Stanislawski, 2013, p. 8; Schumann, 2009, p. 51). In particular, for Schumann (ibid.) and Grosche (ibid.), this orientation represents a central moment in the departure from two-group theories such as *disabled* and *non-disabled*. Under the deconstruction of such two-group theories teachers are confronted with a broad variety of different types of learning prerequisites of which the consideration of needs is one next to e.g., knowledge, skills, interests, and self-concept. For many of those personality

features well established strategies exist to take them into account. This makes them more of a structural feature of teaching and less of a normative principle. So far there is a dearth of research to move the orientation of teaching towards the needs of learners from a principle to a comprehensive, operationalised and systematic structural feature.

The present paper addresses this research and development desideratum – the theoretical grounding and empirical differentiation of actions and strategies for taking learning needs into account. Following a demarcation of the field of enquiry, theoretical considerations on presuppositions, value judgements and approaches to taking needs into account in inclusive technology education are explored.

The presented study is based on a theoretical framework provided by self-determination theory (SDT) (Ryan & Deci, 2018), which has been repeatedly addressed in educational research overall (Aelterman et al., 2019; Conesa et al., 2022; Niemiec & Ryan, 2009), general studies (Haase, 2018; Hartinger, 2005) as well as technology education research at primary level (Beinbrech, 2003; Schröer & Tenberge, 2023; Tenberge, 2002). The study aims towards the exploration and description of practices, actions and strategies to systematize and develop them towards structural features of needs-adaptive technology education at primary level. The theoretical and normative claims are subsequently illustrated and differentiated based on empirical data, guided by the research question “*What actions and strategies do general studies teachers name and describe in order to meet the needs of all learners in a technology education learning environment on the functionality of robots?*”.

The findings from interviews with teachers in general studies allow to systematize practices of planning, acting and reflecting a technology education unit conducted in a needs-oriented manner on the topic of ‘learning to think and solve problems with learning robots’ (Bohrmann & Tenberge, 2024; Schröer & Tenberge, 2023). For the purpose of the present paper, excerpts from the results of qualitative content analysis as part of the author’s dissertation project are used. The results in form of structurally identified and empirically differentiated structural characteristics are after all discussed against the backdrop of established structures of inclusive teaching and learning in technology education at primary level.

2 ON THE DIVERSITY OF UNIVERSAL NEEDS – A LITERATURE REVIEW

The theory of basic psychological needs describes needs as *innate*, *essential* and *universal* personal dispositions (Ryan & Deci, 2000b, p. 74). Therefore, they are independent of personal characteristics that could potentially lead to marginalisation, such as socio-cultural background and special educational needs. SDT distinguishes among deficiency and growth, as well as physiological and psychological needs (Deci & Ryan, 1993). *Physiological needs* (e.g. nutrition) are linked to the functional principles of homeostasis and are characterised by a specific time of satisfaction (Krapp, 2005, p. 631). *Psychological deficiency needs* are described as being situational (e.g. safety), while *psychological growth needs* are permanently effective and expand under favourable developmental circumstances (Kuhl, 2001, p. 450.; Ryan & Deci, 2018, p. 81). To date, the assumption of three basic psychological needs, that are focused here as well, has prevailed (Ryan & Deci, 2000a):

- (i) *Autonomy*: The need to determine goals, approaches and actions freely, without control.
- (ii) *Competence*: The need to experience requirements as challenges, to be able to meet them and to experience oneself as responsible and self-effective.
- (iii) *Social relatedness*: The need to identify with the goals and values of significant others and to perceive oneself as belonging in a social context and being important to others.

The assumption of the *universality* of psychological growth needs does not imply their *uniformity*. The expression of needs differs depending on individual developmental prerequisites, the context in which they are perceived and subjective attributions of meaning to their satisfaction (Ryan & Deci, 2018, p. 242.). The establishment of inclusive structures and practices in technology education provides such a context, where taking individual, subjective and contextual needs into account is at least normatively desirable (German Society for the Didactics of General Studies, 2013, p. 10; Marquardt-Mau, 1998, p. 8; Ministry of Schools and Education of the State of North Rhine-Westphalia (MSB NRW), 2021, p. 178; Pech et al., 2018, p. 15). If technology education at primary level is understood as an area of education that among other things focuses on the promotion of personality development, then considering the needs of pupils as part of their personality does not remain a legitimate task (Blumberg, 2008; Einsiedler, 1988; Siebach, 2022; Tenberge, 2002). It should be an integral part of the subject's professional and disciplinary identity.

3 STATE OF RESEARCH AND PROBLEM STATEMENT

There is little research available on the diversity of needs in primary education. So far, the results of Tenberge's (2002, p. 111.) study confirmed the validity of the needs for autonomy and competence in science and technology education and point to their variance. It remains widely unclear how needs differ interindividually between different students and intraindividually as far as the composition of the expression of the abovementioned basic needs is concerned. Studies, as in Haase (2018), usually focus on the satisfaction of needs. In most cases they apply theory-based, needs-oriented treatments and examine their effectiveness or, as in Niemiec & Ryan (2009), investigate how effectively teachers satisfy their students' needs. It remains unclear which actions and strategies teachers use to take needs into account and which expressions of needs a treatment or teacher is unable to satisfy.

Those research findings provide guidance on practices and concepts that facilitate the development of environments that take learners' needs into account. Haase (2018, p. 77) summarises characteristics such as freedom of choice, station learning, experiments and discovery learning for the promotion of autonomy. The need for competence, could be satisfied through self-control, presentations, staggered tips and feedback methods (ibid.). Finally, the need for social relatedness could be satisfied through partner and group work, caring and playful forms of learning (ibid.). Quantitative research findings suggest in structural equation models that the satisfaction of competence and autonomy needs can predict a high level of intrinsic motivation. However, correlations of this kind are considered ambiguous, which can be attributed to the complex interplay between open-ended situations and the individual interests and goals of learners. (Bieg et al., 2011, p. 135) The question of how to consider diverse needs represents a

deepening of this issue, as it focuses on the fundamental drives that underlie the subordinate motives and goals.

While studies assume that needs are universal and not uniform, the present study assumes that not all learners want to act equally self-determined (autonomy); that not all learners want to be challenged equally (competence) and that not all learners want to share actions and goals with others equally (social relatedness). The study therefore takes a closer look at school practice, where teachers deal with different expressions of needs on a more routine basis.

4 STUDY

The article utilizes an empirical approach to the consideration of needs in primary level technology education. The qualitative sub-study within a greater mixed-methods context, conducted as part of the author's dissertation project, discusses the actions and strategies that teachers identify and describe for taking different needs in technology education classes into account.

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text – especially for translating the teachers' statements in the results chapter from German into English appropriately. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

4.1 Design

Subsequently to a preliminary survey for teachers and students, teachers ($N = 4$) conducted a self-planned technology education unit on the functionality of robots with emphasis on problem-solving. The teachers (hereafter referred to as LP_2AM, LP_3BA, LP_3DR and LP_4ES) were recruited from the Integration of Theory and Practice project (ITPP) at the University of Münster. The unit was conducted in one second, two third and one fourth grade class. They were teachers with many years of experience, to ensure that they possess as wide of a range of strategies as possible. The teachers were previously instructed about fundamental assumptions about students' needs and a set of tasks and learning objectives for teaching the technology education unit 'learning to think and solve problems with learning robots'. The unit consisted of several task formats that varied in complexity from easier Start-to-finish programming assignments to more complex problem-solving tasks such as programming a parcel delivery robot. All the tasks were designed to incorporate the use of the Bluebot® educational robot. In addition to introducing students to sequential programming, the lesson aimed to illustrate the importance of the unambiguity of commands and the input-processing-output principle. After planning for and conducting the unit in their own classes, the teachers were interviewed using a structured methodological approach (Krell & Lamnek 2024). The interviews went on for approximately 60 minutes addressing questions about *actions and strategies* to consider diverse needs whilst planning and conducting the unit. For the purpose of desubjectification interviews contained questions that intended to express answers as advice to preservice teachers.

4.2 *Methods of Data analysis*

The qualitative research approach of the sub-study is supported by the assumption that the genesis of theories about inclusive teaching cannot be shaped without the inclusion of school practice (Dexel, 2020; Seitz, 2009, p. 247). Although basic psychological needs require theoretical sensitivity, their theoretical framework is so far not sufficient for describing how they are considered. The central goal of identifying need-oriented practices of technology education teachers as a key to promoting inclusive education is therefore pursued using an evaluation method based on the structuring content analysis described by Kuckartz & Rädiker (2022) with deductive and inductive analysis components. The deductive coding schema consisted of main categories based on the basic needs and theoretical subcategories assigning segments to objects needs are geared towards according to Nuttin (1984, p. 1) (entities, occurrences, persons/relationships, emotions). The coding schema was differentiated with inductive categories in an iterative analytical process.

For this pragmatic approach according to Steinke (2007) and Döring & Bortz (2016) the *empirical* anchoring of epistemic acquisition is of fundamental importance. This means that the results obtained from data analysis have to be sufficiently substantiated by the data. To ensure this, a comprehensive coding schema was created in the first step. It described and justified the deductive categories and established a set of coding rules. The coding guide specified on the conditions under which inductive subcategories could be formed and provided examples of where this could occur. In this way, the analysis followed what was intriguing, true and important from the perspective of the test subjects without reacting to every statement with new categories. Analytical categories are indicated with italics in the following chapter.

5 RESULTS

Teachers considered taking the needs of all learners into account ‘a lofty goal’ (LP_4ES, pos. 70). The assumptions about the quality of this aspiration were described as sometimes overwhelming and sometimes associated with temporal tolerance. For example, the passage ‘I can only ever try’ (ibid.) illustrated that efforts to take needs into account sometimes remain merely attempts. In another passage, *resignation* was evident in reference to the question of how the teacher could do justice to all children: ‘I won’t (.) and I have to accept that.’ (LP_3DR, pos. 105).

The other two teachers claimed to use *time resources* to do justice to all children, which should on the one hand serve to ensure *social integration*: ‘By sitting in a circle with all 25 of them in the morning and seeing how they are doing [...] You have to take the time.’ (LP_2AM, pos. 69) On the other hand, one teacher cited to use time strategically to promote autonomy: ‘First, I listen to [...] what the children have to say. (...) And, um (...) I basically diagnose that for myself [...] at home and then see. (...)’ (LP_3BA, pos. 52)

The statements of all teachers were similar in terms of value judgements. The focus was on their own *diagnostic judgements*: ‘Okay, so I wouldn’t put any value on assessments and I wouldn’t [...] rely on the statements of colleagues [...]. I would always take the time to get to know the

children myself first.’ (LP_3DR, pos. 109) For LP_3BA as well ‘the highest principle is, basically, my own perception’ (LP_3BA, pos. 58).

5.1 *Adressing the need for competence*

It terms of taking the need for competence in technology education into account, giving students the opportunity for cognitive, psychomotoric, affective and emotional action with the subject matter appears as a core category. The quote in the title of this article illustrates this fundamental strategy to provide all pupils with differentiated and adaptive action-oriented challenges.

The approaches the teachers expressed in the interview passages are characterised by a high degree of individuality. In her statements, LP_2AM often relied on *guided learning aids* to enable all learners to experience competence. She keeps ‘*cards with clues or short films*’ (LP_2AM, pos. 75) ready and used them to support the *specifically composed learning groups*. She justified her approach, which was described as not very conducive to autonomy, with the learners’ insufficient ability to make decisions for themselves.

5.2 *Adressing the need for autonomy*

In contrast, LP_4ES described the design of settings that specifically promote autonomy and competence: ‘So *different levels of difficulty*, but I also have a bit of *natural differentiation* in there by leaving some freedom [...] and letting them decide what they feel confident doing, what they want to try out’ (pos. 70). She repeatedly described her actions and strategies as ‘*intuitive*’ (pos. 76) and ‘*natural*’ (pos. 82). As a result, she found it difficult to assign ‘*vocabulary storage*’ (pos. 82) or ‘*images where I can look again to see how something works*’ (pos. 80) to specific needs: “I really have to think about why I am doing this and what method it is.” (pos. 78). Finally, she described her approach to *learners’ questions*, which were said to be geared towards taking their autonomy needs into account. For several teaching topics, she described structures for formulating, working on and answering questions through *research*, *trials* and *experiments* or through *Socratic discussions*.

5.3 *Adressing the need for social relatedness*

LP_2AM reported that on the *home visits* she makes when she takes over a class (LP_2AM, pos. 69). She also emphasised the importance of *creating transparency* and *empathy* for diverse learning requirements for herself and among the learners: “And I always say, ‘Yes, if someone can’t swim very well. Does it make sense to take a boat out to sea and say, “Right, now let’s swim back to the island?”’” (ibid.). In her examples, she focused her *attention on external or internal characteristics* of learners affected by marginalisation (impaired vision, experience of flight, dyscalculia, illness of parents). In Addition, the quote illustrates, how the consideration of needs for competence and social relatedness are interrelated.

Time and again, the relevant sections suggest that it is challenging for the teachers interviewed to take needs for belonging into account strategically in specific situations. Given that the consideration of belonging needs is consistently described in relation to specific situations under the category of ‘events’, it can be assumed that such situations require a high degree of sensitivity

to individual circumstances and empathy, which also appears objectively challenging to translate into a strategy.

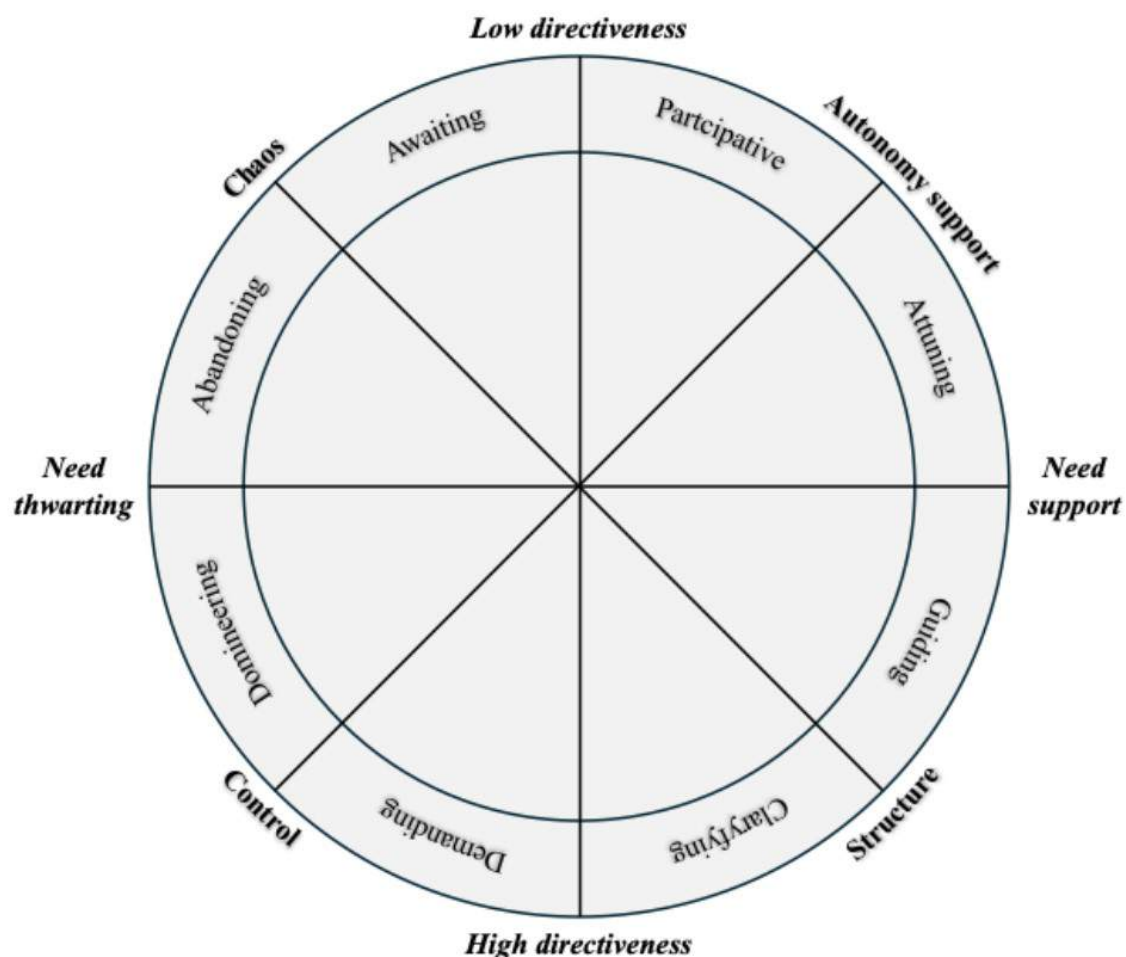
In order to address different expressions of the need for a sense of belonging, LP_2AM describes the strategic use of free work periods for one-to-one discussions and the associated assessment. “I have three days where they come in and work until 8.15 [I: hm (affirmative)], when I have plenty of time for one-to-one conversations [...]” (LP_2AM, pos. 69)

DISCUSSION AND OUTLOOK

The teachers interviewed recognise taking learners’ needs into account as an important aspect of technology education. At the same time, they emphasise the complexity and difficulty involved both in theory and in practice. The results suggest that needs-adaptive technology education is similar in structure to established action-oriented designs that promote learners’ subjectivity and engagement with the subject matter. The results can be used to identify and classify suitable practices and assign them to pupils’ needs. Based on the circumplex model by Aelterman et al. (2019, p. 499), which is the first to structure characteristics of more or less autonomy-oriented teaching, the extracted starting points in needs-oriented general studies can be clustered (Figure 2).

Figure 2

Graphical representation of the circumplex model of Aelterman et al. (2019, p. 499)



Accordingly, cards with clues become measures for promoting autonomy through structure, that enable self-directed action in the learning process in an accompanying or explanatory manner. This contrasts with teaching practices that refrain from control or take a wait-and-see approach, which are used in the data for *learning diagnostics* or *social purposes*. On the second axis of the model, which distinguishes between highly controlling and less controlling environments, the inclusion of *questions from learners* can be characterised as a participatory feature. *Socratic discussions*, on the other hand, are described as more demanding in nature.

Questions remain open about the educationally appropriate consideration of different needs in technology education classes, which can only be answered from the overall study. It is conceivable that models for other basic psychological needs can be extrapolated from the available data and assumptions. The overall results point towards a dimension of more or less *structured* environments to satisfy different expressions of needs for competence. To address different expressions of the need for social relatedness a differentiation between stronger *community* and stronger *individuality* can be deduced from the results.

It must be assumed that, given the varying nature of people's needs, a highly differentiated and adaptive approach to addressing these needs is required. Next to giving students challenging tasks with opportunities to psychomotorically and cognitively act with the subject matter it appears to be of importance to make use not only of opportunities for action but also of the skills required to promote self-efficacy. Questions remain open about the interaction between needs and abilities, which has not been taken into account here. From an educational research point of view, it is not only the question considered here that is of interest, namely which learners are motivated in a context to decide for themselves, to take on challenges or to negotiate goals and approaches with others, but also which learners are capable of doing so in a self-effective manner and what support they need.

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How Do Design Students Use ChatGPT When Ideating?

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Abstract

This paper explores how design students use Generative AI (GAI) tools, in particular ChatGPT, during the ideation phase of a design process. Although design students use GAI tools to support ideation, little is known about how they apply them and how this relates to their creativity. This explorative study describes how design students interact with ChatGPT during ideation and considers what this might mean for teaching creativity in design education. The study took place within an existing project course and analysed the individual concept generation of 44 User Experience Design students. The dataset includes ChatGPT chatlogs, three resulting concepts per student, and short self-reported descriptions of tool use. Two analyses were conducted: a qualitative content analysis of the chatlogs and a comparative analysis of the concepts developed from the generated output.

These findings show that ChatGPT-supported ideation is often initiated through broad, task-driven prompts with limited output steering. Iterative interaction occurs, but is not the default mode. At the concept level, generated content often informs concepts directly, with purpose, form, and meaning more frequently retained, and interaction more often adjusted. The most common configuration consists of concepts in which all four dimensions remain the same, indicating direct transfer of generated content. Alignment analysis further shows that concepts often remain more closely aligned with generated output than students' descriptions suggest.

Taken together, these findings indicate that AI-supported ideation unfolds through differing configurations of interaction and concept development. The prevalence of limited steering and direct adoption suggests a lack of consistent creative engagement. At the same time, instances of more iterative use and loosely inspired concepts show that alternative forms of engagement do occur. This highlights the need for more deliberate and reflective engagement with generative tools and a crucial role for design education in teaching and supporting this type of engagement.

Key Words: Generative AI, Design Education, Creative Thinking, Ideation, AI literacy.

1 INTRODUCTION

Since the late 2022 we have seen a fast adoption of Generative Artificial Intelligence (GAI) tools in various creative industries, including design practice. Designers can use these tools to support their creative thinking and making activities, for example by automating routine tasks and generating initial design suggestions (Melker et al., 2025). Design is an inherently creative process (Goldschmidt, 2014). However, being creative as a designer is not always an easy task, especially when you are still in the process of learning. Within the context of design education, GAI tools might therefore provide novice designers with new and different ways of creative support.

At the same time, concerns are raised about novice designers' reliance on GAI tools (Popescu & Schut, 2023; Schut & Detweiler, 2025). If novice designers partially outsource their creative thinking and making to GAI tools, then questions arise regarding their opportunities to develop their creative ability independent of these tools. Although design students use GAI tools while designing, little research has examined how they interact with these tools and how the generated content is being used in their creative process. Therefore, this explorative study investigates how design students use the GAI tool ChatGPT when ideating ideas and creating concepts to shed more light on how these tools are integrated in an ideation process.

2 LITERATURE REVIEW

In creative practice, tools are not neutral instruments. Schut & Detweiler (2025) argue that, next to the designer, tools and material possess a form of agency, meaning that the designer–tool–material interplay influences the creative process and its outcomes. Creativity in design therefore emerges not solely from the autonomous designer. Unlike earlier digital tools that required active engagement, GAI can produce outputs automatically with minimal user input (Jose, 2023). Aspects of the creative process that once required manual effort can now be partially outsourced. Whereas traditional tools depended on a designer's skills to produce viable results, GAI tools can generate a large set of ideas in response to a simple prompt. The integration of GAI into design workflows may thus influence how ideas are generated and developed.

Several studies suggest that the primary value of generative AI lies in augmenting rather than replacing human creativity (Heigl et al., 2018; Anantrasirichai & Bull, 2022). Although generative AI can produce content autonomously, designers play a crucial role in steering its operation to ensure alignment with their creative vision and contextual requirements (Jansen & Sklar, 2021; Liu et al., 2024; Tsao & Nougues, 2024). In ideation contexts, prompt formulation plays a decisive role in determining the likelihood of producing creatively valuable outcomes (Heigl et al., 2018). Urban et al. (2025) found that effective prompts explicitly included evaluation criteria, with high-performing students requesting ideas that were “original” or “useful,” while low-performing students provided no additional specifications. While GAI can enhance creativity by providing new tools and perspectives (Hwang & Wu, 2025), other research suggests that it may impede creativity by fostering over-reliance on machine-generated solutions, potentially leading to homogenized outputs (Elgammal et al., 2017). If GAI diminishes the need to reflect or

engage in higher-order thinking, it raises concerns about weakening cognitive resilience (Jose, 2023).

Skilled designers can craft precise prompts that communicate their creative vision effectively, producing outputs aligned with intended goals (Oppenlaender, 2022), whereas less experienced users often provide more generic prompts that require refinement (Tsao & Nougues, 2024). Students frequently turn to GAI when lacking inspiration (Jose et al., 2023), reflecting a broader trend of cognitive off-loading that may affect memory, attention, and metacognition. Jose (2023) argues that cognitive off-loading can foster passive interaction and reduce individuals' capacity to reflect on their own thinking. Similarly, Boers (2024) found that students rarely employed cognitive strategies aimed at enhancing human–AI interaction, instead repeating generated suggestions. While GAI tools can improve efficiency in creative tasks, they also raise concerns about cognitive autonomy and dependency (Tao, 2023).

Within design education, where developing creative competence is central, a tension emerges between the support offered by GAI tools and concerns about passive use (Schut & Detweiler, 2025). Although GAI tools can help initiate ideation, for example by generating starting points to move beyond the 'blank canvas', working from examples is known to increase the risk of design fixation (Jansson & Smith, 1991). Novice designers are particularly susceptible to fixation on example stimuli (Nicholl & McLellan, 2007), which raises concerns when students engage with GAI tools without deliberate guidance.

To gain further insight into how GAI tools relate to novice designers' creative processes, this study examines how design students use ChatGPT during ideation, from generating initial ideas to developing concepts. The study addresses the following research question: *How do design students use ChatGPT to ideate ideas and create concepts during the ideation phase of a design process?*

3 METHODOLOGY

To address the research question this study adopts a qualitative descriptive research approach to examine how design students use ChatGPT during ideation and how generated content relates to subsequent design concepts. The study is interpretive in nature, focussing on understanding observed practices and patterns of use in context.

3.1 *Participants and context*

The study was embedded within an existing 2nd year bachelor-level User Experience Design design studio course. In this course, students designed interactive “shared spaces” for one of six design briefs of comparable complexity in groups of approximately six students. Of the 88 enrolled students, 48 responded to a call to participate in the research, of whom 44 provided usable data and were included in the analysis. Participation was voluntary, informed consent was obtained, and all data were anonymised prior to analysis.

As part of the course, students individually developed six concepts during the ideation phase of a design project. For three of these concepts, tutors asked students to explore a ChatGPT-supported ideation approach. The use of ChatGPT was not prescribed in a specific manner and no prompting instructions were given. The students decided how and to what extent they engaged with the tool during ideation, allowing us to investigate their ‘uninformed’ approach.

3.2 *Data collection*

The dataset consists of three types of data:

- 78 ChatGPT chatlogs, recorded in concept template documents, documenting students’ interactions with ChatGPT during ideation.
- 132 design concepts, recorded in concept template documents.
- 132 self-reported descriptions of ChatGPT use, included as part of the concept template.

The ChatGPT logs varied in structure due to differences in students’ approaches. Some students used one chat to support multiple concepts, while others used separate chats. This resulted in 78 chatlog documents across 44 participants.

3.3 *Analysis*

Two complementary analyses were carried out to provide insight into both interactional processes and artefact-level outcomes, which are described in the upcoming two sections.

3.3.1 *Analysis of ChatGPT support ideation*

An analysis of the 78 ChatGPT chatlogs was conducted to examine how students prompt and interact with the tool during ideation. The analysis followed qualitative content analysis (Schreier, 2012), with coding procedures informed by established qualitative data analysis practices (Miles et al., 2014). Atlas.ti was used to support coding and data organisation. Only student prompts were coded, ChatGPT responses were excluded.

Following Schreier (2012), a coding frame was developed by combining concept-driven and data-driven approaches. Prompt types identified by Urban et al. (2025) were used as an initial reference and iteratively refined, adapted, or extended based on the data (see Table 1). Coding was conducted iteratively. An initial subset of chatlogs was coded by the first two authors to establish the coding frame through discussion and consensus. After approximately 22 chatlogs, a stable scheme was reached. The second author then coded the remaining data, consulting the first author in cases of uncertainty. Consistent with Miles et al. (2014), coded data were organised into tables of code occurrences and co-occurrences. These displays, together with the coded transcripts, were used to compare instances and identify patterns in prompting behaviour.

Table 1

Coding frame: Design students' ChatGPT prompts (A comprehensive overview of all codes can be found in Table 2 in the appendix)

Code	Code count	Description	Source
ID1 - task instruction	67	Idea generation based on task instruction. The initial prompt rephrasing information from a task instruction.	Urban et al. 2025
ID4 - contextual info	43	Idea generation based on contextual information. Specific instruction for idea generation to include gathered information (for example from research)	Emerged from data

3.3.2 Analysis of Concept Development

A comparative analysis of the design concepts and the ChatGPT-generated content was performed to examine to what extent the students let the generated content inform their concepts. The dataset consisted of 132 design concepts, 78 ChatGPT chatlogs and 132 corresponding self-reported descriptions of ChatGPT use, recorded in concept templates.

A cross-case comparison was done to analyse the data (Miles et al., 2014). Each concept was treated as a case and compared to the corresponding ChatGPT-generated content across four dimensions: form, interaction, purpose, and meaning. These dimensions reflect core aspects of UX designs well known by the students and thereby provided a consistent basis for comparison. For each case, each dimension was labelled as either *same* or *changed*. A dimension was labelled *same* when the core idea or function was retained, and *changed* when the concept introduced a clear modification, reinterpretation, or addition. This binary coding enabled consistent comparison and supported pattern identification.

Students declared use of ChatGPT content was then examined based on their self-reported descriptions. Categories of use were developed inductively from the data and used as contextual information to support interpretation. Next, an alignment analysis examined the correspondence between declared use and the same/changed patterns across the four dimensions. Alignment types were developed iteratively from the data, enabling comparison between reported use and observed transformations.

Following Miles et al. (2014), a cross-case analysis examined patterns across the dataset by organising data in tables. Frequencies and co-occurrences were examined descriptively to identify patterns across cases.

3.4 *Generative AI disclosure*

In accordance with conference guidelines, generative AI tools were used only supportively for copy editing and language refinement. All text content, ideas, analytical work, interpretations, and conclusions were produced exclusively by the authors.

4 RESULTS

Here we present the results of both the ChatGPT supported ideation and the concept development.

4.1 *ChatGPT supported ideation*

This section reports on interaction patterns observed in students' use of ChatGPT during the ideation phase. The findings are descriptive in nature.

4.1.1 *General interaction patterns*

Across the dataset, students' interactions with ChatGPT during ideation are characterised by a limited set of recurring interaction patterns. Ideation sequences most often start with prompts that closely reproduce or lightly rephrase the task instructions. These initial prompts are typically framed as requests for ideas and are rarely accompanied by explicit output specifications. This starting condition is reflected in the frequent co-occurrence of task-instruction-based prompting and the absence of output specification. In these cases, ChatGPT is provided with the task context but little guidance regarding the desired form, scope, or direction of the response. As a result, the interpretation and structuring of the task are largely delegated to the system.

Example prompt:

“Can you give me some useful ideas on how to present the information from the deals from The Hague climate accord in an engaging way for students, in a travelling expo?”

While ChatGPT is consistently used as an ideation support tool across participants, most interactions remain short and open-ended. Extended exchanges involving follow-up prompts, feedback, or refinement occur less frequently and are concentrated in a limited number of chatlogs. This indicates that dialogical, back-and-forth interaction does not occur by default.

4.1.2 *Iterative back-and-forth interaction through follow-up prompting*

Against this general interactional baseline, a small subset of chatlogs shows a different form of engagement characterised by iterative back-and-forth interaction. In these cases, participants explicitly refer to previous ChatGPT outputs and request adaptations, alternatives, or refinements. This interaction pattern is marked by the presence of follow-up ideation prompting and feedback-related prompting. Feedback is more often formulated in general or directional terms than as detailed critique. The limited occurrence of this pattern indicates that extended dialogical

interaction is not a dominant mode of ChatGPT use during ideation. Nevertheless, these cases provide insight into how iterative interaction is constructed when participants do engage in continued exchange.

Example prompts:

“Some ideas are cliché. I’m not sure, about ideas with feet. Is it cultural appropriate according to Muslim culture?”

“I like the first one, where depending on the choices the future changes. Could you make some variations of that one? “

4.1.3 *Output specification versus non-specification*

In addition to variation in conversational depth, the dataset shows clear differences in the extent to which participants explicitly steer ChatGPT’s output. NOS (no output specification) is the most frequently observed condition and appears across the majority of chatlogs. OS (output specification) occurs considerably less often and is unevenly distributed across participants. When present, output specification is typically introduced after an initial response from ChatGPT and often in combination with feedback or follow-up prompts. This suggests that output steering is more commonly reactive than part of the initial prompt formulation.

Example prompt, Output Specification:

“I don’t like it. Can you give me 5 more ideas. Use simple language. I want idea to be futuristic. but also accessible to older people.”

The contrast between output specification and non-specification highlights variation in how much control participants exercise over ChatGPT’s responses. While interpretation of this variation is reserved for the discussion section, its descriptive presence is central to understanding how ideation unfolds in practice.

4.2 *Concept development*

This section reports on the students’ use of the ChatGPT generated content in the creation of their concepts. The findings are descriptive in nature.

4.2.1 *Concept dimensions*

Across the dataset, differences emerged in the distribution of same and changed labels across the four concept dimensions. *Purpose* is the most stable dimension. In most concepts, the intended function remained aligned with the content generated by ChatGPT ($n=100$), while changes in *purpose* occur much less ($n=32$). Retention of *form* ($n=80$) also occurs more often than alteration ($n=52$), indicating that the set-up and material characteristics of the concepts were often

maintained. *Meaning* follows a similar pattern, with underlying ideas or conceptual framings more often retained ($n=79$) than changed ($n=53$). *Interaction* differs from the other dimensions. Here, stability ($n=64$) and change ($n=68$) are nearly evenly distributed, with slightly more instances of alteration. *Interaction* is therefore the dimension in which participants most often adjusted the content generated by ChatGPT. Overall, participants appear to maintain the *purpose*, *form*, and *meaning* more frequently than altering them, while *interaction* shows a more balanced pattern between stability and change. A complete numerical overview of these distributions is provided in Table 3 in the Appendix.

4.2.2 Co-occurrence of concept dimensions

Beyond individual dimensions, the analysis reveals recurring patterns in how stability and change co-occur across multiple dimensions. The most frequent configuration consists of concepts in which all four dimensions are labelled as same ($n=59$). In these cases, form, interaction, purpose, and meaning remain intact between the compared artefacts, indicating direct transfer of the content generated by ChatGPT with no observable changes. The second most frequent configuration consists of concepts in which all four dimensions are labelled as changed ($n=30$). These cases reflect comprehensive modification across form, interaction, purpose, and meaning, indicating substantial alteration of the generated content

Several mixed configurations also occur, though less frequently. For example, one recurring pattern involves changes in form, interaction, and meaning while purpose remains stable ($n=14$). Another involves changed interaction combined with stable form, purpose, and meaning ($n=10$). Additional combinations also occur, but in smaller numbers. Overall, these mixed configurations indicate that changes most often involve interaction, either alone or in combination with other dimensions, while purpose remains stable in most of the concepts. A complete numerical overview of these distributions is provided in Table 4 in the Appendix.

4.2.3 Self-reported ChatGPT use & Alignment

Alignment analysis examined how participants' self-reported use of ChatGPT corresponded with the patterns of stability and change across form, interaction, purpose, and meaning. Participants describe their use along a continuum, ranging from direct adoption of generated content, through adaptation, to inspiration without material reuse. A small number describe substantial modification. Direct adoption ($n=38$), adaptation ($n=41$), and inspiration ($n=49$) occur in relatively similar proportions, while modification ($n=1$) and no-information : ($n=3$) cases are rare.

When ChatGPT is described as a source of inspiration, alignment is most often consistent with mixed stability and change (*inspired* $\times$ *consistent*: $n=40$). In some cases, however, the concept dimension patterns show more stability than the description suggests, indicating closer alignment with the generated content than articulated (*inspired* $\times$ *expanded*: $n=8$). Instances of less alignment than described do not occur in this group. Descriptions of adaptation show more variation. Many cases align with mixed change, meaning that participants describe modifying ChatGPT output and the concept dimension patterns show both stability and alteration (*adapted*

× *consistent*: $n=30$). A considerable number of cases display greater stability than implied, indicating that concepts remain more closely aligned with the generated content than the description suggests (*adapted* × *expanded*: $n=11$). Where direct adoption is reported, alignment is often consistent with stable concept dimension patterns (*direct_adoption* × *consistent*: $n=27$). Cases described as substantial modification are few and consistently associated with extensive change (*modified* × *consistent*: $n=1$).

While inspiration frequently aligns with mixed dimensional patterns ($n=40$), the presence of greater stability in some cases ($n=8$) suggests more substantial uptake than stated. Combined with the frequent correspondence observed in adaptation ($n=30$) and direct adoption ($n=27$), this indicates that many concepts remain closely aligned with generated output, with limited alteration in part of the dataset. A complete numerical overview of these distributions is provided in Table 5 in the Appendix.

5 DISCUSSION

The findings show that, with these students, ChatGPT-supported ideation is often initiated through broad, task-driven prompts with limited output steering. By giving limited context and output specification, the students, perhaps unknowingly, leave various output decisions up to the tool. When combining this insight with the finding that iterative back-and-forth interaction occurs, but it is not the default mode of engagement, more concerns arise. Students appear to lack initiative in steering and redirecting the generated content based on for example their research insights and personal creative needs in an ideation process. Furthermore, the concept analysis indicates that, although various concepts have been more loosely inspired by the generated content, the content also often informs concepts rather directly.

It is well known that working from examples can lead to fixation on (elements of) example solutions (Jansson & Smith, 1991). Here we see how tools like ChatGPT can be used as idea-example-machine, creating a situation in which it becomes very easy for students to adopt the generated content in their subsequent concepts. Although the students could have chosen to engage differently with ChatGPT, we want to highlight that this is not an easy task for novices. Design students would need to understand what could stimulate their creative thinking during ideation and then how to prompt the tool to receive that type of support. Furthermore, tools like ChatGPT are not neutral in their interactions, but actively steer by suggesting follow up interactions (e.g. *Would you like me to elaborate on any of these ideas?*) (Schut & Detweiler, 2025).

The lack of iteration and the often more direct adoption of the generated content points to a lack of creative engagement from the design students. This observation can be related to literature raising concerns regarding cognitive off-loading (Jose, 2023). If students outsource their creative thinking activities and let the tool, perhaps unconsciously, steer their ideation outcomes, what does that mean in relation to the quality of their design output, their agency within this process and their ability to learn to be creative within the educational context?

The previous section describes a more concerning use of ChatGPT. However, the findings also show instances in which the students do engage more iteratively with the tool. Also the concept analysis shows several concepts that are more loosely inspired by the generated content. Although we are not sure what is behind these differences in use, it might be linked to differences in more skilled and more generic prompting practices (Oppenlaender, 2022; Tsao & Nougues, 2024). It might also relate to the importance of active steering and reflective engagement in AI-supported creativity (Heigl et al., 2018; Urban et al., 2025). While such steering does appear to occur in certain instances, it is not consistently present across the dataset.

Design education needs to play a role in teaching appropriate use of these tools in the context of creative ideation. Such an approach should emphasise reflective engagement with GAI tools, as their generative and suggestive nature differs from earlier design tools. This involves supporting students in reflecting on their own creative processes, recognising what stimulates their ideation, and developing an understanding of how prompting and tool behaviour influence generated outcomes.

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7 APPENDIX

Table 2

Coding frame: Design students' ChatGPT prompts

Code	Code count	Description	Example	Source
ID1 - task instruction	67	Idea generation based on task instruction. The initial prompt rephrasing information from a task instruction.	“can you give me some useful ideas on how to present the information from the deals from The Hague climate accord in an engaging way for students, in a travelling expo?”	Urban et al. 2025
ID2 - creativity	10	Idea generation specifically for creativity. Specific instruction for idea generation together with specific evaluation criteria (originality and/or usefulness).	“The above ideas are interesting; however, I would like to instead focus more on leveraging the online habits of the target group towards participating in a book club”	Urban et al. 2025
ID3 - previous answer	29	Idea generation (based on previous answer) . Participants selected one idea from previous answers and asked ChatGPT to generate more ideas based on their selection.	“I like the first one, where depending on the choices the future changes. Could you make some variations of that one?”	Urban et al. 2025
ID4 - contextual info	43	Idea generation based on contextual information. Specific instruction for idea generation to include gathered information (for example from research)	“From our research we noticed residents feel disconnected from the Dutch society and women don't have an active voice and can't participate, partly because of their culture, meaning that many	Emerged from data

			people feel like it's not their place to speak up.	
FB1 - general	30	Feedback without any specific details.	"Let's move on to other ideas because i am not convinced. "	Urban et al. 2025
FB2 - creativity	46	Feedback specifically asking ChatGPT to improve originality or usefulness of its answers.	"it's supposed to be in a museum/expo for kids. And it should fit in one room. The experience should be quite interactive and fun"	Urban et al. 2025
FB3 - detailed	14	Detailed feedback and critical remarks.	" Some ideas are cliché. Im not sure, about ideas with feet. Is it cultural appropriate according to Muslim culture?"	Emerged from data
IG - Information gathering	4	Using ChatGPT as an information resource (similarly to Google search or Wikipedia).	"what's a more than human design approach"	Urban et al. 2025
PAC - Providing Additional Context	12	Providing additional context.	"this is another help from a research: Language barriers limit participation and confidence People who don't speak Dutch or English will avoid events and support"	Urban et al. 2025
OS - Output Specification	56	Specific instruction for the type of generated output (number of ideas, level of detail, tone of voice, ...)	"make a design direction shorter, formal style"	Emerged from data
NOS - No Output Specification	210	Lack of specific instruction for the type of generated output	Not applicable	Emerged from data
V- Visualize	27	Asking ChatGPT to visualize something	"Generate and image to represent this concept"	Emerged from data

Table 3*Concept dimensions*

Dimension	Label	n (concepts)
Form	same	80
Form	changed	52
Interaction	same	64
Interaction	changed	68
Purpose	same	100
Purpose	changed	32
Meaning	same	79
Meaning	changed	53

Table 4*Co-occurrence of concept dimensions*

Pattern label	n (concepts)
All dimensions same	59
All dimensions changed	30
Form/Interaction/Meaning changed; Purpose same	14
Interaction changed; others same	10
Form/Interaction changed; Purpose/Meaning same	7
Interaction/Meaning changed; Form/Purpose same	6
Meaning changed; others same	3
Form changed; others same	1

Interaction/Purpose changed; Form/Meaning same 1

Purpose changed; others same 1

Table 5

Self-reported ChatGPT use & Alignment

Self-reported ChatGPT use	Alignment type	n (concepts)
direct_copy	Consistent	27
direct_copy	Expanded	3
direct_copy	Reduced	2
direct_copy	Contradictory	0
adapted	Consistent	30
adapted	Expanded	11
adapted	Reduced	0
adapted	Contradictory	0
inspired	Consistent	40
inspired	Expanded	8
inspired	Reduced	0
inspired	Contradictory	1
modified	Consistent	1
modified	Expanded	0
modified	Reduced	0
modified	Contradictory	0
no_info	Unclear	3

Post-Digital Images as Boundary Objects in STEAM Subject Art

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Abstract

In Austria, a shortage of qualified STEAM (Science, Technology, Engineering, Arts, Mathematics) teachers is affecting creative subjects such as art and design and is increasingly leading to the use of teachers from other disciplines as well as those in the midst of career changes. Concurrently, digital and image-based media are shaping the everyday lives of students and teachers alike, and the continuous emergence of new digital image cultures is progressively blurring the lines between analogue and digital worlds. Against this backdrop, questions arise regarding the potential these digital images offer for art education and how they can be used for teaching and learning processes.

This research project presents an examination of students and art teachers' post-digital image practices in the context of visual literacy as well as differences in the professional knowledge levels of qualified subject, out-of-field, and career-changing teachers. The aim is to investigate how post-digital images can support collaborative teaching and learning processes while relativising existing knowledge asymmetries in the classroom. As part of an exploratory mixed-methods cross-sectional study, secondary school students ($N = 360$) and art teachers ($N = 45$) at schools in Tyrol (Austria) were surveyed.

This project seeks to make the use of post-digital images visible and to develop starting points for well-founded, everyday, and collaborative art education. Due to the everyday relevance of post-digital images, another goal that underscores this work is to determine to what extent integrating these images in teaching is beneficial for alternatively qualified teachers.

Key Words: Post-Digital Images, STEAM Subjects, Art Education, Boundary Objects

1 INTRODUCTION

Austria is experiencing a shortage of qualified STEAM teachers, which particularly affects creative subjects such as art and technology & design. In general secondary schools, art ranks sixth among all subjects in terms of teacher shortages (Schnider & Braunsteiner, 2024). To cover this shortage, out-of-field and career-changing teachers are increasingly being employed in the STEAM field. These teachers face considerable challenges and pressure to meet professional requirements, especially at the beginning of their careers as teachers (Baeten & Meeus, 2016). In addition to acquiring professional knowledge, meeting these requirements increasingly requires an in-depth understanding of digital and technological topics.

Furthermore, digital technologies have become increasingly important in many areas of life and education. STEAM subjects are central in this regard, as they encompass the teaching of technological skills, design processes, and interdisciplinary problem-solving. Concurrently, teachers – regardless of their level of qualification – are uncertain about how to use digital media (Härtel et al., 2018); specifically, there is a clear need in art education for qualified teachers to receive further training in digital topics (Grünwald & Goreth, 2023).

Students, however, routinely use digital media, especially image-based social media platforms such as TikTok and Instagram (Feierabend et al., 2025; Wedel et al., 2025). In 2025, the average daily screen time for 12- to 19-year-olds in Germany was reported to be 231 minutes (Feierabend et al., 2025). Wedel et al. (2025) further show that young people, on average, spend more time on social media platforms than adults. Visual communication via digital media – such as posting, forwarding, and sending images and videos – is thus part of the everyday communication practices of young people.

Applied to the school context, one can infer that students already possess basic visual and media-related skills due to their intensive digital media use; as such, art subjects have a different didactic starting point than other subjects. Concurrently, continuous engagement with digital media and content is blurring the boundaries between the analogue and digital worlds, thus leading to a post-digital state.

1.1 *Post-Digital Images*

The term *post-digitality* refers to the interweaving of digitality with the environment, be it social, political, or cultural (Klein, 2019). The prefix *post* does not refer to a time after digitality but rather expresses the permanent establishment of the mental and historical state of modernity, which can no longer be clearly distinguished from other states (Schmidt, 2020). In the context of digitality, the prefix thus represents the dissolution of boundaries between analogue and digital states and encompasses the ubiquity and self-evident use of digital media as well as the resulting digital penetration of society. Consequently, the question of whether to reject or accept technologies, including in the school context, is obsolete (Schmidt, 2020); rather, a reflective and critical approach to digital media, images, and their structures is required. Accordingly, addressing digital and post-digital images in the classroom is of central importance, especially in STEAM subjects that focus on technical skills and interdisciplinary problem-solving processes.

Based on the concept of post-digitality, the term *post-digital image* can be derived, where such an image is understood as an entity that is interwoven with the social environment via digitality (Schwarz, 2024). Access to such entities is purely digital – occurring, for example, via gestures such as scrolling, swiping, and tapping. Post-digital images belong to the everyday images of non-art, which are ubiquitous in large quantities (Arvedsen et al., 2022). Characterised by continuous circulation, mutation, and reinterpretation within digital networks, these images interact closely with social, cultural, political, and ecological contexts. They are continuously shared, edited, and redesigned via social media platforms; hence, memes have become a representative image category (Schwarz, 2024).

1.2 *Post-Digital Images as Boundary Objects in STEAM Education*

In STEAM education – especially art – engaging with post-digital images has didactic potential, as the images reveal the intertwining of analogue and digital worlds while enabling critical reflection on changing communication and perception processes. Additionally, post-digital images offer learning potential, as students use digital tools to transform two-dimensional images into three-dimensional models, thereby integrating creative, technical, and spatial ways of thinking.

At the same time, post-digital images are produced through technologically shaped production processes, such as algorithmic image processing, AI-based image generators, and automated image editing. As a result, images are no longer only media of communication but also technological artefacts whose design, circulation, and perception are closely connected to digital infrastructures and platform logics. Against this backdrop, both technological thinking and a deeper understanding of the underlying processes, as well as digital technological literacy, are becoming increasingly important, particularly in the context of AI-generated image content such as so-called ‘brainrot memes’ or ‘slop content’. In this regard, STEAM subjects play a central role, as they make it possible to analyse these phenomena from multiple disciplinary perspectives and to explore their structural interrelations.

Since post-digital images are directly connected to young people's everyday lives, students and teachers reach a comparable level of reception, which partially relativises traditional knowledge asymmetries. These images are characterised by low-threshold and participatory access, which can facilitate exchanges in art education regardless of prior artistic knowledge while also promoting collaborative teaching and learning processes.

Post-digital images can function as boundary objects (Star & Griesemer, 1989) by overcoming boundaries within teaching-learning relationships and fostering collaboration between different actors. The concept of boundary objects can facilitate coordination and knowledge transfer across heterogeneous social contexts, thereby promoting knowledge exchange and coherent collaboration despite differing levels of knowledge and experience (Akkermann & Bakker, 2011).

Furthermore, such objects can serve as starting points for design-orientated learning by enabling the collaborative engagement with technological and design-related issues. Their particular strength lies in their combination of flexibility and structural stability: they can be interpreted

differently by various actors while simultaneously functioning as shared points of reference across contexts (Star & Griesemer, 1989). In this way, they support collaborative design and problem-solving processes.

Since students and teachers are on a comparable level in the reception of post-digital images, questions arise regarding how each group responds to these image phenomena, what visual literacies become visible in the process, and to what extent this results in interfaces for collaborative teaching.

1.3 *STEAM Teachers' Professional Knowledge in Post-Digital Image Practices*

Due to teachers' varying levels of knowledge of, experience with, and forms of participation with post-digital images, they do not necessarily need to appear omniscient in the classroom, which can be an asset, especially for teachers with alternative qualifications, such as out-of-field and career-changing teachers with less subject knowledge than qualified subject teachers (Prince & O'Connor, 2018; Widagsa et al., 2025). Additionally, those who have changed careers may have fewer pedagogical skills (Lucksnat et al., 2022).

However, professional knowledge is a central component of the teaching profession (Baumert & Kunter, 2006). Following Shulman (1986), Kunter et al. (2011) divided professional knowledge into a three-part model consisting of pedagogical knowledge (PK), pedagogical content knowledge (PCK), and content knowledge (CK). While PK encompasses knowledge about classroom management, classroom development, and learning processes, PCK includes the ability to prepare subject-specific content in a didactically appropriate manner and to design differentiated learning processes. CK refers to an in-depth, subject-specific understanding as the basis for lesson planning and implementation (Kunter et al., 2011). However, this research project focuses on PCK and CK, as PK is not centrally relevant to answering the underlying research question.

Since the integration of post-digital images in art education has received little research attention to date, questions arise as to what professional knowledge art teachers have on this topic, the extent to which differences exist in specialised knowledge among teachers with different qualification levels – particularly due to the everyday relevance of these image phenomena – and whether collaborative forms of teaching are being pursued in the context of subject didactics.

1.4 *Research Context*

The aim of this research project is to investigate how art teachers and students address post-digital images in visual literacy. On this basis, an interface was developed to enable well-founded and collaborative communication between both groups in art education. Additionally, differences in professional knowledge among teachers with different qualification levels – out-of-field, career-changing, and qualified subject teachers – regarding post-digital images were analysed with a focus on subject-specific and didactic knowledge to clarify the extent to which addressing this topic in the classroom is beneficial, especially for alternatively qualified teachers.

The study's objective gives rise to two central research questions, which are the focus of the study design:

- (i) How do teachers and students respond to post-digital images in visual literacy to create an interface for knowledge transfer in art education?
- (ii) To what extent can differences in professional knowledge regarding post-digital images be observed between out-of-field, career-changing, and qualified subject teachers?

The following section presents the research design used to empirically investigate these two research questions.

2 RESEARCH DESIGN

This exploratory cross-sectional study employed a mixed-methods approach. The central research questions were examined using an anonymised online questionnaire that included closed-ended and open-ended questions. The sample included students and teachers who were surveyed at a specific point in time.

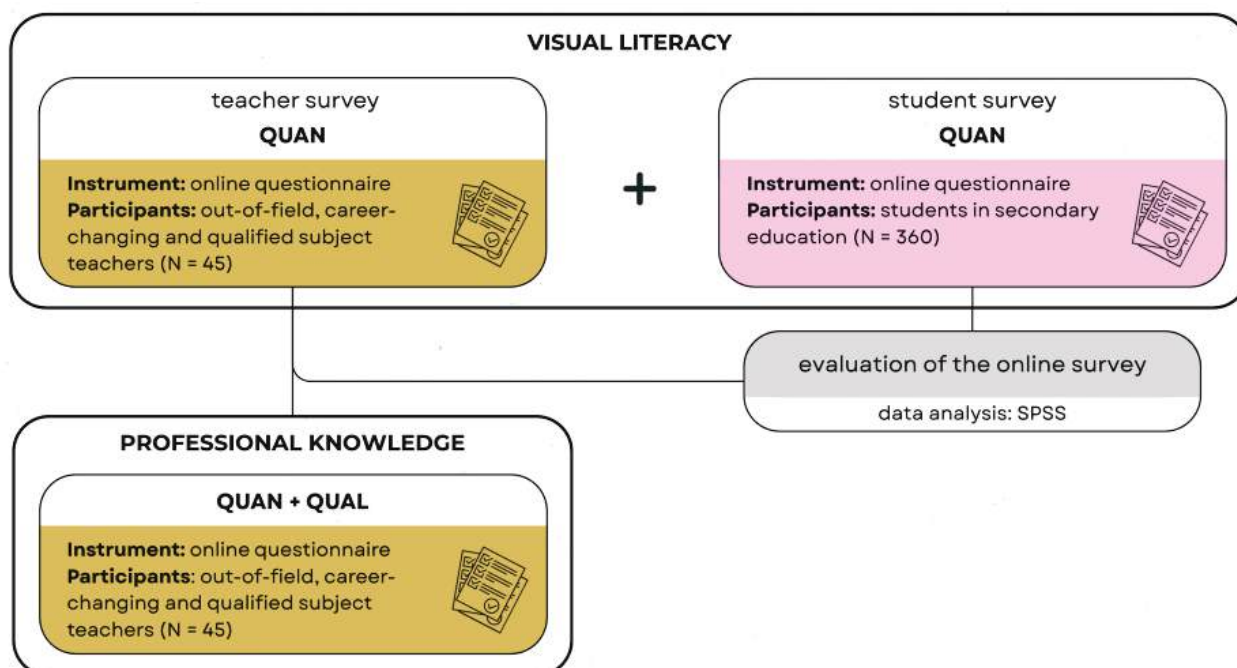
2.1 *Participants*

For the study, secondary school students ($N = 360$) in Grades 8 and 9 at secondary and middle schools in Tyrol, Austria, were surveyed. Data were collected during regular art classes using an anonymous, exclusively quantitative questionnaire regarding the use of post-digital images. The sample was obtained by contacting schools throughout Tyrol; participating schools had provided prior consent. Participation required a written declaration of consent from the participant's legal guardians.

In addition, teachers ($N=45$) were surveyed using an online questionnaire containing both closed-ended and open-ended questions. The sample included subject teachers, out-of-field teachers, and career-changing teachers in art (see Figure 1). Teachers were recruited through courses and professional development programmes at the University of Education Tyrol; participation was voluntary.

Figure 1

Research design to answer the research question



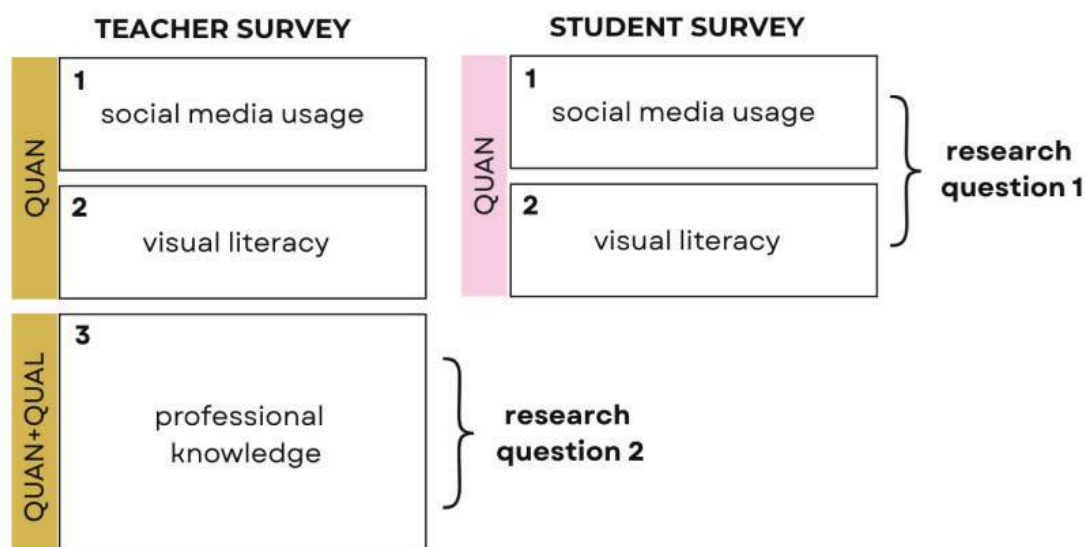
2.2 Research Instrument

The survey instrument and study design were submitted as part of an ethics application to the review board of the Faculty of Teacher Education at the University of Innsbruck (Austria) and were deemed ethically unobjectionable and in accordance with the university's ethical guidelines.

The survey instrument consisted of an online questionnaire created using SoSci Survey, which was divided into two sections. The first section was aimed at students and teachers and contained exclusively closed-ended questions on social media use and visual literacy (see Figure 2). The second section was reserved for teachers and included both quantitative and qualitative questions on professional knowledge.

Figure 2

Sections differentiated according to teacher and student surveys



The first section, social media usage, was based on the Social Media Use Scale (SMUS) questionnaire by Tuck and Thompson (2024), which consists of 17 items that comprise four factors: image-based SMU (five items; $\alpha = .86$), comparison-based SMU (three items; $\alpha = .75$), belief-based SMU (four items; $\alpha = .78$), and consumption-based SMU (five items; $\alpha = .77$). This section covers students' and teachers' general social media usage to allow for an analysis of group-specific differences in usage intensity. Participants responded to each factor from the SMUS questionnaire using a nine-point Likert scale, which ranged from 1 = 'never' to 9 = 'hourly or more frequently'. An example item from the image-based SMU category is as follows: 'Looked at how many people liked, commented on, shared my content, or followed/friended me'.

The second section, visual literacy, was developed independently on the basis of relevant literature, after which its content was validated by an expert ranking ($N = 3$). This section operationalised the response to post-digital images in five dimensions: visual value, visual performance, visual persuasiveness (according to Burri, 2008), active response, and affective response. The items were responded to on a five-point Likert scale that ranged from 1 = 'does not apply at all' to 5 = 'applies completely' ($\alpha = .89$). An example item from the visual persuasiveness dimension is 'Now, after looking at the image, I want to look at it again because it has aroused my interest'.

The aim of this section of the questionnaire was to identify similarities and differences in students' and teachers' responses to post-digital images and, on this basis, to derive potential interfaces for knowledge transfer in art education. Before responding to the items, participants were randomly presented with two out of three images for 8 seconds each. The selection was based on source images from popular social media memes and adhered to both content-related and structural criteria. To enable diverse patterns of reception and interpretation, the stimuli differed in the interplay of foreground and background as well as in the type of subjects depicted (person, animal,

object). The presentation duration was based on Ellison et al. (2020), who identified an average viewing time of 7.65 seconds.

The third section, professional knowledge, was also designed based on theory, relevant literature, and Kunter et al.'s (2011) three-part model. The items were rated on a five-point Likert scale (1 = 'does not apply at all' to 5 = 'applies completely'). An example item from this dimension is 'Sociotechnical aspects (e.g., treatment of images, reaction to images) should also be taken into account in image analysis'. The test subjects were also provided with a text field for qualitative justification of their answers, which deepened the quantitative findings and allowed the researcher to reconstruct the underlying reasoning. The qualitative data were analysed through coding, with the analysis supported by an intracoder reliability check.

The data collected through the exploratory mixed-methods design was evaluated using the statistical programmes SPSS and MAXQDA. The scales for social media usage, visual literacy, and professional knowledge were formed according to their theoretical structure and checked for internal consistency. Inferential statistical comparison methods were used to analyse group-specific differences between students and teachers.

3 RESULTS

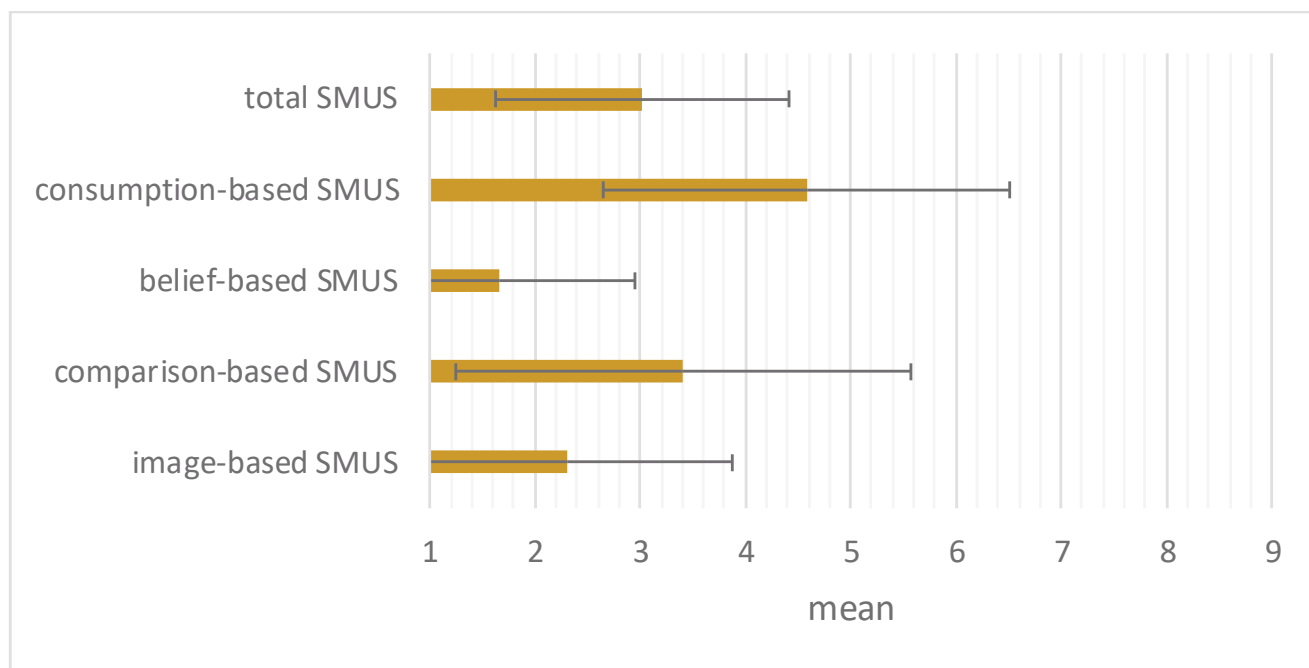
The first section of the questionnaire on social media use provides differentiated insights into the social media usage of students and teachers.

Regarding the general frequency of social media use, students had a mean score of $M = 5.91$. ($SD = 0.69$) on a seven-point scale (1 = 'never' to 7 = '(almost) all the time/constantly'), indicating daily to multiple-times-daily use. For the group of teachers, the same item yielded a slightly lower mean score of $M = 5.35$ ($SD = 1.17$). The higher standard deviation suggests greater variability in usage intensity within this group.

A differentiated analysis of the four factors of the SMUS questionnaire reveals varying patterns of social media use within the student group (see Figure 3).

Figure 3

Mean values of the four-factor model of the SMUS questionnaire on a nine-point scale (student group).



In addition, the study assessed how frequently teachers address memes and post-digital visual phenomena in art education. On a five-point scale (1 = ‘never’ bis 5 = ‘several times a day’), this item yielded a mean value of $M = 1.50$ ($SD = 0.83$).

4 DISCUSSION

Given the limited research on the use of post-digital images in art education, an exploratory research approach was deemed appropriate to systematically explore the topic, generate initial hypotheses, and enable further research. Since post-digital images constitute an integral part of everyday communication practices (Feierabend et al., 2025; Wedel et al., 2025), the research design aimed to identify interfaces in the responses of students and teachers, as well as their didactic potential for art education.

The results show that social media play a central role in the everyday lives of both groups. Students exhibit the highest mean value in the domain of consumption-based SMUS, indicating a strong receptive use of digital content. At the same time, post-digital image phenomena are still rarely addressed in art education. Against this background, it appears relevant to further investigate the potential of systematically integrating post-digital images in both art education and in interdisciplinary STEAM approaches.

For the analysis of the subsequent sections of the questionnaire, combining the concept of visual rationality (Burri, 2008) with affective and behavioural responses within the framework of visual literacy makes it possible to examine image processing beyond purely visual analyses and to consider the action-related dimensions of digital affordances. The quantitative survey allows for comparative analyses across different grade levels and school types, while qualitative approaches in follow-up studies could provide further depth of understanding.

The section on professional knowledge captures teachers' knowledge of post-digital image practices and their implementation in art education. Different approaches may emerge, particularly regarding the use of post-digital images as boundary objects or their didactic positioning within a post-digital present. The mixed-methods approach enabled an analysis that combined quantitative comparability with the qualitative reconstruction of individual reasoning.

It should be noted that this study captures snapshots of how post-digital images are used and implemented in art education. Given the dynamics of post-digital image practices, longitudinal and other further studies would be useful to analyse development and transformation processes in a more differentiated manner. Furthermore, the selection of images represents only limited access to post-digital image phenomena. Due to the fast-paced nature of these image phenomena and their close interconnection with current social developments, it is challenging to capture their ongoing relevance in a once-off survey. However, the general questions were meant to allow future researchers to use updated image examples in follow-up studies and to transfer results to different post-digital image contexts.

Beyond art education, post-digital images have potential for STEAM education, as they combine aesthetic, technological, scientific, and social dimensions, in addition to mediating interfaces between disciplines. Specifically, the affordances that come into play when responding to these digital images provide a wide range of starting points for interdisciplinary approaches. While the art education perspective focuses on visual and image aesthetics, the computer science perspective enables the examination of image generation processes, algorithmic structures, and interface logics, as well as data visualisation analyses from a scientific perspective.

5 CONCLUSION

Since post-digital images have, to date, been insufficiently researched in art education, they offer considerable potential for art education practice and, beyond that, for STEAM education. As everyday visual phenomena, they offer common spaces for reception and negotiation between students and teachers and, as boundary objects, they support collaborative mediation processes.

Against the backdrop of a teacher shortage and the increasing involvement of alternatively qualified teachers, the didactic implementation of post-digital images – especially due to their everyday relevance – appears not only relevant to teaching practice but also beneficial to the profession. The results of the present study provide in-depth insights into both; nevertheless, further research would be useful to develop a differentiated and continuous understanding of this topic through in-depth and longitudinal research designs.

6 DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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From Using to Learning: Educational Possibilities of 3D Printing in Technology Education through Design-Based Research

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Abstract

Digital fabrication technologies such as 3D printing are increasingly used in school education and are often associated with creative making. However, previous studies have pointed out the risk of superficial making, where students focus on visual outcomes rather than engaging in design reasoning. This study examines the educational potential of 3D printing by exploring how students conceptualize its role in relation to a contrasting fabrication method, woodworking. A design-based research (DBR) approach was employed in an open-ended problem-solving task combining woodworking and 3D printing with 177 first-year lower secondary students in a Japanese public school. Students freely selected materials and fabrication methods based on their design ideas, questionnaires, and open-ended reflections. Among 120 analysed cases, products were classified into functional and decorative groups based on the role of 3D-printed components. Quantitative results showed no significant differences in enjoyment or perceived difficulty between groups. However, the functional group demonstrated significantly higher awareness of the characteristics of 3D printing. Qualitative text analysis revealed that while the decorative group emphasized ease of use and appearance, the functional group more frequently referred to design considerations, complex geometries, and the complementary relationship between fabrication methods. These findings suggest that the educational value of 3D printing depends not merely on access to the technology, but on how it is positioned within design decision-making. Learning environments that juxtapose multiple fabrication methods can support learners in developing a more conceptually grounded understanding of materials, processes, and design.

Key Words: 3D Printing, Technology Education, Design-Based Research, Learning Design, Digital Fabrication

1 INTRODUCTION

In recent years, with the development of the Maker Movement and digital fabrication technologies, their use in educational settings has expanded (Halverson & Sheridan, 2014). In particular, 3D printing has been introduced early in school contexts and has been increasingly used across a wide range of subjects and learning contexts (Ford & Minshall, 2019). For example, integrating 3D printing into STEM project-based learning has been reported to enhance students' perceptions of creativity and problem-solving abilities (Ali Bicer et al., 2017).

While these studies highlight the educational potential of 3D printing, some challenges have also been identified. In school-based making activities, visually attractive artifacts tend to be highly valued, which may lead students' attention to be directed toward decorative features rather than functional performance. Blikstein (2013) described this tendency as the “keychain syndrome,” in which learners' focus shifts away from design reasoning and consideration of technical principles and toward the production of appealing outputs.

This issue resonates strongly with long-standing discussions in technology education, where learning is conceptualized not as the completion of artifacts but as the process of judging what works in response to a design problem. From this perspective, design activity involves evaluating and selecting technical means—such as materials and fabrication processes—in relation to purposes and constraints (Williams, 2010; de Vries, 2005). These perspectives suggest that technology education offers a productive theoretical lens for addressing educational challenges associated with digital fabrication.

However, review studies on the educational use of 3D printing have highlighted its potential benefits, such as enhancing creativity, supporting problem solving, and enabling iterative prototyping. At the same time, its adoption in K–12 education remains limited, and the integration of 3D printing into educational systems has been identified as an important challenge (Ford & Minshall, 2019). Within this context, particular attention should be paid to how learners position 3D printing in relation to other materials and fabrication processes, especially how they understand it as a technical means within design decision-making.

Accordingly, this study situates 3D printing in relation to learners' prior experiences with manual fabrication, focusing in particular on woodworking as a contrasting example. An open-ended design-based problem-solving task combining woodworking and 3D printing was implemented. On this basis, the study explores how students conceptualize and articulate the advantages of 3D printing and examines differences in these framings from the perspectives of decorative and functional use. Specifically, this study addresses the following research questions:

- (i) What aspects of 3D printing do students identify as advantageous when engaged in a problem-solving task that incorporates both woodworking and 3D printing?
- (ii) Compared with students who use 3D printing primarily for decorative purposes, what kinds of design-related considerations characterize students who use 3D printing in a functional manner?

2 THEORETICAL BACKGROUND

2.1 *Analytical Perspective of This Study*

This study focuses on how students perceive the advantages of 3D printing in a learning task that combines 3D printing and woodworking. In particular, students' post-activity reflections are examined with attention to whether their use of 3D printing is framed primarily in decorative terms or in functional terms.

In technology education and design research, design activity has long been conceptualized as a process involving problem solving and judgment rather than merely the production of finished artifacts (Cross, 2001; Lewis, 2004; Williams, 2010). From this perspective, the educational significance of design lies in learners' engagement in judging what works in response to a given design problem. However, Vossoughi and Bevan (2014) have pointed out that making activities can sometimes be reduced to step-by-step, recipe-like construction, limiting opportunities for deeper engagement in design. This suggests that the structure of learning tasks and environments plays a critical role in shaping the quality of learners' engagement in design activity. Accordingly, investigating how students interpret the advantages of 3D printing as a digital fabrication technology provides an important lens for considering how such technologies are positioned within technology education.

2.2 *Educational Characteristics of Digital Fabrication*

3D printing is an additive manufacturing process in which objects are fabricated through the layer-by-layer deposition of material based on digital design data. This process allows relatively complex geometries to be realized and supports iterative modification of designs through changes to digital models (Gibson, Rosen, & Stucker, 2015).

In contrast, conventional fabrication methods such as woodworking are largely based on subtractive processes and involve different principles and constraints. Previous studies have examined the educational impact of 3D printing by comparing it with traditional fabrication methods. For example, Greenhalgh (2016) reported that, while 3D printing improved precision and craftsmanship, students perceived hand construction as more beneficial for supporting the design process. These findings suggest that different fabrication methods afford different forms of engagement in design activity.

Differences in material properties and fabrication processes shape both the possibilities and limitations of design and are therefore expected to influence learners' points of attention during design activity (Ashby, 2011; de Vries, 2005). From an educational perspective, engaging students with multiple fabrication methods can make these differences explicit and provide opportunities for learners to consider why particular materials and processes are appropriate for specific purposes. Furthermore, it is important to examine how learners interpret these differences and position them as technical means within their design decision-making.

2.3 *Constructionist View of Learning*

Papert (1980) proposed constructionism, which emphasizes that learners construct knowledge through the process of designing and making meaningful artifacts. From this viewpoint, making is not simply a means of producing an end product but serves as a medium through which ideas are externalized, examined, and reconstructed.

Research on design activity further suggests that learners engage in a reflective conversation with materials and representations such as sketches, models, and prototypes (Schön, 1983; Goldschmidt, 1991). These representations function as resources that support learners in inspecting, revising, and developing their ideas.

Grounded in this constructionist perspective, the present study does not attempt to directly measure students' internal understanding. Instead, it examines how students construe 3D printing as a technology by analyzing their final products and their post-activity responses.

3 RESEARCH DESIGN AND METHODS

This study adopted a design-based research (DBR) approach (Design-Based Research Collective, 2003) to examine students' learning in an open-ended problem-solving task that combined woodworking and 3D printing. The present study is positioned as an exploratory cycle within an initial implementation of a learning design that emphasizes comparison and selection among different fabrication methods. The findings are intended to inform subsequent refinement of learning design.

The study was conducted in one public lower secondary school in Japan. Participants were 177 first-year lower secondary students. All students followed the same instructional sequence and had no prior formal experience with 3D printing. Prior to the main task, students engaged in preparatory activities using small-scale tasks with restrictions on the number of materials and component sizes, through which they learned basic procedures for woodworking and 3D printing.

In the main task, students were asked to identify a problem in their everyday lives and to design and fabricate a product using appropriate materials and fabrication methods. The task was open-ended, and students were not restricted in their choice of materials or processes. They could use woodworking only or combine woodworking with 3D-printed parts according to their design ideas. Laminated wood and 3D-printed parts could be used without numerical limits. The task was implemented over twelve class periods (five periods for planning and design, and seven periods for fabrication).

After completion of the task, students' final products were collected, and a post-task questionnaire and open-ended written reflections were administered. Both the questionnaire and written responses were completed anonymously during class time. Students were informed that their responses would be used only for research purposes, and participation was voluntary.

For the present analyses, 120 students who provided complete sets of final products, questionnaire responses, and written reflections were included.

The questionnaire consisted of items rated on a four-point response scale (4 = strongly agree, 3 = somewhat agree, 2 = somewhat disagree, 1 = strongly disagree) addressing enjoyment of the task, perceived difficulty, awareness of the characteristics of 3D printing, understanding of material properties, understanding of fabrication processes, changes in perspectives on materials and processes, and selection of materials and processes according to purpose, and these items were developed based on the instructional goals of the unit and relevant prior research in technology education.

The items included statements such as: “I enjoyed the free-making activity aimed at solving a problem,” “I found the activity difficult,” “I was able to design and create parts by considering the characteristics of the 3D printer,” “I was able to understand the differences in properties between materials such as wood and plastics,” “I was able to understand the differences between fabrication methods such as woodworking and 3D printing,” “Through the activity, my way of thinking about materials and fabrication methods in everyday life changed,” and “If I had another opportunity for free making, I would be able to select materials and fabrication methods according to my purpose.”

Open-ended responses were collected using two prompts: “What do you think are the advantages of 3D printing? Please describe freely.” and “Please write your impressions of the lesson freely.” Students were asked to respond freely without a fixed template.

Open-ended responses were written in Japanese. Morphological analysis and frequency analysis were conducted using KH Coder (Higuchi, 2016), focusing on content words such as nouns, verbs, and adjectives. Function words were excluded. After consolidating semantically similar word forms, the authors examined the contexts in which frequent words appeared and interpreted their meanings.

Analyses were conducted on the original Japanese data, and key words and expressions were translated into English for reporting. Final products were classified into a functional group and a decorative group based on the role of 3D-printed parts within the products. Two authors conducted the classification independently and discussed discrepancies until agreement was reached. Questionnaire data were summarized using descriptive statistics, and group differences were examined using Welch’s independent-samples t-test.

No generative AI tools were used to produce the text or conduct the analysis in this study. Generative AI was used only for minor language refinement, including translation support. All interpretations are those of the authors.

4 RESULTS

4.1 *Classification of Final Products and Questionnaire Results*

Students' final products created in the main task were analysed with a focus on how 3D-printed parts were used in relation to wooden components. Based on the role played by 3D-printed parts within each product, the products were classified into two groups based on the role of 3D-printed parts: the Functional group and the Decorative group.

Products in the functional group included 3D-printed parts that served functional roles, such as hooks or storage components designed for specific objects or shapes, with the aim of improving usability or performance. In these products, woodworking and 3D printing were combined to address particular functional requirements.

In contrast, products in the decorative group included 3D-printed parts with primarily decorative or aesthetic qualities, such as name plates or star-shaped charms. In these cases, 3D printing was used mainly to enhance the appearance of the product and did not play a functional role. Representative examples of products from each group are shown in Figure 1.

Figure 1

Representative examples of products in the functional and decorative groups



These examples illustrate how 3D-printed parts were integrated with wooden components, highlighting the distinction between functional uses and decorative applications.

Of the 120 students whose final products were analysed, 73 were classified into the functional group and 30 into the decorative group. The remaining 17 students used woodworking only and did not incorporate 3D printing; therefore, they were excluded from group-comparison analyses.

A post-task questionnaire was administered to examine students' perceptions of the task.

Across all students ($N = 120$), mean scores for all questionnaire items exceeded the midpoint (2.5), indicating generally positive perceptions of the task. The mean score for enjoyment was 3.58 ($SD = 0.57$), and the mean score for perceived difficulty was 3.11 ($SD = 0.66$). The mean score for awareness of the characteristics of 3D printing was 2.88 ($SD = 0.85$). Mean scores for understanding of material properties and understanding of fabrication processes were 2.98 ($SD =$

0.72) and 3.10 (SD = 0.74), respectively. The mean score for changes in perspectives on materials and processes was 3.18 (SD = 0.66), and the mean score for selection of materials and processes according to purpose was 3.29 (SD = 0.73).

Group comparisons between the functional and decorative groups were conducted using Welch's independent-samples t-test (Table 1). No significant differences were found for enjoyment or perceived difficulty. However, the functional group showed significantly higher scores on awareness of the characteristics of 3D printing than the decorative group ($t = 2.53$, $p = .014$, $d = 0.58$).

Table 1

Comparison of the functional and decorative groups on questionnaire items

Item (short description)	Functional group (n=73)	Decorative group (n=30)	<i>t</i>	<i>p</i>	<i>d</i>
Enjoyment	3.63 (0.54)	3.43 (0.63)	1.51	.139	0.35
Difficulty	3.15 (0.66)	3.03 (0.67)	0.81	.420	0.18
Considered features of 3D printer	3.01 (0.81)	2.53 (0.90)	2.53	.014*	0.58
Understanding material properties	3.00 (0.71)	2.87 (0.73)	0.85	.399	0.19
Understanding fabrication processes	3.15 (0.72)	2.93 (0.78)	1.31	.197	0.29
Change in perspectives	3.15 (0.66)	3.10 (0.71)	0.34	.739	0.08
Ability to select materials and processes	3.40 (0.66)	3.13 (0.78)	1.63	.109	0.38

Note: Values are *M* with *SD* in parentheses. Group differences were examined using independent-samples Welch's *t*-test. $p < .05$.

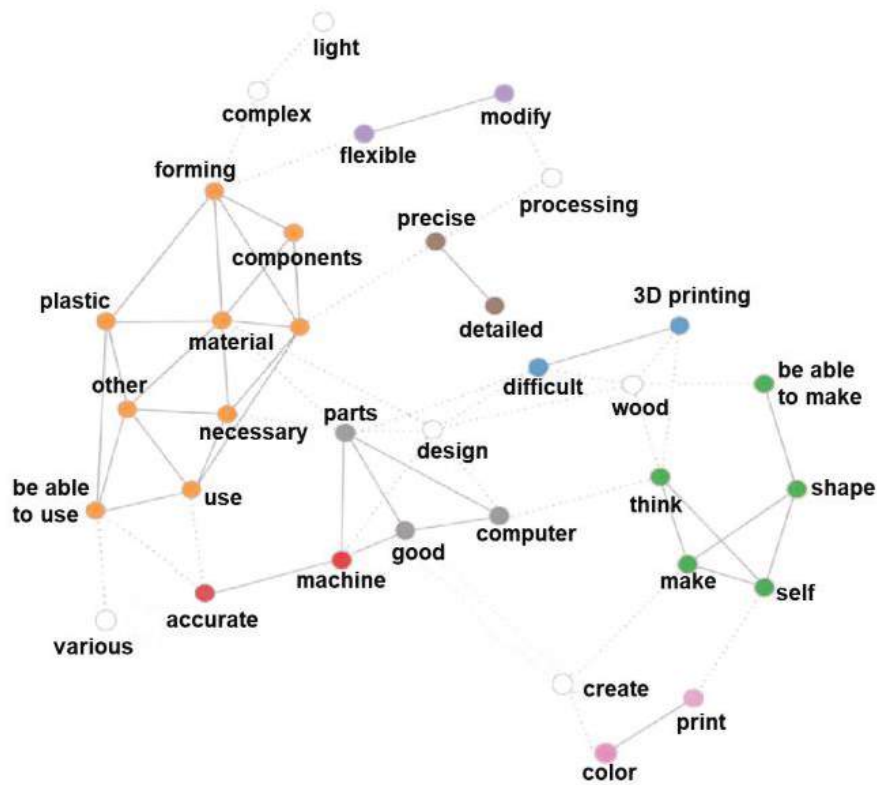
4.2 Co-occurrence Network Analysis of Students' Responses on the Advantages of 3D Printing

To examine how students perceived the advantages of 3D printing, a co-occurrence network analysis was conducted on open-ended responses collected after the task (Figure 2).

In the network, nodes represent words and links indicate co-occurrence relationships between words based on their tendency to appear together in the responses. In this study, node size does not represent frequency; instead, the network focuses on structural relationships among words. The network reveals several interconnected clusters of words, reflecting different ways in which students interpreted the advantages of 3D printing.

Figure 2

Co-occurrence network of students' perceptions of 3D printing



One cluster centers on words such as “make,” “shape,” “self,” “create,” “print,” and “color,” indicating that students perceived 3D printing as a means of giving form to their own ideas and supporting visual expression.

Another cluster includes terms such as “plastic,” “material,” “components,” “parts,” and “forming,” suggesting that students understood 3D printing in relation to materials, parts production, and fabrication processes.

A further cluster is organized around words such as “precise,” “detailed,” “accurate,” and “machine,” indicating that students recognized the precision and mechanical characteristics of 3D printing.

In addition, words such as “design,” “computer,” “3D printing,” and “difficult” form a cluster associated with digital design processes, suggesting that students perceived 3D printing as a technology connected to design and to the production of forms that are difficult to realize otherwise.

Taken together, these clusters indicate that students perceived the advantages of 3D printing not only in terms of appearance, but also in relation to fabrication, precision, and digital design processes.

4.3 Comparison of Characteristic Words Between Groups

To further examine the differences between the functional group and the decorative group, characteristic words were extracted using KH Coder. Characteristic words are those that appear more frequently in a particular group compared to others and are identified based on association measures such as the Jaccard coefficient (Higuchi, 2017). The values shown in Table 2 indicate the degree to which each word is characteristic of a given group in comparison to the other group.

Table 2

Characteristic words in the decorative and functional groups (association scores)

Functional group (n=73)	Score	Decorative group (n=30)	Score
shape	0.297	make	0.209
make	0.257	self	0.133
wood	0.143	be able to	0.133
think	0.130	easy	0.098
computer	0.071	color	0.083
flexible	0.062	3D printing	0.079
design	0.062	design	0.061
complex	0.062	decide	0.061
light	0.052	hand	0.061
parts	0.041	like	0.057

Note. Scores indicate the degree to which each word is characteristic of the respective group based on association measures (e.g., Jaccard coefficient).

Differences were observed in the types of words appearing in each group. In both groups, “make” was a prominent word. In the decorative group, words such as “easy,” “color,” and “self” were extracted as characteristic words, indicating that students referred to the usability of 3D printing as well as personal preferences and visual appearance.

In contrast, the functional group included words such as “shape,” “wood,” “computer,” “design,” “complex,” and “parts.” These words suggest that students referred to aspects related to materials, digital tools, design processes, and geometric forms. In particular, the appearance of the word “wood” indicates that students referred to the relationship between 3D printing and other materials, while the word “complex” suggests that 3D printing was understood in relation to the production of complex shapes.

These tendencies were also reflected in students' written responses. For example:

- "A 3D printer is very useful because it can solve problems that cannot be solved with wood alone, and I think it will be useful in the future."
- "It is possible to make small parts or round parts that are difficult to make with wood."

In addition, some students referred to characteristics of digital design and machine-based fabrication:

- "If I design what I have in mind, I can make it exactly as designed."
- "It is difficult to make something exactly as intended with wood, but with a 3D printer, the machine will make it as long as the design is correct."

Overall, these results indicate that students in the functional group tended to refer more to materials, design processes, and forms, whereas students in the decorative group emphasized usability and visual aspects.

In addition, some students mentioned changes in how they viewed materials and fabrication methods in everyday life, such as noticing that materials and processes are selected according to purpose or becoming more aware of the effort and ingenuity involved in making everyday products.

5 DISCUSSION

This study examined students' learning in an open-ended problem-solving task that combined woodworking and 3D printing, using both quantitative and qualitative data. No significant differences were found between the functional and decorative groups in self-reported understanding of material properties or fabrication processes. However, students in the functional group reported significantly higher awareness of the characteristics of 3D printing during design. In addition, analysis of written responses indicated that students in the functional group tended to reflect on their design and fabrication processes with attention to the characteristics of different materials and processes.

These findings can be interpreted from the perspective of constructionism (Papert, 1980). Papert argued that learning is not simply a matter of constructing artifacts but involves constructing ideas and concepts through the act of construction. Students in the functional group did not treat 3D printing merely as a means of producing shapes; rather, they engaged in design by considering the properties and constraints of fabrication methods through comparison with woodworking. This suggests that their activity involved not only assembling products but also developing conceptual understanding of fabrication processes.

At the same time, learning with digital fabrication does not automatically lead to such conceptual understanding. Blikstein (2013) warned that the accessibility of digital fabrication may cause learners' activity to converge on operation and output, resulting in superficial making that lacks design judgment or engagement with technical principles. The tendencies observed in the decorative group are consistent with this concern, as 3D printing appeared to be used mainly as a means of enhancing appearance.

An important implication of this study is that, even within the same learning environment, students may frame 3D printing in qualitatively different ways—as a functional design resource or as a decorative addition. While combining woodworking and 3D printing can create conditions that open possibilities for conceptually rich construction, it does not guarantee that all students will engage in such learning.

Woodworking and 3D printing embody fundamentally different relationships between design and fabrication. In woodworking, students interact directly with material and can make situational adjustments during cutting and assembly. Larger components and structural elements are relatively easy to handle, and design and fabrication often proceed in an intertwined manner. In contrast, 3D printing involves automated fabrication based on digital design data, requiring shapes and dimensions to be explicitly specified in advance. This enables high-fidelity reproduction and the creation of complex geometries and small parts that are difficult to realize through woodworking.

Students in the functional group referred to features such as “small parts that are difficult to make with wood” and “being able to make exactly what was designed,” indicating awareness of these differences. The significantly higher scores for awareness of 3D printing characteristics further support the presence of such understanding among some students.

From a design-based research perspective, these findings suggest that the educational value of 3D printing arises not simply from providing opportunities to use the technology, but from positioning it within learning designs that foreground its technical characteristics and principles (Brown, 1992; Design-Based Research Collective, 2003). In other words, what matters is not whether students use 3D printing, but how it is positioned in relation to other materials and processes.

In technology education, this implies the importance of addressing not only operational skills, but also additive manufacturing processes, material behavior, and the relationship between digital design and physical fabrication. When such knowledge is integrated into instruction and juxtaposed with other fabrication methods such as woodworking, students may begin to view fabrication technologies not as tools to be used uncritically, but as technologies that should be selected and justified according to purpose.

This perspective is relevant beyond 3D printing, extending to emerging technologies such as laser cutters and artificial intelligence, which can produce sophisticated outcomes without requiring users to understand underlying mechanisms. Future learning design should incorporate prompts that encourage comparison among technologies and activities that require students to articulate

reasons for their choices, thereby supporting a gradual shift from decorative to functional framings.

This study has several limitations. In addition to being conducted in a single school and grade level, the classification of products and interpretation of written responses involved researcher judgment. Furthermore, the questionnaire items were developed specifically for this study and were not based on a standardized scale; therefore, issues related to the validity and reliability of the measurements remain. Future research should address these limitations by examining the findings in other educational contexts and by developing more robust and validated measurement instruments.

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Engineering Education: Pedagogy and Practice within Newfoundland and Labrador's Post-Secondary Engineering Curricula

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Abstract

The purpose of this study was to understand the classroom pedagogical practices of post-secondary engineering educators in Newfoundland and Labrador, Canada. In particular, engineering educators and students representing a range of disciplines from a degree-granting institution and from a diploma-granting institution were asked to reflect on their experiences and perspectives regarding teaching methods. There exists a body of research advocating for active learning over passive approaches with scholars calling for greater implementation in engineering education, where passive learning is viewed as being prevalent. This study captured the extent to which this calling has manifested in engineering education within the locale while simultaneously explicating educator and student perspectives on engineering education pedagogy. The research was situated within an interpretivist framework and adopted a qualitative intrinsic single-case design with embedded units. Data were gathered through an online questionnaire and semi-structured interviews. Thematic analysis of the resulting data highlighted recurring patterns associated with instructional practices, instructional preferences, and challenges that helped answer the main research question: What are the classroom pedagogical practices of post-secondary engineering educators across the province of Newfoundland and Labrador? The findings revealed a complex and evolving pedagogical landscape in engineering education within the province. While traditional, lecture-based methods remain prevalent, there is growing momentum toward integrating more active, student-centred approaches. Educators recognize the value of balancing passive and active learning strategies to accommodate diverse student needs, backgrounds, and learning preferences.

Key Words: Pedagogy, Active Learning, Passive Learning, Engineering Education

1 INTRODUCTION

Engineering education plays a role in shaping how technology is perceived and applied to influence our environments. Consequently, it continues to evolve as programs strive to prepare graduates for increasingly complex and interdisciplinary professional contexts. These contexts

contribute significantly to key societal domains, including innovation, economic growth, quality of life, sustainability, and environmental stewardship. Numerous researchers have argued that *active learning* represents a crucial pedagogical approach for enhancing students' understanding of course material (Burns et al., 2023; MacRobert, 2018; Michael, 2006; Patrick et al., 2021; Prince, 2004). Nevertheless, despite widespread advocacy for active learning methods, Felder (2021) contends that passive approaches, most notably lecture-based instruction, continues to dominate many engineering programs. It can be argued that engineering programs operate inside distinctive institutional, regional, and personal contexts that influence both teaching practices and the integration of technology within localized curricula. Accordingly, the purpose of this study was to understand the *classroom pedagogical practices* of post-secondary engineering educators in Newfoundland and Labrador to gauge the extent to which student-centred and active learning approaches have been implemented. To guide this inquiry, the following research question was posed:

What are the classroom pedagogical practices of post-secondary engineering educators across the province of Newfoundland and Labrador?

Both engineering educators and students involved with post-secondary engineering education within the province were asked to voluntarily participate in this study to help answer its research question.

2 LITERATURE REVIEW

Engineering education exhibits a tension between traditional, teacher-centered methods and innovative, research-informed active learning approaches (Newstetter & Svinicki, 2014; Ramnath et al., 2023). This ongoing dialogue between traditional and innovative perspectives highlights the diversity of pedagogical philosophies that shape engineering education. Understanding how these philosophies manifest in actual classroom practice requires examining the extent to which educators' approaches align with or diverge from these theoretical positions.

Due to the scarcity of research on engineering education, studies from broader STEM fields were also consulted due to their pedagogical similarities.

In relation to pedagogy, a theme emerged in the literature indicating that educators employ a range of instructional practices during classroom sessions, each involving varying degrees of student participation in the learning process. While studies such as Akiha et al. (2018), Barreiro and Bozutti (2017), and Stains et al. (2018) shared findings that supported the dominance of teacher-centric learning approaches, other studies reported findings that cast doubt on the universal dominance of lecture-based instruction in engineering and STEM fields (Borrego et al., 2010; Campbell et al., 2016).

Regarding pedagogical innovation, a substantial body of literature supports the benefits of active learning in promoting student engagement and achievement. For instance, Freeman et al. (2014) conducted a meta-analysis comparing examination performance and failure rates among STEM students taught using active versus traditional (lecture-based) methods. Their results indicated

that active learning led to improved examination scores and reduced failure rates. However, not all scholars agree on the interpretation of these findings. Hora (2014), as cited in Campbell et al. (2016), cautioned that Freeman et al. (2014) treated lecturing as a uniform instructional category. They argued that “faculty can use a variety of different strategies while also maintaining ‘continuous exposition by the teacher,’ which was the condition for ‘lecturing’ in the Freeman et al. study” (p. 584). This critique raises important questions about whether all studies included in the meta-analysis measured comparable forms of instruction (Hora, 2014, p. E3024).

When applied to engineering and STEM education, the efficacy of active learning methods at promoting a higher level of course material comprehension is inconclusive. Through a meta-analysis study, Theobald et al. (2020) reported that active learning environments reduced the examination achievement gap between STEM minoritized group students (MGS) and their STEM non-MGS peers by 33% compared to traditional lecture-based classes. Furthermore, Gren (2020) conducted a quantitative study to determine the effects of a flipped classroom approach to teaching software engineering and concluded that the study found *possible* positive effects to using a flipped classroom approach but emphasized that its effectiveness depends on instructors being well informed about implementing active learning environments. In contrast, Estébanez (2017) conducted a mixed methods case study of two groups of students enrolled in the first course of a computer science major: a field that the author aligns with engineering. Both groups received lectures, but the control group followed a purely instructor-centred approach, whereas the treatment group incorporated periods of active, cooperative learning. Subsequent course assessments revealed no significant effect on the academic performance of students between the two groups.

Research on student preferences for active versus passive learning methods showcases mixed feelings. Several studies (Estébanez, 2017; Gren, 2020; Patrick et al., 2021) reported that students generally prefer active learning approaches over passive ones, although this trend is not universal.

A comprehensive review of the scholarly literature on pedagogical practices within engineering curricula revealed a rich and dynamic field characterized by diverse approaches and perspectives. However, several notable gaps were identified. First, there is an absence of research situated within the local context that examines pedagogical practices in post-secondary engineering programs. Second, there is a general lack of in-depth teacher and student perspectives on engineering education pedagogy, particularly within the local setting. Collectively, these have strong implications for improving engineering education locally. Third, existing studies are predominantly focused on degree-granting institutions, with limited attention given to diploma-granting colleges. Examining both degree- and diploma-granting institutions within a single, geographically bounded system provides a comparative lens through which to understand how differing educational missions, such as applied workforce preparation (three-year diploma) versus theoretically oriented professional formation (five-year degree), influence instructional approaches. In response to these gaps, this study sought to contribute meaningful insights into the pedagogical practices of engineering educators and students within the province.

3 METHODOLOGY

This study employed an intrinsic single-case qualitative design with embedded units to investigate pedagogical practices in post-secondary engineering education in Newfoundland and Labrador. Participants were purposefully sampled to include current engineering educators and students from one degree-granting institution and one diploma-granting institution. Data were collected through questionnaires and semi-structured interviews. Separate questionnaires were developed for educators and students, each with two sections. The first collected demographic and contextual information to support descriptive analysis and confirm maximal variation sampling, including program level and discipline affiliation. The second section included open-ended questions aligned with the research questions. Interviews were conducted to explore the phenomena in greater depth through questions distinct from those in the questionnaire. Each interview combined structured and flexible questioning guided by an interview protocol. A total of 170 student questionnaire responses were analysed, spanning first- to fourth-year students across 12 disciplines, along with 13 in-depth student interviews. Educator perspectives were captured through 17 usable questionnaire responses and 11 interviews, representing 14 disciplines across both institutions.

Data were analysed using thematic analysis following Braun and Clarke's (2006) six-phase framework. First- and second-cycle coding procedures (Miles et al., 2014), including descriptive, in vivo, process, and emotion coding, were used to systematically code and refine themes representing both explicit and latent findings. Themes were not determined by frequency thresholds but by their relevance to the research questions, alignment with existing literature, or conceptual significance. The analysis was inductive rather than theoretical, meaning themes were generated from the data rather than imposed through pre-existing frameworks.

GenAI was not used in the production of this research.

4 FINDINGS

The data collection methods provided rich descriptive data that allowed for the identification of important themes associated with pedagogical practices, educator perspectives, and student perspectives. The following presents an initial overview of the key elements identified within these three areas.

4.1 *Pedagogical Practices*

An activity was deemed 'active' if rationale existed that it "involves students in doing things and thinking about the things they are doing" (Bonwell & Eison, 1991, p. 2). Analysis of the data led to the classification of practices as either active or passive and the setting in which they occurred. Settings associated with active practices included: *outside-class*, *in-class*, and *indeterminate*. Settings associated with passive practices included *outside-class* and *in-class*.

4.1.1 Outside-Class Active Practices

A range of active learning practices occurred outside the classroom. Common approaches included the use of textbooks and recorded lecture videos, often supporting flipped classroom models, to help students engage with course content independently. Laboratories and simulations provided hands-on, experiential learning opportunities that allowed students to apply theory in practical or virtual environments. Practice work, for example assignments, problem sets, and projects, required students to actively apply and problem solve beyond class time. Office hours and supplemental instruction (SI) sessions supported individualized and peer-assisted learning, while interactive learning and peer assessment platforms reinforced engagement through quizzes, feedback, and collaborative review.

4.1.2 In-Class Active Practices

Within the classroom, educators employed tutorials, in-class work, and interactive learning platforms to promote engagement through problem solving, discussion, and real-time feedback. Flipped classroom approaches shifted content acquisition outside of class, allowing class time to focus on application and collaboration. Discussions and question-and-answer (Q&A) activities were commonly used to encourage participation, assess understanding, and support deeper exploration of course material.

4.1.3 Indeterminate Setting Active Practices

Some active learning practices could not be clearly categorized as in class or outside of class. Hands-on activities and group work were reported as occurring across multiple settings, including lectures, laboratories, and project work. Problem-based learning (PBL) was also frequently cited, reflecting a core pedagogical approach in engineering education that emphasizes critical analysis and solution development in both in- and out-of-class contexts.

4.1.4 Outside-Class Passive Practices

Although many outside-class activities were active, some passive practices were identified. Field trips were commonly described as observational experiences in which students primarily watched engineering processes in real-world settings with limited interaction beyond occasional questioning.

4.1.5 In-Class Passive Practices

Many in-class instructional practices were characterized as passive, involving minimal student interaction or visible cognitive engagement. Traditional lectures dominated this category, with content delivered verbally or visually through the use of slides, notes, or worked examples, and few mechanisms to confirm student understanding. Watching videos during class functioned similarly when not paired with discussion or follow-up activities; this passive dynamic also extended to independent video viewing outside class. Gap or fill-in-the-blank notes, while supporting attention, did not explicitly require students to actively process or apply concepts.

Demonstrations and instructor-led simulations were also classified as passive, as students primarily observed processes or digital representations without direct manipulation or exploration.

4.2 *Educator Perspectives*

This section presents educator perspectives on teaching practices in post-secondary engineering education, focusing on factors influencing instructional decisions and perceptions of active and passive learning.

4.2.1 *Factors Influencing Teaching Practices*

Educators reported that their teaching practices were shaped primarily by prior experience, pedagogical knowledge, and contextual constraints. Practical classroom experience and reflection were viewed as more influential than formal pedagogical theory in refining instructional approaches. Time limitations, curriculum pacing, large class sizes, classroom design, and limited resources were cited as barriers to implementing active learning strategies. Educators also reported uncertainty or lack of confidence in adopting unfamiliar pedagogical approaches. Instructional choices were further influenced by subject matter (foundational or fact-based courses that led to favouring lectures), institutional culture, peer practices, budget constraints, student workload and attendance, and mixed access to relevant professional development. Overall, teaching practices reflected an interplay of experience, institutional context, and responsiveness to student needs.

4.2.2 *Perceived Effectiveness of Pedagogical Practices*

Educators overwhelmingly perceived active learning approaches, particularly hands-on, problem-based, and project-based learning, as most effective for fostering engagement and understanding. However, they also acknowledged that active learning could slow content coverage and may not suit all learners or contexts. Passive instruction was viewed as necessary for introducing foundational or conceptual material but was commonly described as disengaging when overused. Most educators emphasized the importance of balancing active and passive approaches to support diverse learners and instructional goals.

4.2.3 *Interest in Adopting New Teaching Practices*

Many educators expressed interest in adopting more student-centred approaches, including flipped classrooms and dialogic teaching methods. Despite this interest, implementation was often constrained by time, staffing, and resource limitations.

4.2.4 *Improving Engineering Education*

Educators identified several opportunities for improving engineering education in Newfoundland and Labrador, including increased staffing, expanded and more relevant professional development, improved laboratory and technical infrastructure, and stronger alignment with

industry needs. Enhancing experiential learning opportunities, such as work terms and co-op placements, was also viewed as critical for preparing students for professional practice.

4.2.5 Suitability of Active Learning and Student Preferences

Active learning was perceived as particularly well suited to design-based, applied, and equipment-focused engineering topics, with many educators suggesting it benefits most areas of engineering education. Educators noted that student preferences for active or passive learning vary widely based on background and readiness, reinforcing the view that no single teaching model is universally effective. A blended approach combining active and passive methods was widely seen as the most inclusive and effective strategy.

4.3 Student Perspectives

This section summarizes student views on teaching practices, highlighting perceptions of effectiveness, engagement, active learning, and career preparation in engineering education.

4.3.1 Perceptions on Effective and Ineffective Teaching Practices

Students distinguished effective from ineffective teaching based on engagement, clarity, and relevance. Passive approaches, such as lectures dominated by reading slides verbatim, minimal explanation, and poor organization, were widely perceived as disengaging, limiting understanding, and reducing motivation. Poorly designed or time-constrained labs, vague assignments, and uncontextualized readings were also criticized. Fully online instruction was sometimes seen as less effective when lacking in-person interaction.

Conversely, active, applied, and student-centred practices were strongly preferred, although a few students cited a preference for instructor-centred practices. Hands-on learning through labs, projects, simulations, and tutorials supported problem solving, conceptual understanding, and real-world application. Worked examples reinforced learning and exam preparation. Students valued instructors who expanded on material. They also valued educators who encouraged discussion and provided opportunities to make mistakes and learn from them. Visual aids, recorded lectures, and online access to materials further enhanced learning.

4.3.2 Perceived Frequency of Active Learning

Students reported that active learning occurred inconsistently across courses with frequency depending heavily on the instructor. Many noted that labs or projects were the primary structured spaces for active learning, while in-class discussions or ‘hands-on’ activities during class were less common. Some students experienced frequent active learning, but overall, the practice appeared underutilized across the curriculum.

4.3.3 *Influence of Teaching Practice on Class Attendance*

Teaching practices were seen as a key factor in motivating attendance. Engaging, interactive, and well-structured instruction encouraged students to attend, while passive, reading course notes verbatim often led them to prefer independent study. Practical components such as labs and assignments were particularly strong motivators for attendance, whereas disorganized or off-topic instruction discouraged it. External factors, such as scheduling conflicts or personal commitments, also influenced attendance.

4.3.4 *Course Material Influence on Teaching Practice*

Students emphasized that teaching methods should align with course content. Applied and hands-on subjects benefited from active, experiential instruction, whereas theory, or ‘math-heavy’ courses required structured problem solving and guided practice. Misalignment, such as overemphasis on theory without practical application, was seen as a barrier to effective learning.

4.3.5 *Engineering Education and Career Preparation*

Students viewed their education as providing essential foundational knowledge but noted that professional readiness depended heavily on experiential learning, work terms, and applied instruction. Some felt theoretical coursework alone provided minimal preparation for engineering practice, while others acknowledged the value of courses when paired with labs, projects, and real-world examples. Broader skills, including project management, planning, and self-directed learning, were also highlighted as important outcomes of the program.

5 DISCUSSION

No significant differences were identified between degree- and diploma-granting institutions in relation to their respective engineering education landscapes. Lecture-based instruction continues to dominate post-secondary engineering education, even as awareness of the benefits of active, student-centred approaches grows. While educators generally support active learning in principle, its adoption is often constrained by practical factors such as limited class time, large enrolments, rigid curricular structures, resource availability, and professional cultures that prioritize research over teaching. These trends align with STEM education found in other contexts as reported by Stains et al. (2018), Akiha et al. (2018), and Borrego et al. (2010). Like Stains et al. (2018), this study highlighted that lectures are not monolithic; many educators embed interactive strategies, such as demonstrations, guided questioning, problem-solving, and discussions, creating a continuum of practice between fully passive and fully active instruction. It can be argued that passivity decreases as the educator increases the variety and or frequency of active learning elements during the lecture period. Active learning is more frequently experienced in laboratories, tutorials, or elective courses, whereas core engineering courses often rely heavily on traditional lecture formats. The findings also suggested a trend toward pedagogical hybridization, where conventional lectures are incrementally adapted to include active elements.

Both educators and students recognize that active learning in engineering education is context-dependent and requires careful design, scaffolding, and alignment with course content. Educators reported selectively incorporating active methods as supplementing rather than replacing lectures and emphasized the need for professional development to implement active learning strategies effectively. They also highlighted the importance of flexibility, as students vary in readiness and preference for active versus passive learning. From the student perspective, interactive, hands-on experiences were generally preferred and seen as enhancing engagement, understanding, and practical skill development, while traditional lecture methods were often perceived as disengaging and limited in preparing students for professional careers. Both groups noted that content type shapes pedagogical effectiveness, with applied courses benefiting from hands-on approaches and mathematically or theoretically intensive courses requiring structured problem-solving practice.

6 CONCLUSION

This study illuminates the evolving terrain of post-secondary engineering education in Newfoundland and Labrador, revealing both long-standing practices and emerging innovations. Centring the perspectives of educators and students emphasizes the need for responsive, inclusive, and forward-thinking pedagogies. Although challenges persist, the findings provide a clear view of current practices and guidance for future development. These insights extend beyond post-secondary Canadian engineering classrooms. At prior school levels, active pedagogies within technology education can foster critical thinking and problem-solving, supporting smoother transitions to post-secondary studies and promoting more equitable outcomes. Implementing such practices offers practical guidance for educators aiming to bridge early classroom learning and future engineering readiness.

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Secondary School Technology Teachers' Views on the Core Ideas of Technology

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Abstract

For decades, discussions in science education have debated the inclusion of technological literacy and its relationship with scientific literacy. Early Science-Technology-Society (STS) approaches helped link science to social relevance but often reduced technology to a by-product of science rather than a distinct human activity. Although some countries eventually introduced technology as an independent subject, it still faces structural and epistemological challenges: there is no universal definition of this discipline, leading to curricula and standards that vary in both structure and content. Despite existing frameworks intended to clarify technological knowledge in education, these models have not fully clarified the specific conceptual core of technology, somehow still subsumed to scientific conceptual knowledge. Moreover, with the search for its own identity still unresolved, technology education faces other challenges such as its relationship with engineering education. In this context, and with a focus on disciplines with a more consolidated body of didactic knowledge, such as science, this study explores how secondary-school technology teachers identify the core ideas of their subject. Drawing on the tradition of science education and its construct of “big ideas,” eleven teachers participated in collaborative sessions analysing national and international curricula and proposing possible “big ideas for technology”. Through thematic analysis of their written and oral contributions, 33 concepts were identified, but only 14 appeared in more than one group, revealing limited consensus. Common ideas included materials, energy, mechanisms, control, and communication, but teachers mixed conceptual, practical, and ethical dimensions without a coherent classification. Understanding teachers' difficulties in constructing a comprehensive view for technology core ideas can help to develop a useful didactic framework to guide teaching and curriculum design. As a first approximation, the authors propose an epistemic three-level framework for structuring technological knowledge: natural resources and phenomena used by technology, processes and devices, and useful applications.

Key Words: Technology Education, Core Ideas, Teachers' Views

1 INTRODUCTION

Approaches for integrating technological and scientific literacy (Cajas & Gallagher, 2001), such as Science, Technology, and Society (STS) frameworks (Membiela, 1997) have failed to sufficiently differentiate science from technology or provide the robust technology education required. By subordinating technology as a scientific product (Acevedo-Díaz, 1994), offering a science-centric perspective (McComas & Burgin, 2020), they often neglected technological development as a distinct activity (Strieder et al., 2017).

Countries such as Spain have introduced technology as an independent subject despite conceptual gaps (Acevedo-Díaz, 1996; Nordlöf et al., 2022). The rise of STEM education, integrating science, technology, engineering, and mathematics, has further highlighted technology and engineering education, intensifying the field's enduring particularly the still underdeveloped specification of technology's core ideas (Doyle, 2025; Perales & Aguilera, 2020).

Drawing on the vision of integrated STEM education which should address the concepts and practices of the various STEM disciplines (Sanders, 2012), the present study aims to contribute knowledge on the key concepts or ideas of technology that should be developed in compulsory secondary education. The article draws on secondary school technology teachers' perspectives on which ideas should be prioritized, aiming to identify the components of a conceptual framework for more effective technology education.

2 LITERATURE REVIEW

2.1 *Technology and Engineering Education in Primary and Secondary School*

The lack of consensus within technology education results in curricula and standards that vary significantly in both structure and content (Nordlöf et al., 2022). With the search for its own identity still unresolved, technology education faces new challenges, such as its relationship with engineering education. Thus, while other disciplines, such as science education, benefit from a consensus regarding the core ideas and practices that should be taught in compulsory education (Harlen, 2010; National Research Council, 2012), what should be taught regarding technology and engineering (T&E) remains less clear. In recent years, the educational community has presented various proposals concerning the T&E content that should be part of compulsory education. While some of these proposals seek to identify common elements between them and other STEM disciplines (Chae et al., 2010), our interest focuses on that which is specific to T&E.

Regarding technology as a subject, the works of Ankiewicz (2015) and Nordlöf and colleagues (2022) are noteworthy. The former, drawing on Mitcham's framework (1994), identifies four dimensions: object, knowledge, activity, and volition. Conversely, Nordlöf and colleagues propose a three-component heuristic: technical skills, technological-scientific knowledge, and socio-ethical understanding. The two approaches are complementary with regard to addressing the cognitive dimension of technology. To reconcile both perspectives, we propose considering the notion of "engineering technology," which links the design of artifacts with their manufacture, spanning a spectrum of activities ranging from those typical of engineering (more knowledge-

based) to those of the technologist, technician, or artisan (more manual-skill-based) (Mitcham & Schatzberg, 2009; Vincenti, 1990). The omission of this knowledge-based activity dimension would explain why it is proposed that technological-scientific knowledge be grounded in a general scientific approach, rather than in an epistemologically more appropriate approach specific to technology or engineering (Couso & Simarro, 2020; Simarro & Couso, 2021; Yesilyurt et al., 2024).

Be that as it may, the new role assigned to T&E has not been accompanied by a solid didactic framework, resulting in superficial proposals with certain shortcomings (English & King, 2015). Altogether, this situation confirms the need for new frameworks that enable primary and secondary school teachers to design and implement high-quality educational proposals (Li et al., 2019).

2.2 *The Importance of Establishing the Core Ideas of Technology*

In this context, and although we agree with other authors that technology education must integrate knowledge *of* and *about* technology (Ankiewicz, 2019; Buch, 2003), we believe it is necessary to examine separately each of the elements that constitute knowledge in technology and engineering. With certain consensus regarding the engineering practices to be developed in the classroom from a school engineering perspective (Couso & Simarro, 2020; Yesilyurt et al., 2024), the specification of what the core ideas *of* technology should be remains an area under development.

Taking science education as a reference, the perspective of focusing instruction on the construction of key ideas or "big ideas" (Harlen, 2010; NRC, 2012) has been fundamental to the didactics of this discipline for decades. This is particularly true for those related to scientific knowledge, which have been embraced by the academic community with a well-established consensus (Osborne et al., 2003). From this perspective, these key ideas are understood as structuring concepts with the potential to explain a vast array of distinct phenomena, offering internal coherence and allowing for their development throughout the years of schooling.

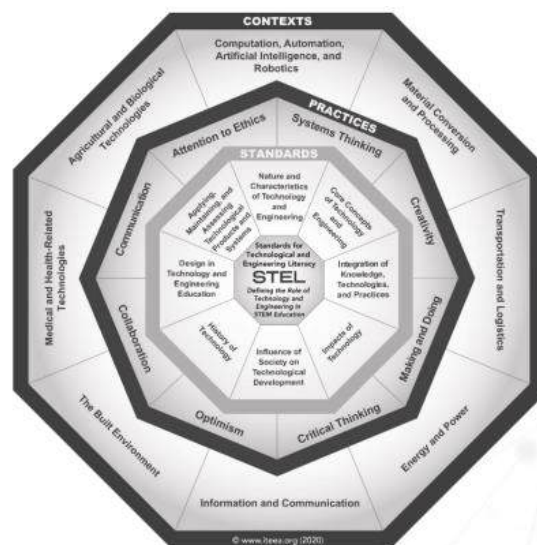
Despite attempts to define the core ideas of T&E, no consensus has been reached and no clear operational framework is available for teachers. The NRC (2012) framework for science education, for example, presents a proposal for engineering ideas that is highly dependent on scientific knowledge. In contrast to the eleven key ideas identified for science, engineering encompasses only two, which are poorly aligned with each other and with the notion of a core idea. As Cunningham and Carlsen (2014) point out, these ideas are linked more to general activities or reflections than to a solid conceptual body. This imbalance reveals the lack of an epistemological vision that recognizes the specificity of T&E without overlooking their links to other disciplines, especially science (Molina-Vásquez, 2021).

Silk and Schunn (2008) identify relevant concepts for engineering, such as structure-behavior-function, trade-offs, constraints, optimization, and systems. In our view, these sit on the boundary between cross-cutting concepts and practices, failing to form a clear conceptual structure for the discipline. Similarly, the new standards from ITEEA & CTETE (2020) propose core ideas for T&E, but they do so inconsistently by mixing practices, cross-cutting concepts, and specific

technologies, which hinders their educational operability (Figure 1). More recently, studies adopting a more epistemic approach have attempted to identify the engineering knowledge used in primary and secondary education. These have evidenced the existence of specific T&E knowledge (beyond mathematical and scientific knowledge); however, despite specifying the knowledge linked to the idea of practices or the nature of engineering, they have not succeeded in detailing this knowledge at a conceptual level (Yesilyurt et al., 2024).

Figure 1

Basic standards for Technological and Engineering literacy (source: ITEEA & CTETE, 2020)



The lack of consensus regarding the object of T&E disciplines and the diversity of its definitions (Cupani, 2018), explain the existing diversity and lack of agreement. Nevertheless, from a competency-based perspective, it is necessary to establish these key ideas that must serve as the foundation for participating in disciplinary practices. For instance, evaluating whether a solution is optimal may require knowing the available resources and their long-term availability (Molina-Vásquez, 2021). Beyond values, which also play a role in decision-making (Mitcham, 1994), there is no doubt that it is necessary to draw upon relevant conceptual knowledge to weigh the advantages and disadvantages of available options (Mettas, 2011). In design tasks, students often ignore technological conceptual knowledge, restricting the interaction of ideas essential for effective technological problem-solving (Gustafson et al., 1999). Furthermore, evidence exists regarding the influence of conceptual knowledge on students' creativity in problem-solving (Lewis, 2009) and on children's ability to transfer knowledge to other contexts (Marcus et al., 2018).

It is necessary, therefore, to define the core ideas of technology and to provide a way to structure this knowledge to afford its didactic transposition (Cajas, 2001; Chevallard, 1985). To this end, the present work poses the following questions:

- (i) What are the core ideas of technology according to secondary school technology teachers?
- (ii) What could be a framework that allows these core ideas to be operationalized for their implementation in the classroom?

3 METHODOLOGY

3.1 Context

This study was conducted within a professional working group consisting of eleven technology teachers facilitated by two researchers. The group met monthly for two-hour sessions focused on the didactics of technology and engineering education.

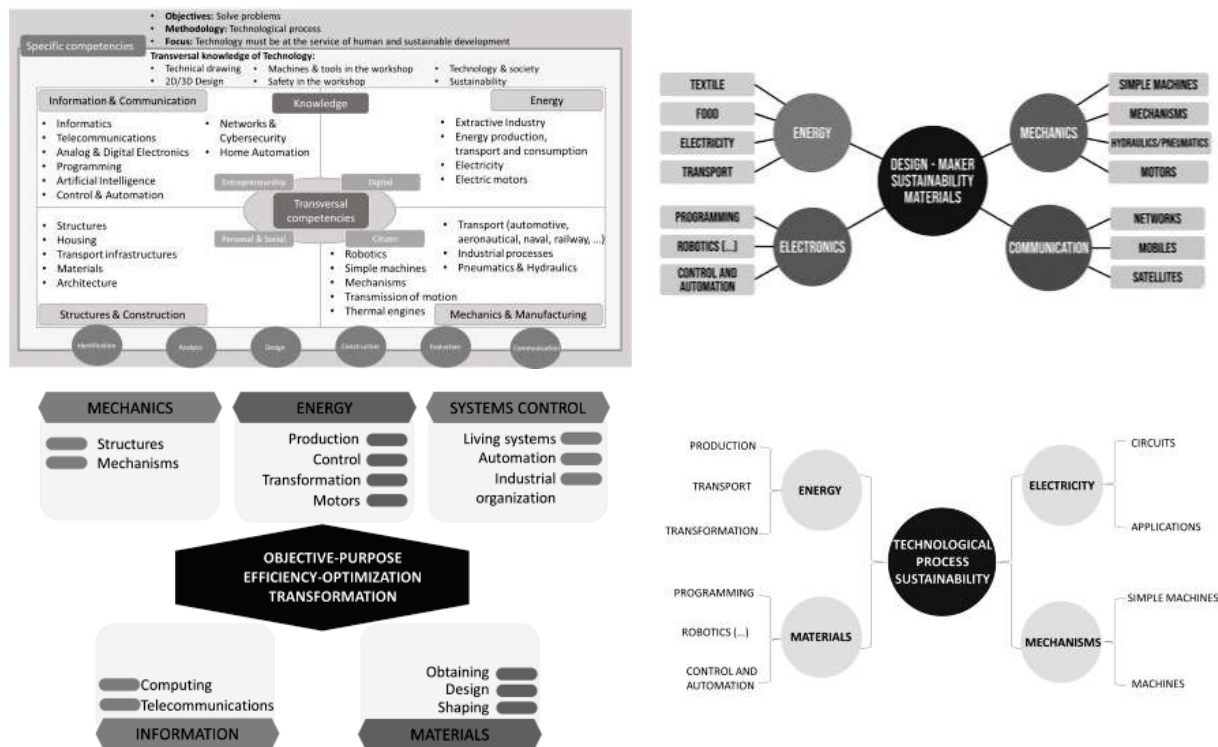
One session was specifically dedicated to identifying the core ideas of technology. For this purpose, a structured small-group activity was implemented, involving four groups of three to four participants: first, an introduction to the concept of core ideas as employed in science education; and second, a review of selected national and international technology and engineering curricula. Following this review, participants were asked to identify the core ideas of technology they considered essential for secondary education, without elaborating them in detail, and to propose an organizational framework for classifying these ideas.

3.2 Data Collection

Each group formalized its proposal in writing. Subsequently, a plenary session was held in which each group presented its proposal to the others, leading to a discussion regarding both the ideas themselves and the proposed classifications. This discussion was audio-recorded using voice recorders. At the end of the session, the written proposals from the groups were collected. Figure 2 shows an edited version of the original diagrams.

Figure 2

Edited (AI-assisted translation) of the original diagrams on core ideas of technology, developed by the technology teacher groups.



3.3 Data Analysis

The diagrams from each group were analyzed by the two researchers using an inductive thematic analysis process (Braun & Clarke, 2006) within an interpretative framework. The researchers consulted the audio recordings of the meeting to ensure an accurate interpretation of the schemes.

The following derived themes emerged: *core ideas of technology*, *other knowledge*, *coherence of classification systems*, and *inconsistencies in classification systems*. The categories identified for each theme were developed by grouping related concepts. For example, all references to materials were grouped under a single category: Materials (extraction/forming/properties/applications). This grouping, however, remained conservative, attempting to preserve the distinction between concepts as proposed by each group as much as possible. Consequently, concepts such as satellites and telecommunications were not integrated if a group had listed them separately in their proposal.

4 RESULTS AND DISCUSSION

Results are presented below, with related discussion for each emerged dimension.

4.1 Core Ideas of Technology

Table 1 summarizes the technological concepts identified by each group. As illustrated in Figure 2, Groups 1 and 2 identified a notably broader range of concepts compared to other cohorts. Given that all groups were comparable in composition and followed an identical protocol with the same time limits, this divergence is attributed to the natural variability of group interactions and internal brainstorming dynamics rather than external experimental factors. A total of 33 distinct concepts were identified; however, only 14 were mentioned by more than one group. *Materials* was the only concept identified by all groups. Seven concepts (*Electricity*, *Motors*, *Energy*, *Control and automation*, *Simple machines*, *Telecommunications/Networks*, and *Mechanisms/Transmission of motion*) were identified by three groups, while six (*Transport/Transport infrastructure*, *Structures*, *Computer science*, *Programming*, *Pneumatics and hydraulics*, and *Robotics*) were mentioned by two groups.

Beyond the level of agreement, this extensive list highlights a notable diversity in the nature of the concepts. While some concepts refer to resources (such as energy or materials), others refer to objects (tools) or applications (housing). Consequently, there is no clear hierarchy for these key ideas, a point that will be further explored in the discussion of the identified inconsistencies.

Table 1

Core technological ideas as identified by participant groups (indicates an idea mentioned by more than one group)*

Topic	Gr. 1	Gr. 2	Gr. 3	Gr. 4
*Materials (extraction/shaping/properties/applications)	X	X	X	X
*Engines	X	X	X	
*Electricity	X		X	X
*Energy (production, transformation, transport, and consumption)	X		X	X
*Control and automation	X	X	X	
*Simple machines	X	X		X
*Telecommunications / Networks	X	X	X	
*Mechanisms / Movement transmission	X	X	X	
*Transport / Transport infrastructure	X	X		
*Structures	X		X	
*Computing	X		X	

*Programming	X	X	
*Pneumatics and hydraulics	X	X	
*Robotics	X	X	
*Electronics	X		
Artificial intelligence	X		
Home automation	X		
Extractive industry	X		
Housing	X		
Architecture	X		
Industrial processes	X		
Technical drawing	X		
Design (2D/3D)	X		
Workshop machines and tools	X		
(Social) networks and cyberbullying	X		
Textiles		X	
Food		X	
Mobile phones	X		
Satellites	X		
Living systems		X	
Industrial organization		X	
Design		X	
Applications			X

4.2 *Other Knowledge*

Knowledge in technology is multifaceted, encompassing not only a conceptual understanding *of* technology but also knowledge *about* it: technology as an activity, and the values and ethics that influence its development. While these later aspects of technological literacy are essential for education, they differ in nature from what we define as core ideas *of* technology.

However, despite being explicitly instructed to focus solely on the core ideas of technology rather than knowledge about technology, all groups identified concepts as core ideas that are strictly linked to the ontology of technology, its development as an activity (which we would define as

practices), or an ethical approach (the values associated with technological activity). As with the core ideas, there is an overlap between groups regarding some of these concepts (Table 2).

Indeed, the three aspects mentioned by two or more groups correspond to each of these approaches. From the perspective of volition, three out of the four groups identified sustainability as a key concept of technology. Meanwhile, two out of the four groups referred to the technological process, a term widely used since the inception of the technology subject in Spain. It resonates to some extent with the concept of the scientific method, an outdated concept in science education (Windschitl et al., 2008). Finally, among the aspects mentioned by more than one group, two groups identified the aim of technology (problem-solving).

Other elements related to the ethical impacts of technology (society, human development) and technology as an activity (design, optimization and efficiency, transformation, or the maker methodology) were listed by the groups. In all cases, these elements were identified as either core or cross-cutting (Figure 2) without being classified into any of the structuring elements for the core ideas of technology proposed by groups.

Table 2

Other content identified as core ideas of technology (despite not being conceptual knowledge)

Topic	Gr. 1	Gr. 2	Gr. 3	Gr. 4
*Sustainability	X	X		X
*Technological process	X			X
*Technology aim	X		X	
Technology and society	X			
Human development	X			
Maker methodology		X		
Design		X		
Optimization / Efficiency			X	
Transformation			X	

4.3 *Coherence of Classification Systems*

Teachers' classification system for the core ideas is reflected in the various sections of the diagrams (Figure 2), within which each group placed its core ideas.

Certain commonalities were identified, indicating a degree of coherence between groups. The groups proposed the following classification dimensions: *Energy*, *Mechanics*, *Materials*,

Information/Communication, Electricity/Electronics, and Structures/Construction. There are, however, several nuances to be discussed:

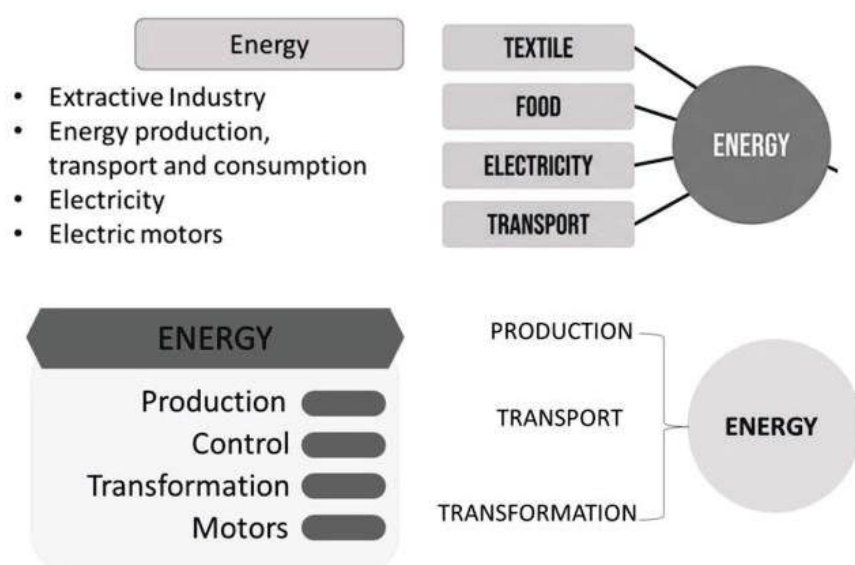
- Energy is the only dimension consistently present across all groups.
- A mechanics-related dimension appears in every group, though labelled variably as “mechanisms” or linked to “manufacturing.”
- The Information and Communication dimension appears in three groups, with variations in terminology: one uses both terms, one uses “information” only, and one uses “communication” only.
- Materials serve as a classificatory element in two of the four groups.
- Electricity and Electronics appear separately: one group uses “electricity,” another “electronics.”
- Only one group references Structures and Construction, and only one mentions Systems Control.

4.4 *Inconsistencies in Classification Systems*

Although teachers showed some consistency in the dimensions used to classify the core ideas of technology, substantial inconsistencies in their application raise doubts about its robustness as organizing frameworks (e.g.: classifying different ideas in common dimensions). Within the Energy dimension, mentioned by each group, we find technology applications (food, textiles) that are not solely energy-based, alongside forms of energy (electricity) and concepts related to energy management (generation, consumption, transport, transformation, etc.) (Figure 3).

Figure 3

Using the Energy dimension as a structuring element to classify different ideas of technology



While this dimension is considered relevant by all groups, it does not appear to be an unequivocal framework for classifying technological ideas. In fact, in this same example, we see that one of the classified elements (electricity) is used as a standalone dimension in some cases and as a component of a different dimension in others.

Similarly, several ideas were assigned to different dimensions across groups. For example, motors were classified under either energy or mechanics, while transport was placed within energy or mechanics depending on the group. These variations underscore the lack of consistency in the proposed classification system, suggesting that the categories do not provide an unambiguous organizational framework.

5 CONCLUSIONS AND IMPLICATIONS

Despite increasing recognition of technology disciplinary autonomy, coherent didactic frameworks defining what and how to teach technology in compulsory education remain underdeveloped. This contributes to limited public understanding of technological artifacts, systems, and design processes (Yesilyurt et al., 2024). Addressing this gap, and given that knowledge of technology is the least explored of these domains (Doyle, 2025) this study examined technological conceptual knowledge from the perspectives of secondary school technology teachers. This work should enhance technological pedagogical content knowledge, central to STEM education (Calvo Utrilla et al., 2025).

The results obtained allowed for the identification of recurring themes as well as inconsistencies between groups. While the former can help establish an initial approximation of the elements that a proposal for the core ideas of technology should include, the latter allows to identify the requirements that such a proposal must address to ensure its consistency.

Specifically, results confirm that there is no common vision among secondary technology teachers regarding the core ideas of the discipline. Despite the limitations of this study, conducted with a small number of participants, the list of core ideas proposed by the teachers highlights the absence of a shared framework within the educational community responsible for teaching this subject. These results are aligned with the aforementioned lack of a comprehensive framework for technology education. Furthermore, regarding the objective of organizing these concepts into big ideas to structure teaching throughout the years of schooling, the results demonstrate that there is also no foundational structure.

Acknowledging that technological knowledge should not be reduced to mere know-how or tacit practice, nor should explicit and descriptive understanding be attributed solely to science (Cupani, 2006), a possible framework could be proposed based on the nature of the core ideas listed by teachers: *resources*, *objects* and *applications* (Table 3). While knowledge regarding resources (energy, materials, ...) would be intimately linked to science, knowledge regarding objects and technological applications would relate to specific technological theories and explanations. This three-level framework would resonate with established definitions of technology (Mitcham &

Schatzberg, 2009) and it also integrates the latest T&E educational frameworks such as the idea of contexts (ITTEA, 2020).

Table 3

Preliminary organization of core technological ideas into an epistemic three-level framework

Framework level	Description	Example
Resources	Natural resources and phenomena used or transformed by technology.	Materials
Objects	Specific technological devices, mechanisms, and the "know-how" of production (could include processes)	Engines
Applications	Useful implementations within specific contexts	Transport

Conceptualizing these three levels facilitates a more exhaustive identification of core technological ideas by providing distinct categories for classification. Furthermore, differentiating these concepts based on their inherent nature allows for the development of tailored pedagogical approaches and the formulation of robust technology standards.

Given the limitations of this study future work should be focused on exploring teachers' conceptualizations of technology core ideas to broader contexts. A more exhaustive and nuanced list of core ideas would help also to work on the necessary further refinement of the three-level framework. The classification of the core ideas into the framework would confirm its validity. Moreover, further research should be focused on the pedagogical content knowledge of the agreed technological core ideas and on the validation of the three-level framework as a good basis for designing teaching and learning sequences.

6 DISCLOSE ON GENAI USE

MS Copilot was used solely for language review, text improvement, and translation of text in images, without generating new content.

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Exploring Facilitators' Beliefs of 'Making' in German Makerspaces

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Abstract

Making activities for children and teenagers are offered in a variety of settings and formats. They are primarily designed and offered by so-called makerspace facilitators. Despite their relevance for such educational activities, little is known about the beliefs of these facilitators. This paper presents initial, preliminary findings based on a subset of the sample (n = 6). In particular, it explores the question: "What understanding do makerspace facilitators have of making?"

The results indicate that makerspace facilitators describe both a narrow, technology-focused understanding of making and a broader perspective, with the technical dimension predominating. Furthermore, making occurs in three context-dependent forms: as a single act in guided making activities, as a transition from an act to process within these making activities, and as a complex process in free projects.

These findings contribute to ongoing discussions in maker education regarding the conceptualization of making. The results provide a starting point for investigating, for example, the influence of technologies and resources in makerspaces on facilitators' beliefs. Moreover, they not only contribute to a deeper understanding of makerspace facilitators' beliefs, but also serve as a foundation for further research into the relationship between facilitators' beliefs and their pedagogical practices, as well as the didactic innovation potential of making for existing approaches for formal technology education.

Key Words: informal technology education, making, makerspace facilitators, maker education, qualitative content analysis

1 INTRODUCTION

Makerspaces offer people of all ages opportunities to exchange ideas and implement their own ideas. Due to varying conditions, the individual educational programs offered can differ significantly.

As a result, meta-reviews point to a wide range of potential educational benefits of making and makerspaces. These relate both to the learning processes of children and young people and to the integration of making into teacher training (Ioannou & Gravel, 2024, pp. 4–7; Schad & Jones, 2020, p. 5). Despite this, there is no uniform understanding of central aspects of maker education, such as making, makerspaces (Ioannou & Gravel, 2024, p. 8) and makerspace facilitators. For instance, Litts (2015) defines making rather broadly as “using tools, materials, people, and other resources to engage in process and make products” (ibid., p. 50). In contrast, Sheridan et al. (2014) define making more narrowly with a technical orientation as “developing an idea and constructing it into some physical or digital form” (ibid., p. 35).

This makes it difficult to compare studies and clearly define the field of research. Against this background, the beliefs of makerspace facilitators have been insufficiently researched to date and represent a research gap (Mersand, 2021), which is addressed in this article with regard to the question: “What understanding do makerspace facilitators have of making?” For this purpose, semi-structured expert interviews were conducted with makerspace facilitators in order to gain insights into their understanding. These facilitators design the maker programs and run them with young makers, so they have practical educational experiences and are therefore considered experts.

2 THEORETICAL FRAMEWORK

2.1 *Making*

In literature, “making” is generally understood to mean a creative act performed by makers. However, there are differing opinions and definitions of the term in academic discourse, with many authors providing only vague definitions. In the context of this article, these are structured according to two criteria: the degree of conceptual breadth or narrowness of the definition, and whether making is understood as a process or an action.

Within the framework of a “broad” definition of making, the view is taken that making can basically be understood as “the creation of something new” (Provenzano, 2016, p. 9). In this case, different activities such as programming, cooking, or dancing are understood as (see Tab. 1).

Table 1*Overview of a broad understanding of making*

broad understanding of the term		
Anderson (2012)	Provenzano (2016)	Savage (2016)
“Knitting and sewing, scrapbooking, beading, and cross- stitching — all Making. These projects represent the ideas, dreams, and passions of millions of people. Most never leave the home, and that’s probably no bad thing. But one of the most profound shifts of the Web age is that there is a new default of sharing online. If you do something, video it. If you video something, post it. If you post something, promote it to your friends. Projects, shared online, become inspiration for others and opportunities for collaboration.” (ibid., p.13)	“Making is the creation of something new that was not there before. [...] People can Make with computer code, they can Make with Legos, they can Make with pencil and scrap paper, and they can Make with whatever they get their hands on.” (ibid., p. 9)	“What is making? [...] Let me be really clear, making is not simply 3D printing, Art Lino, Rasp-berry Pi, LEDs, robots, laser and vinyl cutters. It's not simply carpentry and welding and sculpting and duct tape and drones. Making is also writing and dance and filmmaking and singing and photography and cosplay. Every single time you make something from you that didn't exist in the world, you are making. “ (ibid.)

This contrasts with a "narrow" understanding of making, which emphasizes the technical dimension in particular. The focus here is on designing and constructing one's own ideas through the use of tools and materials (see Tab. 2). Following on from this understanding, "collaborative making" can be classified as a variation of the narrow understanding of the term, which focuses in particular on the joint construction of multi-material, shared objects (Davies, 2024).

Table 2*Overview of a narrow understanding of making*

narrow understanding of the term		
Honey & Kanter (2013)	Martinez & Stager (2014)	Martin (2015)
“Make — to build or adapt objects by hand, for the simple personal pleasure of figuring out how things work.” (ibid., p. 4)	“In a makerspace these processes may be defined loosely: Making is about the active role construction plays in learning. The maker has a product in mind when working with tools and materials. [...] Making is about the act of creation with new and familiar materials.” (ibid., p. 35)	“I draw from these conceptions to form a working definition of making as a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a “product” of some sort that can be used, interacted with, or demonstrated.” (ibid., p. 31)

As already mentioned, another way of classifying definitions of making is to consider whether making is understood as a single act or as an umbrella term for a variety of actions, or whether it is understood as a process consisting of several actions or steps.

This ambiguity makes it difficult to define making clearly and consistently. This problem is exacerbated by the fact that the literature contains numerous characteristics that are generally attributed to making. These characteristics broaden the understanding of the term and, in many cases, are found across the different interpretations presented. The aspects described below do not represent a complete list of these features, but rather serve to provide an overview.

- Traditional craft and digital fabrication technologies: In the literature, making is often described as meaning that the associated activities in a technical context are not limited exclusively to digital manufacturing processes. Rather, tools and manufacturing techniques from traditional crafts are also included (Davies, 2024, p. 3; Martin, 2015, p. 31).
- Motivation: Another characteristic feature of making is the intrinsic motivation of those involved. This motivation may consist, for example, in discovering or learning something new, in the sense of the growth mindset concept, in playing with materials, or in the goal of producing an object that is useful for oneself or others (Honey & Kanter, 2013, p. 4; Martin, 2015, p. 31).
- Iterative process: Making is often described as an iterative process that can involve several rounds of development and revision before a finished product is created (Sheridan et al., 2014, p. 52).

- Learning by doing: Another key feature of making is the fact that knowledge is acquired directly during practical activity (Chan & Holbert, 2020, p. 367).
- Failure-positive: In the maker movement, mistakes are understood as "overcoming small obstacles" (Martin, 2015, p. 36) and are considered an important part of making.

2.2 *Maker Programs and Makerspace Facilitators*

Making usually takes place in so-called makerspaces, physical spaces that serve as a place for exchange and provide access to tools and machines (Mersand, 2021). The literature uses various terms for these spaces, such as FabLabs, hackerspaces, and maker labs. However, the distinction between these types of spaces is not always clear. In the context of this article, the term "makerspace" is therefore used as a collective term for all places that are characterized by making.

In educational contexts, terms like "maker education" and "maker pedagogy" are common and often linked to learning theories from Dewey, Papert, and Vygotsky, among others (Klapwijk & Vries, 2023, pp. 10–12). This form of "educative making" (Lindsey & DeCillis, 2017, p. 10) fundamentally aims to introduce children and young people to the methodology and learning processes of the maker movement (Schön & Ebner, 2019). Maker pedagogies are usually implemented in makerspaces through maker programs, which typically planned and implemented by so-called makerspace facilitators.

Research on makerspace facilitator beliefs is wide-ranging, including studies on perceived achievements and challenges (Abbas & Koh, 2015; Litts, 2015; Turakhia et al., 2024) as well as roles and didactic strategies (Einarsson & Hertzum, 2020; Lee et al., 2018; Otieno, 2017; Turakhia et al., 2024). However, no qualitative study has yet examined facilitators' beliefs about their understanding of making. Investigating their implicit knowledge provides a suitable starting point to address this gap.

3 **METHODOLOGY**

To address this research gap, semi-standardized expert interviews with makerspace facilitators were conducted as part of a doctoral thesis that explores the research question "What contribution can making make to technology education from the perspective of makerspace facilitators?" and ranged from 37 to 101 Minutes in duration. When selecting the sample, care was taken to ensure that the makerspaces were open to the public during opening hours and explicitly offered maker programs for children and young people.

Purposeful sampling was used as the sampling strategy, specifically the maximum variation sampling (Patton, 2015, p. 463), with the legal structure as a criterion in order to be able to examine as wide a variety of actors and educational offerings as possible (see Tab. 3). Several approaches were used to recruit interview partners. Maker Faires in Germany (2023-2025) were visited and German-language online platforms listing makerspaces were consulted.

The resulting sample (n = 6) comprises individuals who plan and implement educational programs in six different makerspaces in four different federal states. The interviews were conducted between April and December 2025, transcribed, and then evaluated using qualitative content analysis according to Kuckartz and Rädiker (2024).

The aim of this sub-study is to gain insights into the understanding of makerspace facilitators. The different professional backgrounds of the respondents as well as their respective understanding of making and learning have a significant influence on the methodological approach, the objectives of the educational offerings, and the design of the makerspace.

Table 3

Sample

Interview	Gender	Legal Structure	Experience with children in makerspaces	Federal State
I_01	No category	Non-profit Association	5 years	Brandenburg
I_02	Female	University-led	10 years	North Rhine-Westphalia
I_03	Female	Municipal - library	2 years	Rhineland-Palatinate
I_04	Male	Non-profit Association - vocational school	14 years	North Rhine-Westphalia
I_05	Female	non-profit private limited company	2 years	Rhineland-Palatinate
I_06	Female	Municipal	3 years	Lower Saxony

3.1 Category System

The category system was developed using an inductive-deductive approach based on the theoretical framework and empirical data. Analytical categories were formed on the basis of different interpretations of making and some characteristics of making (see 2.1) described in the literature in order to gain deeper insights into the makerspace facilitators' understanding of making. This article focuses on four categories:

- (i) Narrow vs. Broad
- (ii) Act vs. Process
- (iii) Intrinsic motivation
- (iv) Failure-positive

The category system was developed and applied using qualitative analyse software Atlas.ti.

4 RESULTS

In the present study, six interviewees responded to the interview request. It is striking that the majority of interviewees in the present sample are female. Further research is needed to investigate whether this gender distribution indicates a bias or can be considered typical for this group of people.

4.1 *Narrow vs. Broad*

The results show that both a narrow and a broad understanding of the term "making" can be identified in all interviews. The narrow understanding of the term occurs in two different forms. On the one hand, making is described as an open-ended activity. Here, making is primarily manifested in trying things out and doing them yourself:

"We are allowed to do things and try things that we might not otherwise do." (I_04)

On the other hand, in the majority of interviews, textile design is explicitly discussed and understood as part of making:

"Maybe just doing some braiding or tying a few knots and perhaps turning that into an interesting project like friendship bracelets, knots, or things like that." (I_03)

Despite these findings, the narrow understanding of making in the sense of a focus on the technical dimension is the predominant view in the interviews. This is particularly evident in the large number of technical activities mentioned, such as building, programming, or manufacturing, and in the reference to manufacturing processes and technologies, including 3D printers, laser cutters, or drills. It is striking that the broad understanding of the term "making" is often discussed together with the narrow, technically oriented view. Thus, very open descriptions of making are initially given, but in the course of the same train of thought, they are increasingly narrowed down to the technical dimension:

"As the word suggests, it means really making something, and I, well, we always use it here in connection with manufacturing something, digitally manufacturing something." (I_02)

Even textile design, which can be classified as a broad interpretation of the term, is often linked to the technical dimension of making in the interviews. This happens either by placing textile machines such as sewing machines or plotters on the same level as classic digital fabrication tools,

or by directly combining textile design processes with digital manufacturing technologies. One example of this is the production of a weaving frame using a laser cutter, followed by a manual weaving process:

"[...] you produce a tool yourself. And then you sit there and do really hard manual work. Yes, then you just weave, with your fingers." (I_01)

4.2 *Act vs. Process*

The results also reveal both conceptions of making, namely making as an action and as a process. It becomes apparent that the respective understandings of the term occur in specific contexts. Over-all, three central contexts could be identified.

If making is understood as an action, such as "building a flashlight" (I_01) or "programming a name tag" (I_05), this understanding often refers to the context of prepared and guided making activities.

The second context describes the transition from an action to a process. In this case, an action within the framework of planned making activities is expanded to include another action:

"'Yes, I've now built something, and can I put an LED in it?' And then suddenly they're sitting there with a soldering iron in their hands. 'But is building this cardboard cell phone already making?' Yes, of course, I can call it that." (I_04)

The third context concerns free making during opening hours, when children and young people carry out their own projects. In this context, making is described as a complex process:

"And sometimes you have to invest a lot of time. Finding a project idea, refining it, developing it further, and also formulating it." (I_04)

4.3 *Intrinsic motivation*

The characteristic of intrinsic motivation in the context of making is evident in the fact that the interviewees name two central motivations for children and young people: on the one hand, the desire to realize their own ideas, and on the other hand, the opportunity to use the technical equipment in the rooms. In the interviews, both are predominantly associated with free making:

"Learning new things, using the technology, and simply being allowed to use it. So they can come here with their idea, theoretically, no matter how absurd it is, whatever they want to do." (I_02)

Even in the context of prepared making activities, children and young people are encouraged and motivated to formulate their own ideas:

"And then, in this case, I first asked them if they are satisfied with the task or if they want to do something else." (I_06)

4.4 *Failure-positive*

The central role of a positive culture of failure is evident in the statements of some of the interviewees. This is particularly evident in the interaction described between the makerspace facilitator and the young people: The makerspace facilitators deliberately allow the young people to make their own mistakes, only to catch them and support them afterwards:

"When things don't work the third time around, you have to catch them and say, 'Come on, it's part of failing, it's part of the process', and we'll try again. Ultimately, this is also about installing or practicing a culture of error and ensuring that a mistake is not a reason for reprimand." (I_04)

5 DISCUSSION

The results regarding the beliefs of makerspace facilitators reveal parallels to the disagreements described in the literature regarding the understanding of the term “making” (Martinez & Stager, 2013, p. 35). This is particularly evident in the fact that the broad understanding of the term changes within the interviews. Despite this variability, a strong technical dimension can be identified in the descriptions. It is striking that aspects of textile design were mainly discussed when the corresponding machines were available in the makerspace. In this context, the question arises as to what extent the equipment of a makerspace and its framework conditions influence the understanding of making. A similar aspect is highlighted in the case study by Litts (2015), which examines the design of offerings and the formulation of objectives at three different makerspaces.

With regard to the distinction between act and process, the descriptions suggest that making is understood at different levels. It is important to critically examine whether the identified contexts of making are generally applicable or specific to the sample studied. It also remains unclear whether the distinction between act and process is actually so clear-cut in everyday life or whether the transitions are fluid.

The results underscore the importance of intrinsic motivation as an aspect of making. However, it remains unclear how much leeway children are actually given to implement their own ideas. In addition, there is a tension between the prescribed structure of making activities and the desired freedom. The positive culture of error and the practice of supporting children and young people in the trial-and-error process has already been observed by Otieno (2020), and the central importance of facilitators is also emphasized in the studies by Blikstein und Worsley (2016, S. 71). Nevertheless, the effectiveness remains unclear.

Returning to the initial research question, “What understanding do makerspace facilitators have of making?”, it can be summarized that makerspace facilitators do not have a fixed definition of making, but rather demonstrate a fluid understanding of the term. This becomes apparent that making is broadly defined, but the technical dimension is emphasized in the descriptions. With

regard to the distinction between “act” and “process”, it is also apparent that the participants demonstrate a differentiated understanding of making, which can be divided into three levels.

The present results are based on a comparatively small sample with a disproportionately high proportion of female interviewees. Future research could extend the study to other makerspaces and alternative settings in order to further refine the identified characteristics of making and to investigate in greater depth the influence of different understandings of making on practice. A continuation of the research topic within the framework of a dissertation is therefore being sought.

6 STATEMENT REGARDING THE USAGE OF AI

Generative AI was used only to translate a written text from German into English.

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Implementing STEAM Education in Estonian Basic Schools: Smart Learning Materials for Experimentation and Exploration in Science, Creativity, and Innovation

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Abstract

STEAM education has emerged internationally as a key interdisciplinary approach aimed at integrating disciplinary knowledge into meaningful and creative learning. This paper reports on the development of STEAM-oriented courses for lower secondary technology education and examines within-subject integration opportunities.

The study focuses on two Grade 7 technology courses (Automata and LED Lamp) designed as design-based, hands-on learning processes. Teacher input was gathered through collaborative idea generation and semi-structured interviews. Analysis addressed how teachers perceived STEAM-related integration and how such perceptions supported feasible integration within the disciplinary logic of technology education.

Findings suggest that technology education offers a natural platform for STEAM integration without mandatory cross-curricular collaboration. Integration manifested mainly through design processes, artefact construction, and reflective activities. The work also underscored the need to systematise teachers' ideas to distinguish viable integrations from less feasible proposals. The paper positions technology education as a potential core carrier of STEAM and outlines next steps for piloting and broader implementation.

Key Words: STEAM Education, Technology Education, Subject-Based Integration, Interdisciplinary Curriculum, Student-Centered Learning

1 INTRODUCTION

STEAM education (science, technology, engineering, arts and mathematics) has become a central concept in recent international discussions on educational innovation. Originating from STEM,

the STEAM framework is widely associated with science and engineering education (Hacker, 2024). Its core premise lies in integrating disciplinary knowledge into meaningful, creative, and often practice-oriented learning activities, where concepts are applied in real-life contexts (Lee, 2024). Within this paradigm, learners are expected to understand the societal and environmental implications of technology and to develop capabilities to use and design technological products, systems, and processes for human purposes (Jones & Roberts, 2024).

Globally, both developed and developing countries consider STEAM education a foundation for industrial and economic competitiveness (OECD, 2023). Growing capacity in STEAM has become a key arena of education policy, attracting substantial governmental investment (Banks & Barlex, 2021). The increasing demand for science, technology, engineering and mathematics specialists is evident also in Estonia (Pärna, 2025) and constitutes a major rationale for strengthening STEAM-related teaching (Hacker, 2024). Central to these efforts is disciplinary integration, pursued through diverse pedagogical approaches (Lee, 2024).

This paper examines subject-based STEAM integration in lower secondary technology education. As a practical, design-oriented subject, technology education inherently connects to science, mathematics, computing, and the arts. Yet such connections often remain implicit and are seldom made explicit or intentional in classroom practice (Lee, 2024). This raises a pedagogical question: how can technology teachers design instruction that fosters meaningful and purposeful links to other STEAM domains within a single subject?

The authors are involved in a national development initiative launched by the Estonian Ministry of Education and Research to create STEAM courses for Grade 7 in technology education. The project *Smart Learning Materials for Experimentation and Exploration in Science, Creativity, and Innovation* includes courses covering different stages of the product development cycle. This paper focuses on two such courses – Automata and LED Lamp – and examines teachers' contributions to the development of course plans, analysing how these inputs broaden within-subject STEAM integration from the perspective of classroom practitioners.

The study addresses two research questions:

- (i) What STEAM-related integration opportunities do teachers propose for the “Automata” and “LED Lamp” courses?
- (ii) How do these teacher-suggested opportunities support intentional integration between technology education and other STEAM domains?

The broader project aim is to increase lower secondary students' interest in engineering and technology and to encourage more learners to consider continuing in these fields at upper-secondary or tertiary level.

2 THEORETICAL BACKGROUND ON STEAM

The growing relevance of STEAM education in the 21st century is linked to its contribution to digital literacy, design thinking, and creativity (Lee, 2024). Research suggests that STEAM fosters meaningful connections between hands-on activity and theoretical knowledge, enhancing conceptual understanding and problem-solving skills (de Vries, 2024).

Motivation and engagement are also central concerns in STEAM education. Studies indicate that integrated, project-based, and creativity-enabling approaches can increase students' interest in science and technology, including among learners who do not usually identify with these subjects (de Vries, 2024; Thibaut et al., 2018). The inclusion of the arts is considered significant: compared to the more utilitarian STEM framing, STEAM is associated with more empathetic, aesthetic, and inclusive learning, which is particularly relevant in earlier school years where creative expression and sensory experience play a key role (Korkeaniemi et al., 2025).

Multiple approaches to implementing STEM/STEAM have been identified in the international literature. Honey, Pearson and Schweingruber (2014) describe a continuum ranging from discipline-specific instruction to deeply integrated models in which knowledge and practices are closely connected. Integration is neither uniform nor linear, but contingent on school context, teacher competence, and learning objectives. Similar variability is noted by Stohlmann, Moore and Roehrig (2012), who emphasise that STEM integration can take diverse forms and degrees. In contrast, Kubat and Guray (2018) advocate a more normative view, arguing that STEM should be treated as a holistic and inseparable domain rather than taught as discrete subjects.

Although most national curricula structure science, technology, engineering and mathematics as separate subjects, they nonetheless acknowledge cross-disciplinary connections and their relevance to real-world contexts (Banks & Barlex, 2021). Real-world problems rarely align with a single discipline; instead, they require interdisciplinary collaboration and knowledge integration (Lee, 2024). Integrated approaches can introduce authentic problem-solving practices into school learning, adding relevance and potentially supporting boundary crossing, though their effectiveness depends strongly on implementation and teacher collaboration (Roehrig et al., 2012).

STEM education entered the Estonian context more broadly in the early 2000s with the translation of *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2007). This introduced a novel approach that connected multiple subject domains and provided teachers with inspirational material supporting the adoption of new teaching methods (Soobik, 2023).

In contemporary Estonian schools, STEM subjects are still taught largely as separate disciplines in accordance with the national curriculum (HTM, 2023), although integrated practices – such as combining science with robotics – are becoming more common. Recent syntheses emphasise that contemporary STEM education is increasingly defined by the integration of technological and engineering knowledge with authentic, problem-based contexts (Deehan et al., 2025). Within this perspective, the role of technology education in supporting subject-based STEAM integration

becomes increasingly salient, as the combination of design and making can serve as a powerful strategy for learning science, technology, engineering and mathematics concepts (de Vries, 2024).

Technology education occupies a unique position in the Estonian curriculum: it combines practical activity, design thinking, engineering knowledge and creativity, enabling multiple levels of connection with other subjects. Its core involves problem-solving, material work, prototyping, and the use of digital technologies (Autio et al., 2017). This multilayered structure provides favourable conditions for STEAM integration – often without explicit planning – given the inherently boundary-crossing nature of the subject (Lee, 2024). Pedagogically, technology education draws on a distinctive epistemology grounded in design processes, artefact creation and iterative problem solving, where knowledge is produced through making rather than solely through symbolic representation.

At the same time, many technology education courses emphasize hands-on activity and technical skills, while systematic integration with other subjects remains largely intuitive or implicit. Teachers often lack a clear overview of how course themes connect to physics, mathematics, art, or computing, and have limited methodological tools or support to make such connections explicit and purposeful in classroom practice (Ankiewicz, 2024; Giffney & Lane, 2025).

3 METHODOLOGY

In 2024, the Estonian Ministry of Education and Research launched a competitive development initiative aimed at strengthening technology and engineering education in general schooling and supporting the design and piloting of STEAM learning modules for Grades 7–12. The initiative emphasises teacher professional development and the creation of subject-specific modules aligned with contemporary learning approaches, practical activity, problem-based learning, and integrated teaching across science, mathematics, technology and the arts (HTM, 2024).

The development of the LED Lamp and Automata courses examined in this paper forms part of this initiative and draws on the authors' involvement in designing and developing these courses. Within the project framework, each course constitutes a separate STEAM learning module.

Both courses integrate several core STEAM domains: electronics (science), soldering and circuitry (engineering), CAD/CAM and laser cutting (technology), G-code and programming (mathematics/informatics), and aesthetic design (arts).

Based on prior experience, technology education teachers involved in the research developed initial course plans. These were then shared with colleagues from different subject areas to identify opportunities for interdisciplinary integration. The plans will be refined based on teachers' input, followed by pilot implementation in schools and the public release of the finalised plans and learning materials for nationwide use.

Artificial Intelligence (AI) technologies were used solely to enhance the clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

3.1 *LED Lamp Course*

The *LED Lamp* course centres on designing and producing a functional and aesthetic lighting object (Figure 1). It follows a product-development and design-based approach in which students progress from ideation to prototyping and refinement. Initial activities focus on basic electronics, circuitry and safety, linking technical skills with design thinking and analysis of existing lighting solutions. The middle phase employs digital fabrication tools (CAD/CAM, 3D modelling and printing), connecting technological practices with mathematical and informatics concepts, including the interpretation of G-code. As the course advances, students gain autonomy in selecting structural solutions, materials and finishing. Overall, the course provides a subject-based framework for piloting feasible STEAM integration within technology education.

Figure 1

LED lamps designed by students

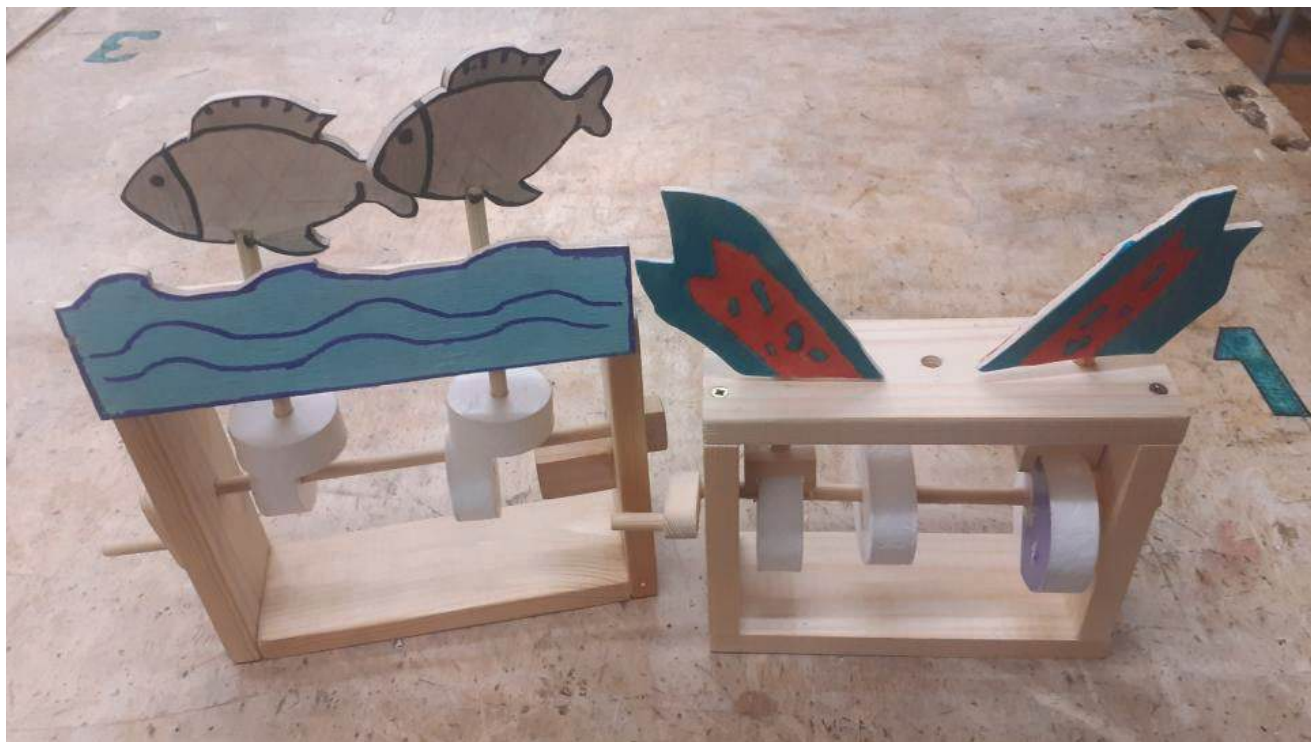


3.2 *Automata Course*

The *Automata* course focuses on designing and constructing mechanical moving objects (Figure 2). It introduces automata through mechanical transmissions, linking the understanding of physical phenomena with structural design and the creation of aesthetic or narrative motion.

Figure 2

Automata mechanisms



The course emphasises the analysis and application of mechanical systems. Students design motion transmissions and cyclical movements, assess the suitability of mechanisms, and apply measurements and geometric relations. STEAM integration manifests across physics (motion, forces), engineering (mechanisms), technology (materials and tools), mathematics (measurement), and the arts (design and narrative).

3.3 Teacher Input Collection

The first phase of data collection consisted of a Delphi-inspired structured idea-generation workshop (Hsu & Sandford, 2007) with teachers from technology-related subjects. Eighteen teachers recruited through the Estonian Technology Education Association participated in the session. Most participants were technology education teachers, while others represented closely related subjects such as craft and home economics and art.

During the workshop, participants were first introduced to the preliminary course plan of the Automata module, supported by a short oral explanation and examples of student artefacts. Teachers individually reviewed the course plan and wrote down possible interdisciplinary connections and integration opportunities directly on printed drafts of the course outline.

After the individual reflection phase, teachers formed small groups of three or four participants. In these groups they discussed their ideas and summarised key integration possibilities as keywords or short notes on large posters (A1 format). The same procedure was subsequently repeated for the LED Lamp course plan. At the end of the session, we collected the annotated course plans and the group posters as the primary data from the workshop.

Because most workshop participants represented closely related subject areas, we conducted a second data collection phase to obtain perspectives from other STEAM disciplines. Using convenience sampling, we invited teachers from mathematics, physics, chemistry, computing and art to participate in interviews.

Before the interviews, participants received a short description of the Automata and LED Lamp courses together with illustrative images. During the interviews, teachers were introduced to the course ideas and asked to suggest possible subject-specific integration opportunities. The discussions were informal and exploratory in nature and focused on identifying potential links between the course activities and the teachers' subject domains.

The final data consisted of written notes on the course plan drafts, keywords recorded on the group posters during the workshop, and audio-recorded interviews that were later reviewed and summarised for analysis (Table 1). The collected materials were analysed using a qualitative thematic approach (Braun & Clarke, 2006).

Table 1

Overview of data collection phases, participants and produced data

Data collection phase	Participants	Subject areas	Data produced
Workshop	18 teachers	Technology education, craft & home economics, art	Annotated course plans, group posters
Interviews	8 teachers	Mathematics, physics, chemistry, computing, art	Audio-recorded interviews and notes

Because many ideas emerged as keywords during group discussions rather than as complete verbal statements, the analysis focused on thematic interpretation of the collected ideas rather than detailed quotation analysis. In contrast, the interview recordings provided more articulated explanations, enabling the identification of more complete statements from the interview transcripts.

During the analysis, teachers' suggestions were grouped into five integration categories aligned with the STEAM domains and complemented by non-STEAM methodological and reflective proposals (Table 1). For instance, a teacher's remark such as "The history of the bicycle could

also be discussed here” was interpreted as a contextual teaching suggestion rather than a STEAM integration proposal.

4 RESULTS

4.1 *STEAM Integration Based on Teacher Input*

The findings indicate that teacher input extended beyond naming isolated disciplinary links and instead enabled STEAM integration to be understood as a multilayered process involving conceptual, technological, methodological and reflective dimensions.

Scientific integration (Science) involved linking scientific concepts and phenomena – such as light, electricity and motion – to concrete technological solutions. Engineering and technological integration (Engineering and Technology) focused on the design of mechanisms, circuits and production processes, the use of digital fabrication, and prototyping as a central learning activity. Mathematical and informatics integration (Mathematics) emerged through measurement, geometric relations and calculations. Artistic and design integration (Arts) highlighted the aesthetic, narrative and communicative dimensions of the technological artefact, where form, light, motion or character acquired meaning-making roles. Beyond the STEAM domains, teachers emphasised methodological and reflective components – such as documentation, presentation, self-assessment and peer feedback – that could help make integration visible to learners.

While the table (Table 2) presents summarised keywords, teachers’ proposals were often detailed and multilayered in terms of how integration with STEAM and other domains could be made explicit. Some suggestions were interesting and well-developed but extended beyond the intended scope of the course. For example, teachers proposed adding an additional function to the LED lamp (e.g., a book holder) or programming the LEDs to blink using Arduino. Although these ideas were conceptually rich and detailed, they extended beyond the intended scope of the course and were therefore not adopted in the further development of the course plans.

Table 2*Examples of teacher-identified integrations across STEAM domains*

Integration Category	Examples in Automata Course	Examples in LED Lamp Course
Science	Motion and forces through mechanical transmissions; effects of friction and speed on performance	Nature and propagation of light; LED functioning; relating luminous output to use context
Technology	Construction of mechanisms; material suitability; selection of tools and fabrication techniques	Use of CAD/CAM; CNC and laser cutting; preparation of production files
Engineering	Design and assembly of transmission mechanisms; testing and refinement of constructions	Circuit design; power supply selection; interaction between construction and electronics
Mathematics	Calculating gear ratios and dimensions; applying geometric relations in design	Measurement and scale; geometric aspects of lamp construction; sequencing and workflow planning
Arts	Creating character and narrative through motion; aesthetic qualities of form and movement	Use of light as a visual medium; interplay of form, material and illumination
Non-STEAM (methodological/reflective)	Storytelling and presentation; documentation and reflection; historical contextualisation of mechanisms	Presentation of final artefacts; writing user/maintenance instructions; self- and peer assessment; historical contextualisation of lighting

4.2 *STEAM Emphases in the LED Lamp Course*

Analysis of the *LED Lamp* course plan revealed strong scientific (science) and engineering emphases, particularly in relation to physics and electrical engineering. Central topics included the nature and measurement of light, LED functioning, circuit operation and electrical safety. Teachers noted that the lamp as a technological artefact enables abstract physical concepts to be linked to practical and comprehensible student activities.

One teacher group highlighted the potential to connect lamp design with real lighting standards and usage contexts – for example, discussing the luminous flux required in workspaces or homes and how this affects construction decisions and LED selection. Such an approach was seen to position physics and technology not as separate topics but as a functional whole.

From a technological and mathematical perspective, teachers emphasised the role of digital fabrication, including CAD/CAM software and CNC/laser tools. Through these activities, measurement, geometry and workflow planning became natural components of the learning process. The artistic and communicative dimension was reflected in the use of light as a visual medium and in the final documentation and presentation activities.

4.3 *STEAM Emphases in the Automata Course*

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5 DISCUSSION

The findings indicate that teacher input did not merely identify isolated disciplinary links but enabled STEAM integration to be conceptualised as a multilayered process involving conceptual, technological, methodological and reflective dimensions. This aligns with the issue that STEAM implementation in schools often remains fragmented and dependent on individual teacher initiative. The present development study suggests that structured and purposive teacher input can help mitigate such fragmentation.

The results support the view that technology education can serve as a central integrating discipline within STEAM, where scientific, engineering, mathematical and artistic aspects converge around design processes and artefact creation (de Vries, 2024). In this study, integration surfaced not primarily through naming subject areas but through learning activities, workflow and reflection.

An important conclusion regarding within-subject integration is that STEAM does not imply the dissolution of disciplinary boundaries or the transformation of technology education into a catch-all subject. Rather, a clear disciplinary focus – electronics and light in the *LED Lamp* course, and mechanics and motion in *Automata* – provided a framework in which other disciplinary perspectives could emerge in functional and justified ways. This supports the view that the “T” in STEAM denotes design-based thinking, problem solving and intentional engagement with the material world.

Although the *LED Lamp* and *Automata* courses were not designed as comparative research objects, the development process revealed that different technological starting points generate distinct STEAM integration profiles. This suggests that STEAM integration emerges from the internal logic of the technological theme and artefact.

The analysis also highlighted the central role of methodological and reflective elements. Documentation, presentation, self-assessment and peer feedback emerged as key sites where integration could become visible and explicit to learners. At the same time, the study pointed to a practical challenge: teachers’ proposals required systematisation and didactic filtering to distinguish subject-justified and feasible suggestions from ideas that extended beyond the intended scope of the course. This underscores the developer’s role as a conscious pedagogical decision-maker.

The study is limited by its small and convenience-based sample of teachers and by the absence of classroom piloting at this stage of development. The findings therefore reflect early expert insight rather than implementation outcomes and should be interpreted as indicative rather than conclusive.

In the next phase of development, teaching and learning materials will be created for both modules and piloted in two comprehensive schools during the 2026/27 school year. The pilot results will inform revisions to the course plans and materials, which will subsequently be made publicly accessible. This iterative development–pilot–revision cycle will enable assessment of how within-subject STEAM integration functions in real classroom settings and how it may be scaled more broadly.

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Caught in an Epistemic Trap: Why Economic Justifications Fail Design and Technology Education

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Abstract

Design and Technology (D&T) education in England occupies an increasingly precarious position within the school curriculum. In response to declining participation, reduced curriculum time, and policy marginalisation, recent and ongoing advocacy by the D&T Association (D&TA) has sought to secure the subject's future through economic justification. D&T is positioned as essential to national productivity, industrial competitiveness, innovation, and labour market preparedness.

Drawing on Ball's work on performativity and neoliberal policy (2003, 2012), the paper conceptualises economic justification as an 'epistemic trap.' It argues that in seeking legitimacy through economic rationality, D&T accepts a mode of valuation that is expedient, volatile, and misaligned with educational purpose. This not only marginalises the subject's intellectual foundations but accelerates the conditions of its potential decline.

The paper uses critical rhetorical analysis of a D&TA policy-facing advocacy document, whilst using Toulmin's model of argumentation (Magalhaes, 2020) as a methodological framework, examining how economic claims are constructed, supported, and qualified. Particular attention is given to the strength of warrants and backing, the absence of meaningful qualification, and the reliance on industry authority. Using Toulmin's framework, aligned with Ball's (2003) concept of performativity, reveals how policy certainty, urgency, and measurability shape the argument, whilst Fricker's (2007) work exposes the epistemic injustices that result.

The findings, based on rhetorical analysis, demonstrate that the economic argument relies on weak educational backing, authority substitution, and unqualified claims. This framing produces an epistemic injustice by deflating the credibility of the subject's educational value, by obscuring D&T's distinctive practices. Paradoxically, the more convincingly the subject aligns itself with economic rationality and success, the more it undermines its existing precarity. The paper concludes that long-term sustainability for D&T depends not on economic alignment, but on reclaiming epistemic autonomy and articulating educational value beyond performative metrics.

1 INTRODUCTION

The future of Design and Technology (D&T) education in England remains perilous, with few precedents for a subject experiencing such a rapid rise followed by dramatic threats to its existence (Spendlove, 2022). Since the millennium, D&T examination entries have fallen by approximately 80%, whilst indicators of investment, government prioritisation, and teacher recruitment point toward an uncertain future. In response to these challenges, I have previously advocated for an alternative vision prioritising the intellectual opportunities the subject offers through Design and/or Technology 2.0 (Spendlove, 2017).

Likewise, the Design & Technology Association (D&TA), whose objective is to be 'the authority on developing high quality teaching and learning', have also acknowledged significant concerns. In particular in response the challenges faced, the D&TA's publication 'Reimagining D&T: Our Vision' (2023), which remains as a centrepiece of their homepage (as of January 2026), foregrounds 'The Economic Case' for reimagining the subject, with evocative language claiming we "must act now to transform the subject and save it from almost certain oblivion" (D&TA, 2023, p.1).

This economic prioritisation takes on heightened significance given England's 2025 curriculum and assessment review (DfE, 2025) which offers an opportunity for bold reconceptualising of the subject. However, the D&TA's current position prioritises economic instrumentalism whilst advocating 'rebranding' rather than pursuing emancipatory curriculum reform grounded in ethical responsibility, disciplinary integrity, and social justice. In highlighting the 'economic case' as primary validation, the vision consequently diminishes the subject's intrinsic disciplinary value.

Drawing on Ball's critique of neoliberal policy (2012) and Fricker's concept of epistemic injustice (2007), this paper examines how D&T has fallen into an 'epistemic trap' that ultimately devalues the subject's intellectual contribution whilst legitimising historical alignment with industrial production, labour-market competitiveness, and capitalist utility. This economic validation therefore distorts the curriculum toward visible artefacts, measurable outcomes, and contrived 'problems,' privileging consumption and fabrication over ethical, cultural, or environmental reflection. Such comparable burden of economic justification is not adopted by other school subjects, therefore D&T aligns itself in a position of epistemic injustice (Fricker, 2007) whereby its academic contribution is undervalued, marginalised, and rendered unintelligible within dominant policy discourse. Consequently, a political blind spot emerges where the subject exists within limited instrumentalist rationalities, reduced teacher professionalism, distorted assessment practices, and a destabilised identity (Spendlove, 2024).

In this paper I will therefore argue that the pursuit of externally validated economic legitimacy constitutes an 'epistemic trap' that manifests in seeking credibility through prioritising industrial utility and productivity, whilst inadvertently undermining the intrinsic educational values that

define disciplinary identity. This trap manifests in two interlocking dynamics: first, historical alignment with industrial production frames the subject through logics of growth, consumption, and capitalist utility, distorting curriculum toward fabrication over ethical reasoning, cultural critique, and environmental responsibility; second, because economic validation burdens D&T uniquely, it results in epistemic injustice whereby inherent values become marginalised within policy discourse.

2 METHODOLOGY AND ANALYTICAL FRAMEWORK

This paper employs rhetorical analysis as a qualitative methodology to provide 'interpretation, meaning and illumination' (Usher, 1996, p.18) of the 'economic case' within the D&TA's 'Reimagining D&T: Our Vision'. Rhetorical analysis was chosen as it is particularly useful for examining how policy arguments are constructed, presented, and mobilised to persuade specific audiences.

Aristotle (320 BC) defined rhetoric as the 'ability of observing in any given case the available means of persuasion' (Magalhaes, 2020). This analysis integrates two complementary frameworks. Firstly Aristotle's 'triad' of rhetorical devices (Lutzke & Henggeler, 2009): ethos (credibility), pathos (emotion), and logos (reason), examine the persuasive strategies. Secondly, Toulmin's argument model (Magalhaes, 2020) provides a structure for systematic evaluation of internal coherence and evidential support. These frameworks are theoretically complementary as Aristotelian rhetoric reveals how persuasion is framed and in what ways, whilst Toulmin's model exposes where argumentative structure weakens, collapses, or relies on assumptions.

Toulmin's model identifies six elements: claim (position advanced), data (evidence presented), warrant (logical connection between data and claim), backing (deeper support legitimising warrant), rebuttal (acknowledgement of conditions under which claims might not hold), and qualifier (indicators of claim strength, scope, or conditionality). As Magalhaes (2020, p.2) notes, "rhetoric deals with the realm of the possible, the probable, the plausible, and the verisimilar", therefore analysing these elements reveals not only what is stated but what is implied, assumed, or strategically omitted.

The 'Reimagining D&T' publication comprises ten pages interspersed with images and endorsing quotes. Given this brevity, a comprehensive approach was taken rather than sampling. The text was read multiple times to identify the core economic argument and supporting rhetoric. Initial readings identified explicit claims about economic necessity whilst subsequent reading facilitated systematically mapping statements according to Aristotle's triad and then applied to Toulmin's structure.

Specific instances were selected based on representativeness of broader rhetorical patterns and centrality to the economic case. For example, macroeconomic data (GVA figures, employment statistics) exemplified logos-based reasoning, crisis-framed language ('almost certain oblivion,' 'we must act now') exemplified pathos-driven urgency, whilst industry endorsements were identified as ethos appeals. These were evaluated against Toulmin's framework to determine

whether data adequately supported claims, whether warrants were explicit or implied, and whether backing, qualifiers, and rebuttals were present or absent. Throughout, attention focused on how simplification, aggregation, and urgency are deployed to generate conviction in the absence of robust evidence or substance.

3 RESULTS

3.1 *Core Claim and Argumentative Structure*

The central claim is that Design and Technology education is economically essential to the UK, and declining provision threatens national prosperity. The implied policy conclusion request Government prioritise D&T through funding, curriculum reform, and teacher incentives. Whilst this may appear reasonable, albeit superficial, the rhetoric relies heavily on association, urgency, and selective economic framing, proving overly simplistic and inadequately supported upon examination.

This economic framing represents an ‘epistemic trap’, as by grounding legitimacy primarily based on economic utility, the argument marginalises D&T's intrinsic disciplinary knowledge, pedagogical distinctiveness, and epistemic value. As a consequence, a sense of ‘epistemic betrayal’ occurs through succumbing to the seductive appeal of ‘reimagining’ D&T as a driver of economic prosperity. Such betrayal inadvertently undermines the foundations that could ultimately sustain curricular standing.

Using Toulmin's framework, the argument maps as follows: Claim - D&T must be prioritised because economically it is essential to UK prosperity. Data - manufacturing, engineering, and design sectors contribute significant GVA (£645 billion), employ large workforce proportions (26% of UK workers), with employers reporting skills shortages and demand for creativity, problem-solving, and technical capability. Warrant (largely implicit) - if economically important sectors require certain skills, school D&T should be strengthened to supply them. Backing (weak and anecdotal) - endorsements from prominent designers, assumed curriculum-labour market alignment, and generalised skills discourse around creativity and innovation. Qualifiers (largely absent)-claims presented as necessary and urgent with minimal conditional language or contextual acknowledgement. Rebuttals (not meaningfully addressed) - potential counterarguments about whether skills shortages reflect labour market rather than educational failures, whether economic priorities may shift, or whether transferable skills are not subject-specific remain unengaged.

3.2 *Claim, Data, and Warrant: The Problem of Implied Causation*

Within the D&TA's economic case ‘claims’ are presented in absolutist terms where D&T is characterised as developing skills 'imperative to success in life and work' without specifying conditions or how this is authentically achieved. This approach excludes debate, whilst positioning teachers as acquiescent in accepting 'that a Reimagined D&T would require a rebrand that includes a name change', with 'Design, Engineering and Innovation' foregrounded as the way

forward. From Toulmin's perspective, strong claims require proportionately strong evidence and support, yet the evidence base does not warrant such certainty or conclusions.

Logos (appeals to reason) appears most prominently in macroeconomic data presentation. Large-scale figures such as £645 billion GVA, 26% of workforce demonstrate manufacturing, engineering, and design economy importance. However, this constitutes rhetorical rather than a logical or convincing argument. Aggregating impressive statistics creates a causal impression without establishing actual causal links. The data suffers three critical problems: firstly, it conflates distinct sectors into single economic category, rhetorically aligning them with school-level D&T; secondly, it demonstrates sectoral economic importance but provides no evidence that GCSE or KS3 D&T is necessary or sufficient for their success; thirdly, paradoxically, the existing robustness of these sectors is despite the documented decline of D&T which consequently undermines the educational necessity claims. As such an association fallacy is evident in that data shows tenuous correlation but assumes causation without justification.

The 'warrant', bridging data to justify the claim, is therefore never explicitly stated. Instead, it's implied through rhetorical association by economic data being presented, D&T being mentioned, and readers expected to infer causal production. In Toulmin's terms, warrants must be defensible and relevant. Here, the warrant that 'economically important sectors requiring skills means school D&T should be strengthened' depends on unstated assumptions that school-level D&T is the primary or most effective location for developing the required 'skills'.

In pursuing a narrow economic case, there is little to suggest that the advocated skills aren't equally or better developed elsewhere in curriculum or across the curriculum, or that the skills 'taught' within D&T align with future industry demands. The warrant therefore functions rhetorically, appearing plausible, but lacking analytical substance.

3.3 *Backing: Authority Substituting for Evidence*

Backing provides deeper support legitimising warrants. The economic case 'backing' is notably weak, taking three problematic forms reinforcing the epistemic trap by positioning external validation as disciplinary coherence. Most significantly, educational-economic causal evidence is absent. The document presents economic data about manufacturing, engineering, and design economy but provides no backing demonstrating how school D&T causally contributes to these outcomes.

Equally absent are any form of longitudinal evidence linking school D&T participation to sectoral entry, productivity, or innovation. Likewise, there is no evidence showing D&T produces economic outcomes more effectively than other subjects or cross-curricular approaches or substantial evidence that KS3 or KS4 curriculum reform alters national skills supply measurably. Without such backing, warrants remain speculative. Economic scale therefore serves as a tenuous proxy for educational impact with rhetorical substitution rather than supporting evidence. Epistemically this is significant as the argument assumes what should be demonstrated, treating school subject-economic outcome connections as self-evident when this requires justification.

Furthermore, the document relies heavily on authority rather than disciplinary knowledge. Prominent designer endorsements provide implicit backing without scrutiny, whilst anonymous, selectively presented teacher statements validate D&T necessity. From Toulmin's perspective, this constitutes weak backing, authority statements don't substitute for disciplinary or empirical justification whilst industry voices validate economic relevance from practitioner perspectives but cannot establish educational necessity or curricular effectiveness.

The reliance on external rather than internal disciplinary authority therefore reinforces the epistemic trap, where the subject's credibility is outsourced to economic actors rather than grounded in its own knowledge base, pedagogy, or educational philosophy. Consequently, epistemic legitimacy is marginalised, overridden and framed by external validation rather than drawing upon disciplinary identity.

3.4 *Qualifier: The Absence of Analytic credibility*

Qualifiers indicate the strength, scope and conditionality of the claim. As such, the subject associations assertions confirm the ambiguity apparent within the economic argument, notably lacking qualification, creating weaknesses undermining analytical credibility.

Claims are presented as universally true rather than context dependent whilst no acknowledgement appears that economic alignment may have limits, unintended consequences, or detrimental impacts on subject, teachers, and students. Phrases like our subject is strong on the 'human skills' that industry is crying out for from education' lack qualification at analytical credibility's expense. Strong, unqualified claims require strong evidence, yet the evidence base is weak. This absolutist, catastrophic framing leaves little opportunity for justifying the subject on grounds beyond economic utility, further entrenching epistemic marginalisation.

3.5 *Rebuttal: The Absence of Counterarguments*

In Toulmin's model, rebuttal acknowledges conditions under which claims might not hold, or counterarguments to anticipate and address. To some extent this might be expected when trying to make a convincing case to government, yet the document fails to engage meaningfully with potential rebuttals, resulting in closed rhetoric appearing persuasive only to those already convinced. Such myopia does little for the credibility of the subject and four critical rebuttals remain unaddressed, each fundamentally challenging the economic case and revealing internal contradictions.

Firstly, skills shortages may reflect labour market failures, inadequate wages, poor conditions, insufficient employer training investment, or regional inequality, rather than educational deficiencies. The document doesn't address whether increasing D&T provision would remedy these structural issues or simply produce qualified individuals choosing not to enter sectors offering unappealing conditions. This omission is analytically significant as it assumes educational supply creates labour market demand, ignoring that demand-side factors may be determinative.

Secondly, the document's own skills characterisation creates unaddressed rebuttal. It repeatedly implies D&T uniquely develops creativity, problem-solving, collaboration, adaptability and social emotional skills, described as essential to future economies. Yet given such skills would need to be transferable if they are able to move from the classroom to industry, then what specifically within D&T makes it economically indispensable compared to transferable skills from other subjects? The argument implies simultaneous development of universal skills (transferable across contexts) alongside subject exclusivity (uniquely developed in D&T), a logical contradiction that appears contrived. Engaging this rebuttal would require either demonstrating D&T develops these skills more effectively than alternatives or abandoning exclusivity claims. Failure to address this contradiction is particularly damaging because it undermines the very skills discourse the argument depends upon.

Thirdly, the document's own data provides unaddressed rebuttal. It acknowledges 77% of designers work outside 'design sectors', inadvertently weakening rather than strengthening the economic case. If 'designers' are distributed across the economy rather than concentrated in discrete sectors, this suggests design capability develops through multiple educational and professional pathways, not primarily through school D&T. The document doesn't address this tension, treating D&T as primary feeder into all design-related domains whilst simultaneously presenting data showing broad sectoral dispersion.

Fourthly, and perhaps most strikingly, the document's own logic provides unaddressed rebuttal. If manufacturing, engineering, and design sectors contribute £645 billion GVA and employ 26% of the workforce despite documented D&T provision decline, this suggests these sectors aren't dependent on school-level D&T as implied. Rather than undermining the economic case, D&T decline has coincided with sectoral resilience. The document doesn't reconcile this contradiction. Acknowledging it would require either demonstrating lag effects (decline manifesting in future economic outcomes) or conceding weaker causal links than asserted.

3.6 *Rhetorical Strategies*

In addition to applying Toulmin's structural analysis, three rhetorical strategies merit further analysis by revealing contradictions, argumentative weaknesses and contributing further to the epistemic trap.

Firstly, the document deploys extensive crisis rhetoric such as 'almost certain oblivion,' or 'we must act now', or 'crisis point', each framing declining D&T provision as existential threat. This 'pathos' driven urgency compresses complex policy trade-offs into moral emergency, discouraging scrutiny of costs and competing priorities. The effect positions opposition or even critical questioning as tantamount to accepting national decline. However, this urgency is rhetorically constructed rather than analytically justified. GCSE entry decline is treated as equivalent to national economic risk without intermediate analysis demonstrating connections. From argumentative standpoints, urgency substitutes for evidence and causality. Emotional framing demands immediate action but doesn't provide the evidence base for determining appropriate action or whether alternative responses might prove more effective. Moreover, crisis

framing reinforces the instrumental justification, that D&T matters because its loss would be catastrophic, not because it possesses intrinsic educational value to children, but rather the economic worth.

Secondly, the document employs 'equity framing' alongside economic arguments, contrasting D&T provision in private versus state schools and introducing rights-based, social justice appeals. This 'pathos' appeal is emotionally compelling: if advantaged 'private' education students receive D&T which is claimed to be 'thriving', this ultimately frames 'state' school students at a deficit and constitutes educational inequity. However, equity framing sits uneasily with economic argument. Rights-based claims and economic productivity claims require different evidence forms and operate according to different policy logics. The document oscillates between these without acknowledging tension. If D&T is economically essential, the equity argument becomes less convincing, economic necessity would justify universal provision regardless of equity concerns. Consequently, the economic case appears instrumental (D&T matters only for what it produces), whilst equity case appears opportunistic (invoked when economic arguments prove insufficient).

Thirdly, the document quotes three prominent 'designers', using their credibility to bolster D&T's legitimacy through 'ethos' amplification. The subject 'borrows' prestige from external authorities. However, this creates a closed rhetoric where insiders validate each other's assumptions without engaging counterarguments or alternative perspectives. No countervailing views from economists questioning causal links between school subjects and national productivity, curriculum theorists critiquing instrumentalism, or labour market analysts addressing skills shortages through structural rather than educational lenses appear. Dialectical absence produces arguments appearing robust to sympathetic audiences but fragile under critical examination. More fundamentally, this reliance on borrowed authority rather than disciplinary knowledge further entrenches epistemic ambivalence. The subject cannot defend itself on its own terms and must continually seek external validation based on unsubstantiated economic cases.

4 DISCUSSION

Whilst the pragmatism of the 'D&T Association's 'Vision' for the future of the subject in English Schools' might be understood, analysis of the 'economic case reveals a fundamental paradox in Design and Technology's positioning during a critical moment for its future. In seeking curricular survival through economic justification, the subject has become caught in an epistemic trap by expediently foregrounding an unsustainable economic case that ultimately undermines the epistemic basis of the subject. This economic framing therefore constitutes an epistemic betrayal threatening the very foundations upon which robust, enduring justification might be built.

By grounding D&T's legitimacy primarily in economic utility and external validation, advocates systematically marginalising the subject's intrinsic disciplinary knowledge, distinctive pedagogical approaches, and educational value. The limited argument positions D&T as instrumentally valuable, justified predominantly by economic value, rather than intrinsically

valuing the knowledge and practice domain in its own right. This represents epistemic infidelity which might be considered understandable in the desperate endeavour to save the subject from 'almost certain oblivion', yet paradoxically this may inadvertently accelerate demise by undermining epistemological foundations that could provide more stable, durable, and educationally defensible justification.

Analysis demonstrates systematic weaknesses across all six Toulmin elements. Claims are overstated and unqualified, presented with rhetorical certainty that evidence cannot support. Data aggregation implies causal necessity without demonstrating actual causal links between school-level D&T and economic outcomes. Warrants connecting education to economic prosperity are implied through association rather than explicitly defended through evidence. Backing relies on borrowed authority from industry voices and alignment assumptions rather than robust educational research, longitudinal evidence, or disciplinary scholarship. Qualifiers acknowledging limitations, conditionality, and contextual dependencies are conspicuously absent, leaving arguments vulnerable to economic condition shifts. Rebuttals exposing internal contradictions and alternative explanations remain unaddressed, creating closed rhetorical systems appearing persuasive only to the already convinced.

As Ball's (2012) analysis of neoliberal policy discourse suggests, in pursuing the economic case the subject becomes governable through external metrics, perpetually vulnerable to industrial priority shifts, automation trajectories, and political economic fashions. Fricker's (2007) framework on epistemic injustice further reveals how D&T's own voice, its testimony about distinctive knowledge practices, pedagogical contributions, and educational meaning, become systematically discounted and marginalised in favour of industry endorsements and tenuous macroeconomic data.

The combined effect locks D&T into epistemic precarity. A subjects justified primarily on instrumental grounds, vulnerable to displacement whenever economic conditions shift, technological priorities change, or skills demandsevolveunexpectedly. Economic framing, rather than securing D&T's future, may ironically ensure continued vulnerability by making legitimacy perpetually contingent on external economic validation rather than grounded in robust disciplinary knowledge and enduring educational purpose.

This analysis suggests escaping the epistemic trap requires fundamental reorientation. D&T must reclaim its disciplinary voice and articulate value in educational rather than purely economic terms. This means foregrounding what the subject distinctively enables such as ethical engagement with material culture, critical interrogation of technological systems, creative problem-framing in ambiguous conditions, iterative design thinking, user-centred empathy, sustainability reasoning, and cultivating human judgment about how the mad world should be rather than merely how it currently is. These capabilities are profoundly educational; they develop citizens capable of shaping technological futures rather than merely serving them.

England's current curriculum and assessment review offers a rare reorientation opportunity. Rather than doubling down on economic instrumentalism, D&T advocates should articulate

visions grounded in ethical responsibility, ecological sustainability, social justice, and collective flourishing. They should position Design and/ or Technology education (2.0) as preparation not for serving existing economic arrangements but for imagining and creating alternatives. Only by escaping the epistemic trap, by reclaiming disciplinary integrity and articulating the inherent value on educational grounds, can D&T contribute meaningfully to socially just, ecologically sustainable, and democratically vibrant futures that education should serve.

5 DISCLOSURE STATEMENT

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the author.

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A Vision for the Treatment of Technology Education within Integrated STEM

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Abstract

Since the inception of the term 'STEM' (Science, Technology, Engineering and Math) in the late 1990's, a persistent challenge for educators has been the STEM gap. Inequities in participation across socioeconomic status, race and sex have challenged educators and policymakers alike. Integrated STEM (iSTEM) education has emerged as a promising meta-discipline which is attractive to a wide variety of learners. iSTEM's value lies in its ability to offer interdisciplinary, student-centred learning experiences, mirroring the real-world complexity of global, and local issues. Despite this, iSTEM still faces considerable challenges. Conceptualisation and enactment of iSTEM experiences remain fragmented, particularly within technology education disciplines. Educators battle to navigate broad and varying definitions, pedagogies, and levels of integration. Building on two previously proposed frameworks, the first addressing the content of iSTEM from an educator's perspective, the second addressing the learning context from the learner's perspective, this paper presents a combined theoretical framework for iSTEM education. In this framework, technology education disciplines are foregrounded as disciplinary domains, not merely a pedagogical tool. This combined framework encompasses findings from a work-in progress systemised literature review. In addition, it spotlights students' volition over their educational journeys, highlighting self-efficacy and social cognitive career theory (SCCT) as key influences. This paper contributes to the ongoing discourse, offering a unified model for iSTEM implementation. It aims to support educators in creating inclusive, coherent and transformative learning experiences and in fostering a lifelong interest in STEM. For students, the framework recognises iSTEM's potential in affording greater volition over their educational and career trajectories. Future research will explore how iSTEM experiences can shape students' educational and career trajectories, with a focus on empowering underrepresented learners through inclusive, affective and authentic STEM provision.

Key Words: STEM, Technology Education, Integrated, Inclusive

1 INTRODUCTION

Despite the global momentum behind improving Science, Technology, Engineering and Mathematics (STEM) education provision, there remains a consistent gap between STEM roles and capable citizens to fill these professions. Educators in this space are constantly working to fill this gap, providing a range of multidisciplinary, transdisciplinary and integrated STEM (iSTEM) experiences, to name a few. In these, a consistent challenge remains the varying definitions and conceptualisations of STEM and iSTEM (Stack Mulvihill, Reid, and Dunbar 2024), creating a lack of clarity and consistency both in the literature and in practice. These difficulties are compounded when attempting to effectively integrate Technology and Engineering education. Math and Science are predominantly procedural and technical in nature, both subjects having a defined and concrete knowledge base. Technology and Engineering, however, have a constantly evolving knowledge base, with “the variability in explicit knowledge which is considered central to the disciplines” (Buckley et al. 2019). This presents a challenge not only for integration across disciplines, but also for those without prior experience within technology education, as they attempt to grapple with a new and constantly evolving landscape.

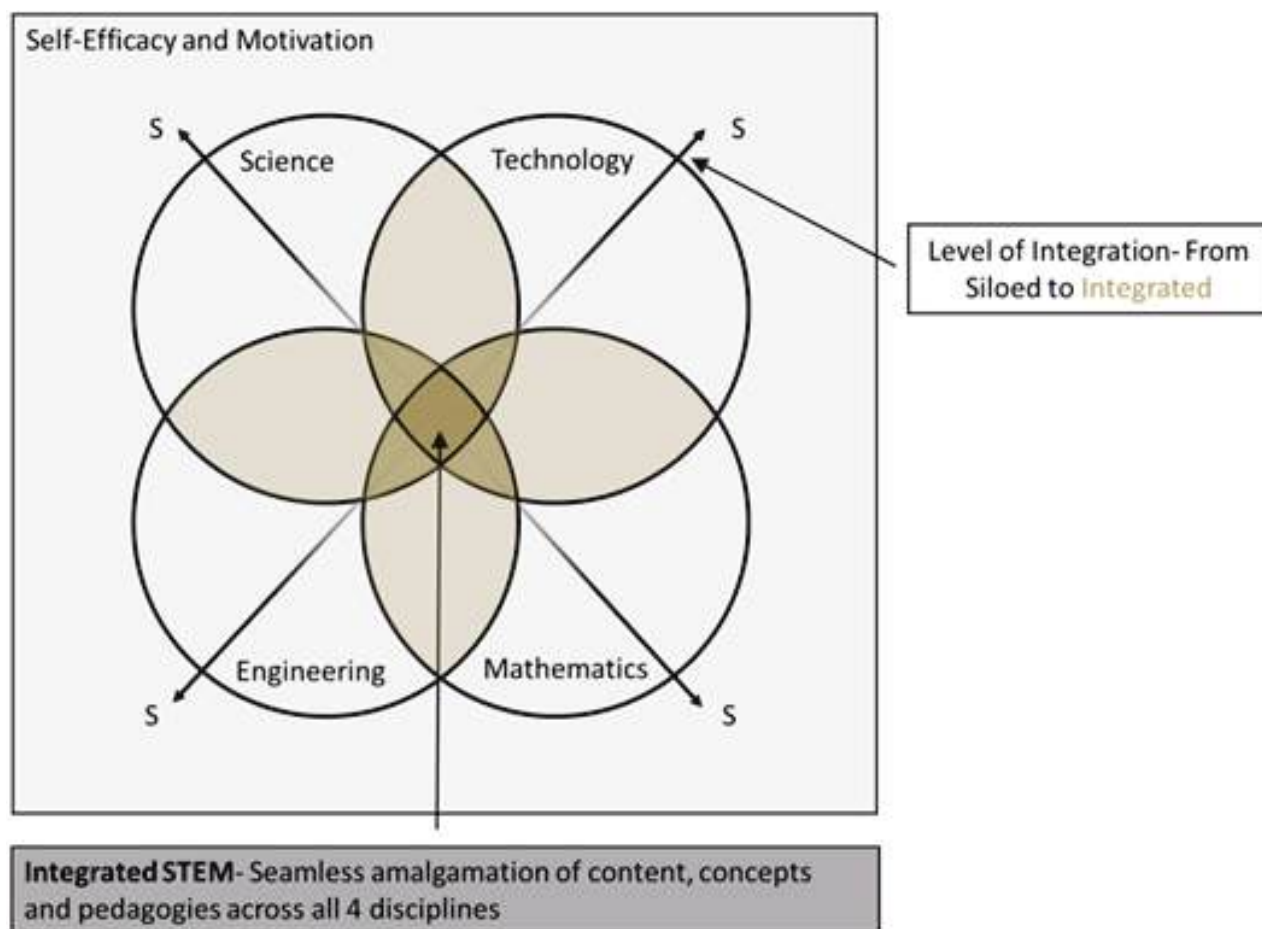
Previous works in this area highlight a number of key challenges for educators, inter alia the lack of clarity in definition, the challenges in effective integration, the low teacher confidence in providing effective iSTEM experiences (Stack Mulvihill, Reid, and Dunbar 2025), and existing frameworks, including those by the author lacking the centrality of technology education as a means to effectively bridge these divides (Kelley and Knowles 2016; Roehrig et al. 2021). In addition to this gap, a compounding issue for educators is the tendency to treat technology, and engineering to a lesser extent as simply tools for iSTEM, as opposed to distinct disciplines. This paper proposes a unified theoretical framework for integrated STEM education, repositioning technology and engineering as central tenets within these experiences. This aims to support teacher educators and practitioners alike on an international stage, in providing effective, and meaningful iSTEM experiences.

2 REVISITING STEM INTEGRATION THROUGH A TECHNOLOGY AND ENGINEERING LENS

Previous works by the authors highlighted in Figure 1 and Figure 2 outline theorised content and context frameworks for iSTEM, respectively. Looking to the content framework firstly, this highlights how an iSTEM experience may be integrated into practice over the course of a class project, module, or curricular segment by an educator. In doing so, the framework also acknowledges aspects of STEM subjects may be delivered in a siloed manner to explore core content within any of the subject areas. The central gold section highlights an ‘ideal’ iSTEM experience, with the seamless amalgamation of content, concepts and pedagogies across all four disciplines.

Figure 1

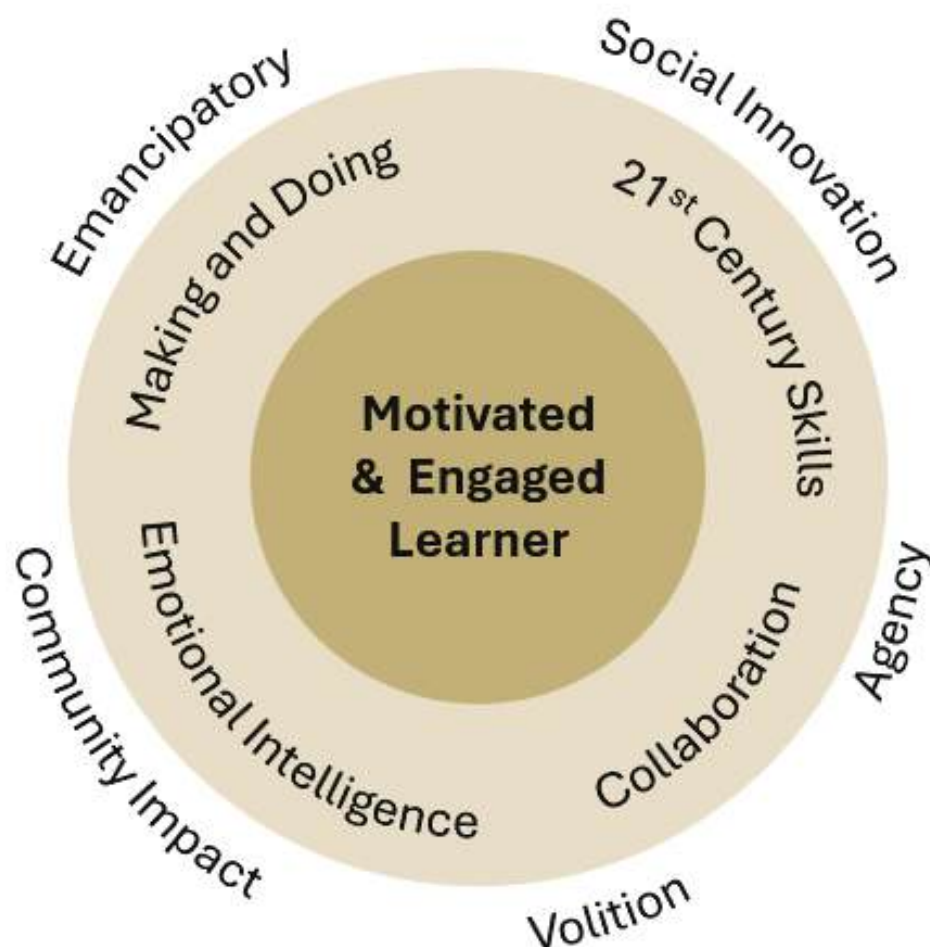
Content Framework for iSTEM Experiences



Looking to Figure 2, this framework shifts its focus to informing the context of an iSTEM experience, placing the ideal learner at the centre, who is motivated and engaged in an effective, engaging and meaningful iSTEM experience. Two further layers radiating from the centre, the first highlighting specific skills and abilities which we aim to develop within an effective iSTEM experience. It's important to note this list is not exhaustive and can be tailored to the specific student cohort. The outer layer outlines common outcomes for students who have engaged in such an experience. From this, the unique appeal of iSTEM experiences is clear; it's ability to provide a wide range of outcomes for students, irrespective of their background. Neither of these frameworks however, accounts for the difficulty in effectively integrating these disciplines- particularly Technology and Engineering.

Figure 2

Context framework for iSTEM experiences



Beyond the authors work, this trend continues with frameworks such as those by Kelley and Knowles (2016) and Roehrig et al (2021). Though effective frameworks, and both highly detailed in their descriptions of key characteristics for effective iSTEM education; both fall short in effectively empathising with teacher's difficulties in effectively integrating the Engineering and Technology disciplines within iSTEM experiences (Stack Mulvihill et al. 2025:6). This is a persistent challenge amongst the literature, even for experienced teachers in the technology disciplines (Aldemir et al. 2022). Looking to a synthesis of iSTEM frameworks, Moore et al. (2020:9) highlight the importance of effective integration of all four disciplines, noting this approach "may further their understanding of each individual discipline and help them transfer skills and knowledge across disciplines". To investigate this gap in the literature, a systemised literature review has been conducted, exploring current levels of integration of Engineering and Technology within iSTEM experiences, as well as lived experiences of students and teachers within these experiences.

3 METHODOLOGY

To investigate this research gap, a systemised literature review was conducted, with the following research questions:

- To what extent are engineering and technology imbedded within K–12 integrated STEM (iSTEM) education?
- What are the main challenges, opportunities, and enabling factors in achieving effective engineering and technology integration in iSTEM?

In addition, more detailed sub-questions were investigated, some of which will be explored by thematic analysis in the following section. The systemised review was taken in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. To achieve this, the first author screened titles and abstracts across four well-known databases for education research. Search strings used are outlined in Table 1. In addition, articles were screened under the following criteria: Peer-reviewed, written in English, open or institutional access, empirical studies, dealt with Technology and/or Engineering integration within STEM, K-12 education setting, and published since 2016. Recently, Science, Technology, Engineering, Arts and Mathematics (STEAM) education has gained momentum as a viable conduit with which to provide similar opportunities to students as iSTEM, the focus of this study. In line with this, STEAM or iSTEAM articles of relevance were also included in the sample. Additionally, the ‘i’ in iSTEM may be interpreted as Inquiry, Interdisciplinary and others, depending on the context. As such, any articles which did not align with the integrated focus of this study were removed at the title and abstract screening stages.

Table 1

Systemised Review search terms and results

Results of Initial Search		
Search strings	Database	Results
TS=("STEM education" OR "integrated STEM" OR "iSTEM") AND TS=("engineering education" OR "technology education" OR "design " OR "maker education" OR "robotics" OR "coding") AND TS=("K-12" OR "primary education" OR "secondary education"" OR "middle school" OR "high school") AND TS=("case study" OR "qualitative" OR "quantitative" OR "mixed methods") AND TS= ("teacher" OR "student")	Web of Science	50
abstract=("STEM education" OR "integrated STEM" OR "iSTEM") AND abstract=("engineering education" OR "technology education" OR "design" OR "maker education" OR "robotics" OR "coding") AND abstract=("K-12" OR "primary education" OR "secondary education" OR "middle school" OR	ERIC	68

"high school") AND abstract:("case study" OR "qualitative" OR "quantitative" OR "mixed methods")		
TITLE-ABS-KEY("STEM education" OR "integrated STEM" OR "iSTEM") AND TITLE-ABS-KEY("engineering education" OR "technology education" OR "design" OR "maker education" OR "robotics" OR "coding") AND TITLE-ABS-KEY ("K-12" OR "primary education" OR "secondary education" OR "middle school" OR "high school") AND TITLE-ABS-KEY("case study" OR "qualitative" OR "quantitative" OR "mixed methods") AND TITLE-ABS-KEY("student" OR "teacher")	Scopus	197
("STEM education" OR "integrated STEM" OR "iSTEM") AND ("engineering education" OR "technology education" OR "design" OR "maker education" OR "robotics" OR "coding") AND ("K-12" OR "primary education" OR "secondary education" OR "middle school" OR "high school") AND ("case study" OR "action research" OR "lesson study" OR "qualitative" OR "quantitative" OR "mixed methods" OR "intervention study") AND ("teacher" OR "student")	EBSCO	7
	Total with duplicates removed	238

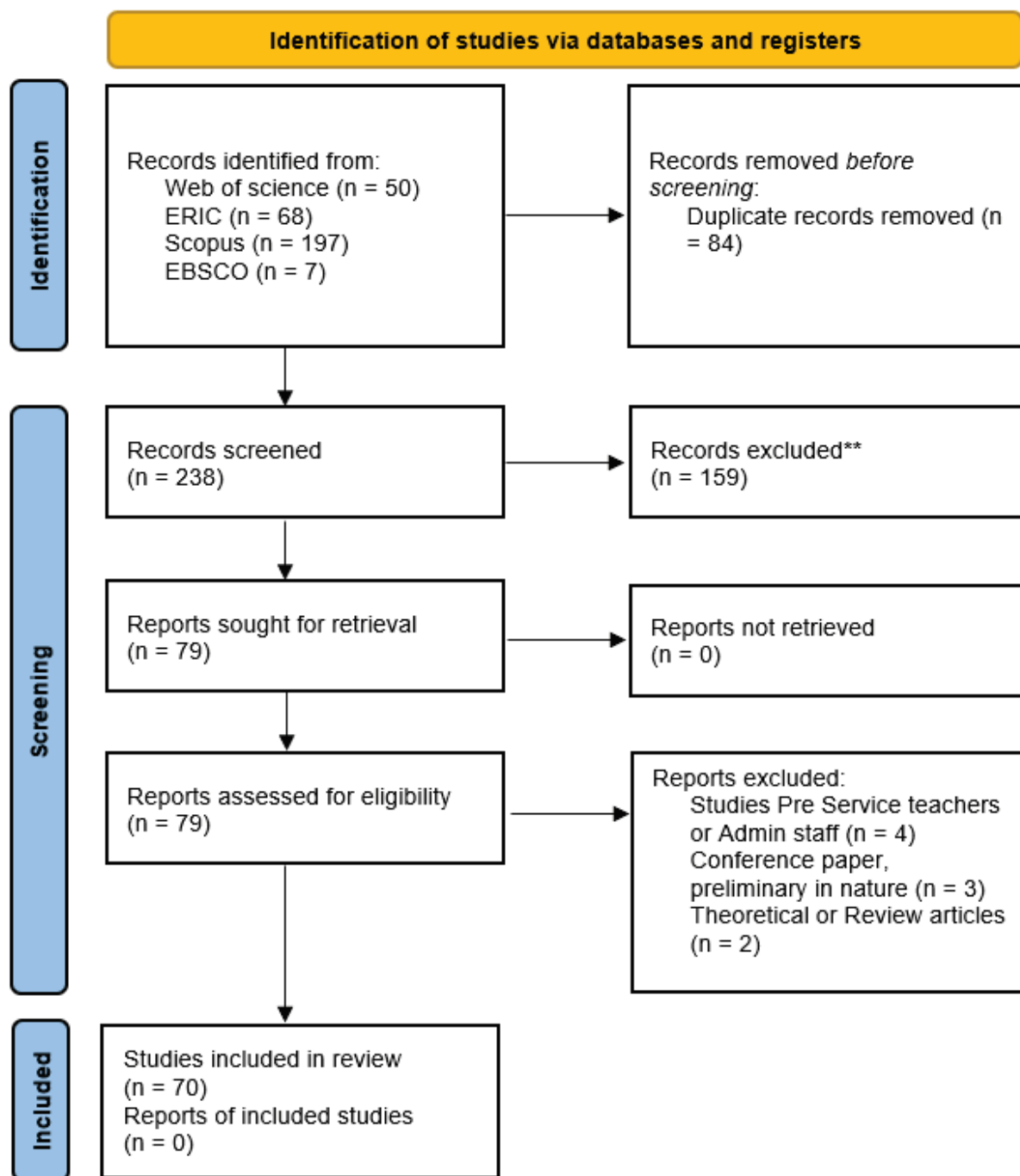
Following this search process, articles were screened for duplicates, leaving 238 articles remaining. Figure 3, below details the reviewing, screening and inclusion process which followed. A total of 70 articles were retained after title, abstract, keyword, and full text screening. The remaining articles were then reviewed and examined in depth. The findings section details some of the emerging themes from these articles.

3.1 *Disclosure on GenAI use*

MS Copilot (Based on GPT-5) was used within this article for sound boarding and feedback only, without generating new content.

Figure 3

Flow chart of the literature search process



4 FINDINGS

Within this section, a synthesis of international research is presented from articles in the systemised review. Here, we present our findings on engineering and technology integration

within iSTEM, with a focus on disciplinary identity, pedagogical practices employed and teacher conceptions of technology and engineering.

4.1 *Conceptions and imbedding of technology and engineering within integrated STEM*

Globally, within K-12 contexts, the levels of integration vary considerably, with engineering and technology disciplines often integrated on a superficial level. Alaqra et al. (2022) allude to this, noting technology and engineering disciplines as “two important but mostly neglected disciplines of studies in middle and high school education”. This is similar within an Malaysian context, as a number of authors note these disciplines are not significantly integrated within second level schools (Akkoyun et al. 2023; Ardianti et al. 2020; Balakrishnan and Azman 2017). Looking to educator’s conceptions of these disciplines, technology ‘integration’ is often seen as simply the use of technologies (Baptista, Conceição, and Filipe 2025; Chang and Chen 2020; Dare et al. 2021; Dasgupta, Magana, and Vieira 2019). This highlights the narrow conceptions of technology often held by educators, far removed from its position as a standalone discipline. Some teachers also self-reported a narrower capability in technology (Aldemir et al. 2022), and a deficit in appropriate PCK (Gunning, Marrero, and Larson 2021), despite having studied technology and engineering respectively, in their undergraduate degrees.

Engineering conceptualisations follow in a similar vein, with educators holding more developed conceptions, but commonly still falling short of a thorough understanding of the domain. This is seen in a number of ways, namely engineering as a pedagogical tool (Bakirci, Kirici, and Kara 2022; Baptista et al. 2025; Dare et al. 2021). This perception risks eroding the disciplinary identity of engineering within iSTEM, reducing it to a set of design-related activities rather than a robust knowledge domain. As discussed by Siegel and Giamellaro (2022), this perception can be problematic, as students “were probably being misled to think that just making stuff is engineering”.

Looking to educators who were new to the technology and engineering disciplines, the wide variance in levels of integration continued. Siegel and Giamellaro (2022) highlighted three distinct levels of integration within their study. Some educators used STEM as a new label for old practices, particularly more practical elements of classes, others adapted hands on and design-based activities, incorporating some elements of the Engineering design process (EDP) (and STEM), while the third group of educators transformed their lessons, rebuilding them around the EDP. These highlight the wide variation in teacher conceptions, and the need for a unified theoretical framework for technology and engineering provision within iSTEM.

4.2 *Instructional strategies supporting integration*

Looking to pedagogical approaches, there were a multitude of used, and suitable strategies which supported the imbedding of Engineering and Technology within iSTEM. Of the studies reviewed in detail for this publication, Project-based learning (Alaqra et al. 2022; Aldemir et al. 2022; Ardianti et al. 2020; Balakrishnan and Azman 2017; Çevik 2018; Çevik, Bakioglu, and Temiz 2024; Ching et al. 2019; Dare et al. 2021; Dasgupta et al. 2019) and the EDP (Bakirci et al. 2022; Baptista et al. 2025; Baran et al. 2019; Cevik et al. 2020; Chang and Chen 2020; Chen and Chang 2018; Dasgupta et al. 2019; De Meester et al. 2021; Gunning et al. 2021) were the most common

strategies, each used in 9 studies. This was followed by Problem-based Learning (8) (Akkoyun et al. 2023; Akpinar and Akgunduz 2022; Baptista et al. 2025; Baran et al. 2019; Bertel et al. 2022; Burrows and Borowczak 2016; Curreli and Rakich 2020; De Meester et al. 2021), and Inquiry-based approaches (7) (Alaqra et al. 2022; Aldemir et al. 2022; Bakirci et al. 2022; Baptista et al. 2025; Çevik et al. 2024; Ching et al. 2019; De Meester et al. 2021). As noted in a previous publication, a surprising finding was the presence of Culturally sustaining/responsive pedagogies, seen in two of the studies (Gunning et al. 2021; Tran and Selcen Guzey 2023). Though these strategies are suitable for the effective provision of technology and engineering, some issues emerged in the literature. Engineering, namely the EDP has been used as a pedagogical tool, with little to no integration of engineering practices or principles (Dare et al. 2021; Siegel and Giamellaro 2022). Additionally, educators ‘used’ these strategies, but with looser definitions of the strategies, it is difficult to ensure that they were implemented effectively (Balakrishnan and Azman 2017). Some stronger examples of effective Technology and Engineering integration were evident however, such as in Dasgupta et al.’s (2019) study, as they investigated the affordances of a CAD enabled learning environment for promoting iSTEM learning. Within this study, they map aspects of the intervention which link to each of the domains of the STEM acronym.

4.2.1 *Teachers’ Lived experiences*

Building on the above, it is important to look to teacher’s knowledge, beliefs and professional development needs in providing effective Engineering and Technology education within iSTEM. As a result of providing iSTEM experiences, many educators reported a growth in their ability to provide effective student-led learning experiences, through Problem, Project and Inquiry based strategies (Alaqra et al. 2022; Aldemir et al. 2022). Additionally, several reported an increase in their Engineering and Technology disciplinary knowledge (Baptista et al. 2025; Burrows and Borowczak 2016; Cevik et al. 2020). Central challenges for educators included a lack of experience and confidence integrating programming within iSTEM experiences (Ntemngwa and Oliver 2018), despite some educators coming from technology backgrounds (Aldemir et al. 2022), and educators’ uncertainty around appropriate levels of scaffolding for students (Baptista et al. 2025).

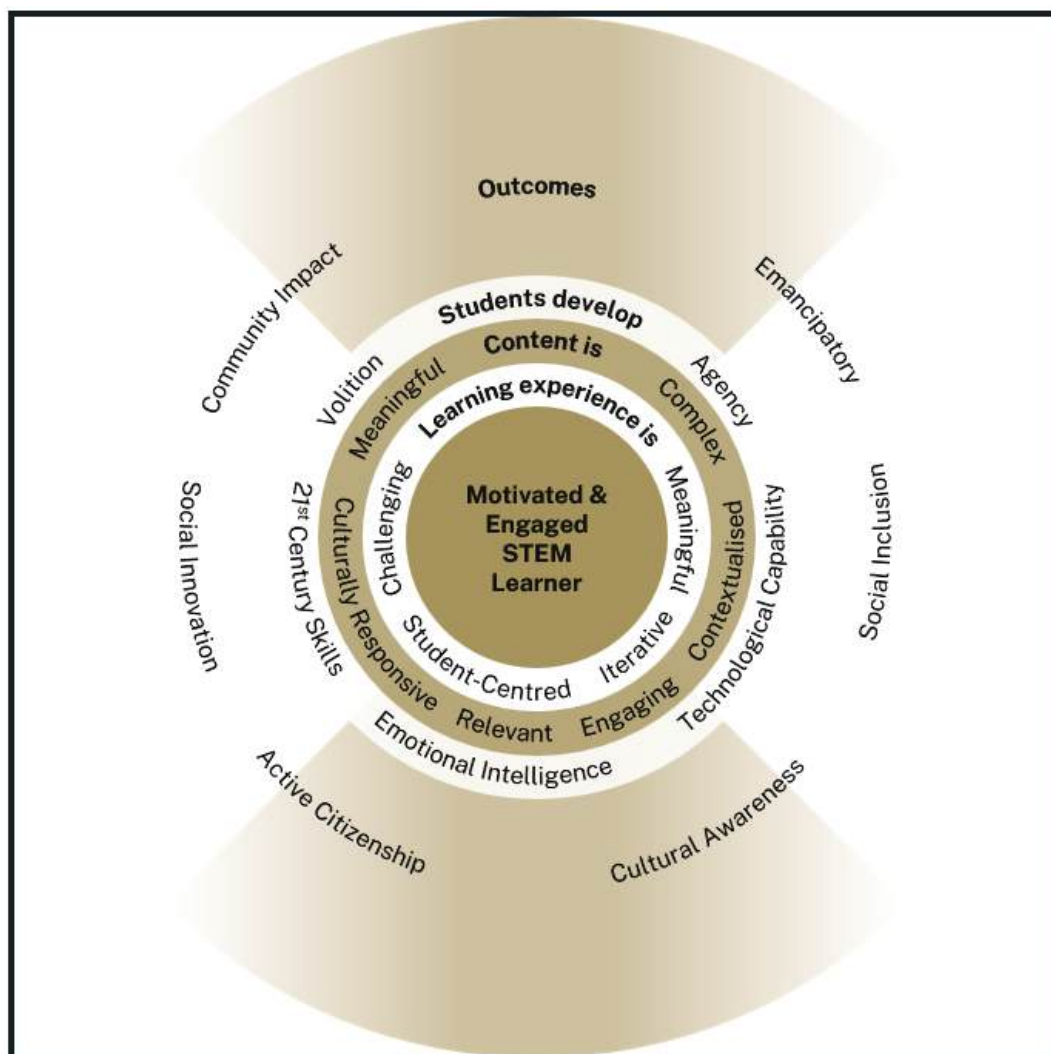
5 **RECENTRING TECHNOLOGY EDUCATION, A COMBINED THEORETICAL FRAMEWORK**

This section presents a developing theoretical framework, for the delivery of effective, integrated iSTEM experiences. The framework is specifically developed to address the current limitations identified within the literature, inter alia: the disciplinary identity, integration challenges, and creating a meaningful and relevant experience for students (Stack Mulvihill et al. 2025). As seen in Figure 4 below, this framework once again places the ideal learner at the centre, motivated and engaged within an effective iSTEM experience. Beyond the student, there are four layers radiating from the centre, the first of which highlights key aspects of students’ learning experiences within such an iSTEM experience. The experience should be student centred, meaningful to the students and challenging for students, as they iterate and navigate through a unit of learning. The next layer looks at content within the experience. iSTEM content should be meaningful, complex and contextualised to the class/school/group engaged in the experience. There are no pedagogical

strategies included in the framework. As highlighted in this, and previous works (Stack Mulvihill et al. 2025:5), there is a wide range of suitable, student-centred strategies for effective iSTEM integration. The primary challenge for educators in this domain is to ensure the strategy alone is not the primary link to any one STEM domain. The third layer from the centre highlights skills, abilities and values students will develop from participating in an iSTEM experience. Volition, 21st century skills and emotional intelligence are just some of the skills which are likely to be developed within an effective iSTEM experience. The final layer highlights common outcomes for students who participate in such activities. iSTEM experiences should be emancipatory for students' as they gain a sense of their own agency. Social innovation and Active citizenship are further potential outcomes listed here. It's important to note for each of these layers, the terms are not exhaustive and may develop in the future, as new possibilities emerge. Finally, the framework highlights four quadrants, but does not label these. This is to represent the four disciplines within iSTEM, while providing a pathway for the educator to facilitate effective integration of their content in a coherent, student-centred manner, agnostic of an individual disciplinary lens.

Figure 4

Theoretical Framework for Integrated STEM



6 CONCLUSION

Through the preliminary findings of a systemised review, and the development of a subsequent framework for iSTEM education, this publication has posed a vision for the future treatment of technology education provision within iSTEM. This paper has highlighted primary strengths and continuing challenges for educators. Challenges include teacher confidence with various aspects of Technology and Engineering, the provision of appropriate scaffolding for students, and the development of consistent conceptions of the Technology and Engineering disciplines.

Future work in this area will include the development of a full systemised review, identification of appropriate professional development opportunities for educators, and an investigation into the impact of iSTEM education provision in alignment with this theoretical framework. This work aims to provide insight into the development of teacher self-efficacy as they provide such experiences, and the impact on student STEM interest, with a view to informing international educational policy and practice

7 ACKNOWLEDGEMENTS

This research is supported through the TUS Presidents Doctoral Scholarship.

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A Phenomenographic Study of Chinese Junior Secondary School Students' Conceptions of Technology

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Abstract

Fostering students' comprehensive conceptions of technology (COT) is a critical goal of technology education. While international research on COT is extensive, studies focusing on mainland China—a context with a unique technological history—remain scarce. This phenomenographic study investigates the COT of 61 Chinese junior secondary students (aged 13–15) through semi-structured interviews and photo-elicitation. The findings reveal that students conceptualize technology across five dimensions: attributes, generation, operation and use, mastery, and functions. Compared to their primary school counterparts, junior secondary students exhibit both more nuanced rational views (e.g., technology as activity, symbol of civilization) and persistent partial understandings (e.g., fragmented views of experiential vs. scientific technology). The study highlights the influence of sociocultural context and weak school-based COT education on student understanding. The findings offer empirical insights for technology educators and policymakers in China and similar cultural settings, suggesting the need for curricula that explicitly integrate the multidimensional nature of technology.

Key Words: Conceptions of Technology, Junior Secondary Students, Mainland China, Phenomenography, Technology Education

1 INTRODUCTION

Cultivating students' appropriate conceptions of technology (COT) is a key goal in technology education worldwide, influencing their critical thinking, career choices, and engagement with technology (Eliasson et al., 2022). While studies have explored COT in various countries, limited research focuses on mainland China, a context with a unique technological history and curriculum development (Su & Ding, 2023). This study, part of a series examining Chinese students' COT, investigates junior secondary students (aged 13–15) and compares results with earlier findings from primary students to chart developmental trajectories. The research questions are:

- (i) What are mainland China junior secondary students' COT?
- (ii) How do COT evolve from primary to junior secondary school?

2 LITERATURE REVIEW

2.1 *Defining Technology*

Defining technology is challenging due to its multifaceted nature. A comprehensive understanding can be synthesized from philosophical frameworks. Mitcham (1994) conceptualized technology as artifacts, processes/activities, knowledge, and volition. De Vries (1996) further distinguished between experience-based technologies (rooted in empirical craft) and scientific technologies (macrotechnologies and microtechnologies derived from scientific principles). Additionally, technology is recognized as a double-edged sword with societal and ethical implications (De Vries, 2005). These nine elements (e.g., technology as artificial objects, as processes, as knowledge, as volition, as situational, as a system, as culturally shaped, its interdependence with science, and its dual nature) form the theoretical reference for understanding students' COT.

2.2 *Empirical Studies on Secondary Students' COT*

International research consistently shows secondary students hold limited and often narrow COT, frequently associating technology only with modern, electronic artifacts (Bame et al., 1993; DiGironimo, 2011). More recent studies using open-ended approaches reveal more nuanced, context-dependent understandings. For instance, Rücker and Pinkwart (2018) found German students categorize technology into types like high-tech, home, and 'real' technologies, while Molina-Vásquez (2021) identified Colombian students' conceptions linking technology to society, culture, and systems. However, a significant gap remains concerning Chinese students, whose technological conceptions are likely shaped by their distinct cultural and educational context.

2.3 *Historical and Cultural Context of Technology in China*

Chinese perspectives on technology have been deeply influenced by its history. Confucianism and Taoism traditionally devalued experiential technology, dismissing it as "diabolic tricks" (Du, 2003). Following military defeats in the 19th century, China was compelled to import Western scientific technology, leading to a reactive veneration of "keji" (science and technology), often conflating the two (Wu, 2016). This historical trajectory—from devaluation to a fragmented coexistence of experiential and scientific technology—forms the crucial socio-cultural background for students' COT.

2.4 *Technology Education in Chinese Junior Secondary Schools*

From 2001 to 2022, technology education for junior secondary students primarily relied on Labor and Technical Education, which lacked unified national standards. Its implementation was characterized by marginalization, insufficient instructional time, and a focus on skills rather than explicit COT education (Ding, 2009). Crucially, the curriculum did not systematically bridge the gap between traditional experiential technology and modern scientific technology. Although new standards were enacted in 2022, the students in this study were educated under the previous system, making this context essential for understanding their COT.

3 METHODOLOGY AND RESEARCH METHODS

3.1 *Phenomenography and Theoretical Framing*

This study adopts phenomenography, which explores the qualitatively different ways people experience a phenomenon (Marton, 1986). Its focus on the “second-order perspective”—how something is conceived—aligns with our aim to capture authentic student views without imposing a predefined framework. This stance is informed by the literature: the multifaceted nature of technology and the unique Chinese cultural context necessitate understanding COT as situated and varied. The study seeks to describe the structure of variation in how technology is conceived by this specific group.

3.2 *Participants*

Purposive sampling selected 61 students (30 male, 31 female) from rural, urban-rural, and urban schools in Hebei Province (20 rural, 20 urban-rural, 21 urban; 20 Grade 8, 41 Grade 9) to ensure regional and age diversity.

Table 1

The specific information of the participants

$N = 61$	Group			Total
	Rural	Urban-rural	Urban	
<i>Boys</i>				
Grade				
8 th	8	2	0	10
9 th	2	8	10	20
Total	10	10	10	30
<i>Girls</i>				
Grade				
8 th	8	2	0	10
9 th	2	8	11	21
Total	10	10	11	31
<i>Total</i>	20	20	21	61

3.3 *Data Collection*

Semi-structured interviews centered on “What is technology?” supplemented by 22 photo-eliciting images (representing Mitcham’s four dimensions). Photo-elicitation is a well-established technique to prompt deeper reflection (Harper, 2002). Interviews (25-35 minutes) included photo selection and open discussion, with ethical safeguards (informed consent, confidentiality).

3.4 *Data Analysis*

Analysis followed the iterative phenomenographic approach (Åkerlind, 2005; Sjöström & Dahlgren, 2002). Meaning units were identified, grouped into categories of description, and structured into a hierarchical, non-exclusive “outcome space.” Two researchers independently analyzed and cross-validated findings to ensure reliability.

4 RESULTS (THE OUTCOME SPACE OF JUNIOR SECONDARY STUDENTS’ COT)

In phenomenographic research, the hierarchical nature of the outcome space suggests that conceptions may coexist at different levels and are context-sensitive. Specifically, individuals may possess multiple, non-exclusive COT that exist simultaneously at different levels (Rücker & Pinkwart, 2018). This study reveals that mainland China junior secondary school students define technology from five dimensions: the attributes of technology, the production of technology, the operation and use of technology, the functions of technology, and the mastery of technology. The five first-level categories of description encompass several subordinate and even tertiary ones, collectively forming each student’s unique COT. Figure 1 shows the junior secondary school students’ COT in mainland China.

4.1 *The attributes of technology*

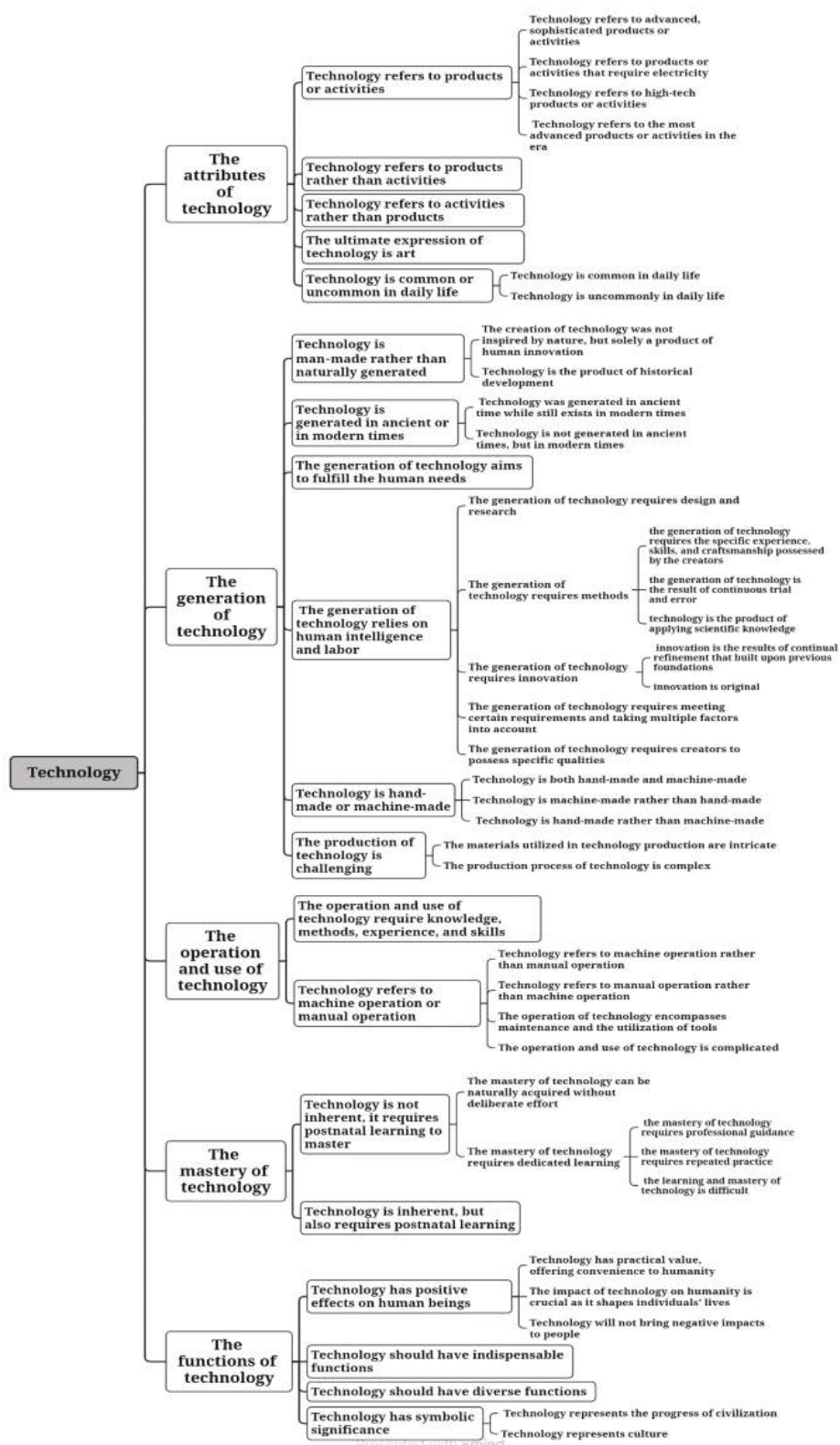
Students define technology from the dimension of the attributes of technology, which includes the following 5 secondary indicators:

4.1.1 *Technology refers to products or activities*

This category of description regards technology as products or activities, which further includes the following four sub-indicators: twenty-two interviewees (36%) believed that technology refers to advanced, sophisticated products or activities, e.g., N-17-M stated: ‘Using a washboard is not technology; using a washing machine is, because it is more advanced.’; twenty students (33%) believed that technology refers to products or activities that require electricity, e.g., C-6-M stated: ‘An electric toothbrush is technology; a regular one is not, because it relies on electricity.’; Twenty-one interviewees (34%) considered that technology refers to high-tech products or activities, e.g., C-18-M stated: ‘A glass cup is not technology; technology involves high-tech things like computers and phones.’; Twelve students (20%) held the view that technology refers to the most advanced products or activities in the era, e.g., C-7-M stated: ‘An electric toothbrush is technology; a regular one is not. But a regular toothbrush was technology when first invented.’

Figure 1

Junior secondary school students' conception of technology in mainland China



4.1.2 Technology refers to products rather than activities

Seven junior secondary students (11%) believed that technology refers to products, while the process of making or using the products is not. This perspective on technology is one-sided, e.g., X-12-F stated: 'Phones and computers are technology, but using them is not. Technology is the outcome.'

4.1.3 Technology refers to activities rather than products

Nineteen middle school students (31%) considered that technology is dynamic rather than static. Specifically, they viewed technology as the dynamic process of creating products or operating them, where the products themselves are not seen as technology but as the results of technology, e.g., C-4-F stated: 'A washboard itself is just an object; when not used, it is not technology. When used, it becomes a tool.'

4.1.4 The ultimate expression of technology is art

Five students (8%) considered that there is a connection between technology and art, with art being the ultimate expression of technology, e.g., C-8-M stated: 'When pottery reaches its highest level, the beauty in it turns into art.'

4.1.5 Technology is common or uncommon in daily life

Thirty students (49%) defined technology based on its frequency of occurrence in daily life. This indicator comprises the following two sub-indicators: technology is common in daily life, considering anything uncommon as not technology, e.g., X-18-M stated: 'Making pottery is not technology; it is not commonly seen. Technology is common in daily life.'; twenty-three students (38%) held the belief that technology is uncommonly in daily life and is something that ordinary people cannot or rarely engage with directly. Products or activities that are commonly observed in daily life are viewed as ordinary and not classified as technology, e.g., N-8-M stated: 'Satellites are technology because they are uncommon. Ancient wine cups are not; they were widely used.'

4.2 The generation of technology

Students defined technology from the perspective of its generation. Data analysis reveals that this dimension encompasses the following six sub-indicators:

4.2.1 Technology is man-made rather than naturally generated

Students perceived technology as a human invention rather than a natural phenomenon. This category of description comprises two tertiary indicators: two students (3%) believed that the creation of technology was not inspired by nature, but solely a product of human innovation, e.g., N-6-F stated: 'Ancient wine cups are not technology; they have natural prototypes. Technology is something newly created by humans.'; eight respondents (13%) thought that technology is the

product of historical development, e.g., N-9-F stated: ‘Satellites are technology; they are an inevitable outcome of social progress over time.’

4.2.2 *Technology is generated in ancient or in modern times*

Students conceptualized technology based on the time of its invention, encompassing two sub-dimensions: Ten students (16%) considered that technology was generated in ancient time while still existing in modern times, e.g., C-9-F stated: ‘Making pottery is technology; it has been passed down from ancient times to the present.’; seven students (11%) argued that technology is not generated in ancient times, but in modern times, e.g., C-7-M stated: ‘Technology is a product of modern times. Ancient wine cups are not technology; they are just vessels.’

4.2.3 *The generation of technology aims to fulfill human needs*

Fourteen students (23%) defined technology from the perspective of its purpose, viewing its generation as a result of human needs. This viewpoint highlights the close relationship between technology and humanity, e.g., N-7-M stated: ‘A T-shirt is technology; its design and production should consider different needs of people.’

4.2.4 *The generation of technology relies on human intelligence and labor*

The students believed that human intelligence and labor are essential factors for the development of technology. This category of description encompasses five sub-dimensions: thirteen interviewees (21%) deemed the generation of technology requires design and research, e.g., X-17-M stated: ‘A glass cup is not technology; it does not require complex design. Technology requires complex design.’; thirty-eight students (62%) believed the generation of technology requires methods. Within this, 21 students (34%) held the view that the generation of technology requires the specific experience, skills, and craftsmanship possessed by the creators, e.g., N-7-M stated: ‘Farming is technology. I tried but failed; successful farming requires experience and skill.’; 17 students (28%) thought that technology is the product of applying scientific knowledge, e.g., C-3-M stated: ‘Satellites are the result of scientific research. T-shirts are not really related to technology.’

4.2.5 *The generation of technology requires innovation.*

This perspective posits that innovation is a prerequisite for the generation of technology. Innovation refers to the creation of something new that did not exist before. Regarding the modes of innovation, five individuals (9%) believed that innovation is the results of continual refinement that builds upon previous foundations, e.g., N-19-M stated: ‘Laptops are technology; they are created by enhancing electronic chips based on phones.’; two individuals (3%) considered that innovation is original, e.g., C-15-F stated: ‘Bronze cups are technology because they are original creations representing ancient innovation.’ Eight students (13%) discussed that the generation of technology requires meeting certain requirements and taking multiple factors into account; nine students (15%) mentioned that the generation of technology requires creators to possess specific qualities. 35% students argued that technology is hand-made or machine-made.

4.2.6 *The production of technology is challenging.*

This category of description defines technology based on the level of difficulty in its production, which encompasses two sub-indicators: nine middle school students (15%) stated that the materials utilized in technology production are intricate; thirty-six students (59%) contended that the production process of technology is complex, e.g., X-17-M stated: ‘A highway is not technology; it is simple. Building a bridge is technology; it involves complex measurements.’

4.3 *The operation and use of technology*

The dimension defines technology from the standpoint of operation and utilization, consisting of four sub-indicators.

4.3.1 *The operation and use of technology require knowledge, methods, experience, and skills*

45 students (74%) argued that technology operation and use require knowledge, methods, experience, and skills, e.g., X-6-F stated: ‘Repairing cables is technology; it requires circuit knowledge and high skill.’

4.3.2 *Technology refers to machine operation or manual operation*

Students defined technology from the perspective of the way in which it is operated and used. This category of description contains two sub-indicators: fourteen students (23%) believed that technology refers to machine operation rather than manual operation, e.g., N-1-M stated: ‘An electric toothbrush is technology; a regular one is not because it is manually operated.’; one student (2%) regarded technology refers to manual operation rather than machine operation, e.g., C-8-M stated: ‘Using a washboard is technology; it requires practice. Using a washing machine is not; just press a button.’

4.3.3 *The operation of technology encompasses maintenance and the utilization of tools*

16 students (26%) considered that technological operations involve maintenance and tool use, e.g., C-12-M stated: ‘Fixing cars is technology; it requires tools. Things need maintenance after being made.’

4.3.4 *The operation and use of technology is complicated*

Twenty-eight students defined technology based on the level of difficulty in its operation and usage. They believed that the operation and usage of technology are often challenging and complex, and if the operation is easy, then it is not technology, e.g., C-8-M stated: ‘Using phones for basic things is not technology unless it requires advanced skills, like hacking.’

4.4 *The mastery of technology*

This dimension defines technology from the perspective of its mastery, consisting of two sub-indicators: technology is not inherent, it requires postnatal learning to master; technology is inherent, but also requires postnatal learning.

4.5 *The functions of technology*

The dimension defines technology from its functional role, and it includes four sub-indicators.

4.5.1 *Technology has positive effects on human beings*

This description category asserts that technology has a positive influence on humanity. In particular, it includes three tertiary indicators: 37 students (61%) believed that technology has practical value, offering convenience to humanity, e.g., X-18-M stated: 'Satellites help people go online. Phones are technology; they provide convenience and save time.'; nine students (15%) believed that the impact of technology on humanity is crucial as it shapes individuals' lives, e.g., C-4-F stated: 'A toolbox is technology. Tools are crucial in manufacturing and daily life.'; 6 students (10%) considered that technology will not bring negative impacts to people, e.g., N-13-M stated: 'Technology should bring benefits. Electric toothbrushes break easily; phones cause addiction. So they are not technology.'

4.5.2 *Technology should have indispensable functions*

Six students (10%) thought that technology is unique and cannot be replaced by other products or activities. If a product or activity can be replaced by something else, then it is not technology, e.g., N-17-M stated: 'Computers are technology because they are unique and cannot be replaced.'

4.5.3 *Technology should have diverse functions*

Eighteen students (30%) argued that technology should have various functions. If it only serves a single function, it cannot be considered technology, e.g., C-5-M stated: 'A glass cup is not technology; it has a single function. Technology should have multiple functions.'

4.5.4 *Technology has symbolic significance*

This category of description defines technology from its symbolic significance, which is a unique COT among Chinese junior secondary school students. It specifically includes two secondary indicators: 5 students (8%) considered that technology represents the progress of civilization, e.g., C-16-M stated: 'Satellites represent social progress. Pottery-making helped civilization move forward.'; eleven students (18%) argued that technology represents culture, e.g., C-8-M stated: 'Ancient wine cups are symbols of culture. Washboards represent the wisdom of our ancestors.'

5 LIMITATIONS OF THE RESEARCH

This study has a limited sample ($n=61$) from three schools in one Chinese province, which may affect generalizability. Future research could expand the sample to include a wider range of regions and school types. The study also did not explore gender differences, suggesting a direction for future analysis. Furthermore, as a cross-sectional study, a longitudinal design would be valuable to better understand the developmental trajectories of COT over time.

6 DISCUSSION

This study reveals that Chinese junior secondary students possess both rational and partial COT, indicating an incomplete understanding of technology. Compared to Chinese primary students (Su & Ding, 2023), their views show developmental progression.

6.1 *Development of More Rational and Nuanced COT*

Junior secondary students exhibit more multidimensional rational views. Unlike primary students who predominantly view technology as products, they define technology as activities, including design, tool use, and maintenance (Lachapelle & Cunningham, 2019; Xu et al., 2021). Their understanding of technology as a human creation to meet needs is clearer, encompassing volition, innovation, and necessary creator traits (Mitcham, 1994; DiGironimo, 2011). They more precisely define technology as knowledge acquired through specialized learning. Uniquely, they develop symbolic interpretations, viewing technology as representing civilization (Jiang, 2009) and culture (Molina-Vásquez, 2021), and some propose “the ultimate expression of technology is art”—a view not found in prior empirical studies.

6.2 *Persistence and Emergence of Partial COT*

Several partial COT persist from primary school. A key issue is the fragmented view of technology types: some students recognize only scientific/modern technology (e.g., requiring electricity), while others recognize only experiential/traditional technology (e.g., handcraft) (Ankiewicz, 2016). Many hold a unilateral view of the science-technology relationship, seeing technology merely as applied science. Other persistent partial COT include defining technology only as products and denying negative impacts. New partial conceptions emerge, notably a belief in “technological autonomy”—that technology develops independently of human will (Burns, 1992).

6.3 *A Comparison of Dimensional Structures Across Educational Stages*

A deeper comparison with primary school findings (Su & Ding, 2023) reveals not just a refinement in content, but a shift in the structural relationship between the five COT dimensions. While both groups conceptualize technology across the same five dimensions, junior secondary students exhibit a more integrated structure. For example, their understanding of “generation” is more consistently linked to “attributes” of complexity and to “functions” of fulfilling needs, forming a more cohesive narrative of technology as a purposeful process. This suggests that a

broad, more specialized junior secondary curriculum may facilitate the synthesis of disparate ideas.

6.4 *Influencing Factors and the Role of Education*

Students' COT are shaped by life experiences as "digital natives" (Prensky, 2004). However, weak school-based COT education appears to be a primary reason for incomplete understanding. In China, technology-related curricula have historically focused on skills without providing systematic, explicit COT education to foster integrated understanding across experiential and scientific technology domains. The variety of courses in junior secondary school (e.g., sciences, history) likely contributes to their more nuanced views compared to primary students (Stables, 1994).

6.5 *Impact of Cultural-Historical Context*

Crucially, students' COT are embedded in China's unique context. The focus on technology as activity is a unique Chinese finding, likely influenced by the historical emphasis on craftsmanship. The fragmented understanding of technology types and the confused science-technology relationship may stem from China's history of passively importing Western scientific technology, which coexisted separately with its rich tradition of experiential technology. Looking ahead, future research could use the baseline COT identified here to assess the effectiveness of explicit COT instruction and employ established international instruments (e.g., PATT) for richer comparative analysis.

7 CONCLUSION

This phenomenographic study investigated the COT among Chinese junior secondary students. The results show that they have not yet formed comprehensive and rational conceptions of technology. Similar to elementary students, they define technology across five dimensions but with both more rational and partial views. Unique Chinese conceptions include "technology refers to activities," "technology represents culture," and "the ultimate expression of technology is art." Simultaneously, they exhibit a fragmented comprehension of scientific and experiential technology, alongside a confused understanding of the science-technology relationship.

The formation of these COT is influenced by multiple factors, with weak school-based COT education being a possible main reason for incomplete understanding. The findings underscore the need for curriculum development that moves beyond a skills-based approach. A more effective curriculum would explicitly teach the multidimensional nature of technology—as process, knowledge, and volition—and deliberately integrate its experiential and scientific dimensions. By providing students with a coherent framework to connect their fragmented experiences, such an approach could help them develop a more unified and accurate understanding of technology. This study provides empirical evidence for technology educators, curriculum policymakers, and teachers to enhance technology education in China and similar cultural settings.

8 AI DISCLOSURE

Artificial Intelligence (AI) technologies were used solely to enhance clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

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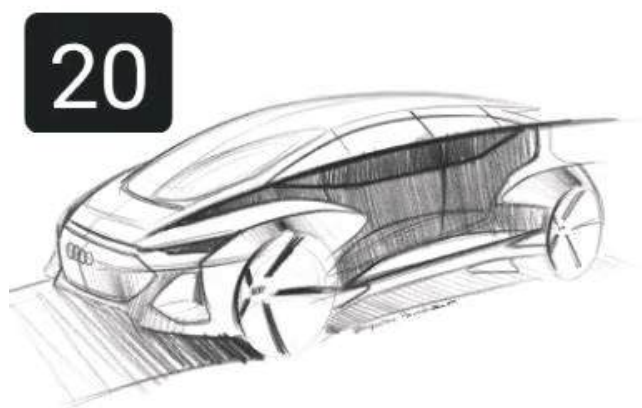
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10 APPENDIX











Technical Blindness and the Limits of Artefact Thinking: A STEAM-Based Pilot Study in Teacher Education

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Abstract

This pilot study explores whether an iterative noticing-and-reflection activity, supported by children's literature, can help pre-service teachers broaden what they see as technology. Three students in Swedish primary teacher education (grades 4–6) participated in a three-phase sequence that included taking photographs and reading children's literature, with an explicit focus on the question "What is technology?". The analysis examined how participants described technology in terms of (i) function and use, (ii) explanations of how or why it works, and (iii) contextual and ethical considerations. Across the three phases, participants initially tended to identify technology mainly as artefacts, particularly electrified devices. After the seminar discussion and repeated documentation, the photographic examples more often included non-electrified tools and everyday technologies, suggesting a shift in what participants noticed and categorised as technology, which was made visible using a STEAM perspective. Participants' written justifications also moved, in some cases, from naming objects toward brief reasoning about purpose, constraints, and alternatives, while contextual and ethical aspects appeared less frequently. As a small exploratory study, the findings do not support any general claims. Still, they indicate that staying with definitional and boundary questions about technology, in combination with aesthetic and narrative resources, may help future teachers in technology education lead the way out of pupils' technical blindness.

Key Words: STEAM, Conceptions of Technology, Perspectives on Technology, Pre-Service Teachers, Aesthetic Learning Processes

1 INTRODUCTION

Technology education in primary school (age 10-12) offers many opportunities for pupils to explore how technology shapes daily life but teaching often relies on taken-for-granted ideas about technology and its purpose. This paper examines how pre-service teachers can be supported in questioning and expanding these ideas through an iterative activity that combines documentation, discussion, and narrative. First, the study background and problem are outlined,

then the guiding theoretical perspectives are introduced, and finally, the design and results of a small pilot study are presented.

1.1 Background

Technology education influences how students understand and engage with the human-made world, shaping their ideas about technology and future aspirations (Frederik et al., 2011; Morieson et al., 2013). Early conceptions impact participation, confidence, and careers (Ankiewicz, 2015; Birney & McNamara, 2024; Pavlova, 2005). However, many hold narrow views equating technology with artefacts, overlooking its societal and cultural aspects. Interest in STEAM education—integrating science, technology, engineering, arts, and mathematics—has grown, promoting interdisciplinary teaching that includes narrative, imagination, and multimodal expression. This broadens students' understanding of technology. Research indicates STEAM can enhance subject knowledge, understanding, and engagement (Cheng et al., 2021; Conrady & Bogner, 2020; Lu et al., 2021; Kress, 1997; Ozkan & Topsakal, 2021; Piila et al., 2021). Mejias et al. (2021) highlight that transformative STEAM approaches could improve educational outcomes. This provides motivation and focus for this study on how teacher education may help students in seeing technology beyond artefacts.

1.2 Aim and research questions

This pilot study aims to explore how an iterative, exploratory activity combining photographic documentation, guided reflection, seminar discussion, and children's literature may support pre-service teachers in broadening their conceptions of technology. To reach this aim, we formulated two research questions

- How do pre-service teachers initially articulate and visualise technology in their everyday lives?
- In what ways does the iterative activity (including discussion and literature) relate to changes in how they perceive technology?

2 THEORETICAL FRAMEWORK

This section presents the outline of the theoretical framework that guides the study.

2.1 Conceptions of technology

Technology is often described as a human activity directed toward artefacts as people make them and use them (Mitcham, 1994), but being human in a technical world also relies on different forms of knowledge (de Vries, 2016). These forms of knowledge help explain why teachers' views of what counts as technological knowledge can vary and shape what they prioritise in teaching (Norström, 2014). To analyse such variation, Nordlöf et al. (2022) proposed a heuristic framework that distinguishes three knowledge categories: technical skills (that it works), technological scientific knowledge (why things work, as well as that they work), and socio-ethical

technical understanding (technology in society, including change over time, values, consequences, and competing interests). In this pilot, we used these categories as three analytical strands in the form of whether it works, why it works, and what it means in context, to analyse participants' photographs and reflections and to trace shifts in what they noticed and how they justified their choices.

2.2 *STEAM and aesthetic learning processes*

In 2013, Art was incorporated into STEM to form STEAM, not as an add-on but to integrate creative materials and multisensory tools into education (Taljaard, 2016). McGarry (2018) argues that including Art enables interdisciplinary collaboration by fostering divergent and imaginative thinking. STEAM is project-oriented, with process-based work allowing students to explore multiple subjects simultaneously and reinterpret prior knowledge across contexts (Skagerström Olsson, 2024). Mathematics, language, art, and technology can be seen as key to future learning and problem-solving (Saimon et al., 2025). Mathematics and language support understanding of the world, while technology enables exploration and representation, including through digital tools like mobile applications that extend perception (Saimon et al., 2025). Art supports expression and creativity, and aesthetic learning processes, using analogue and digital tools, create accessible communicative conditions (Alexandersson & Swärd, 2015). These processes occur through both expression and transferable learning, supporting knowledge development by integrating experiences, emotions, perception, and reasoning (Wiklund & Turlock, 2009). Mejias et al. (2021) note that STEM/STEAM definitions and implementations are often inconsistent, with Art sometimes included superficially or frameworks adopted for policy or funding purposes. While STEAM can support equitable education (Saimon et al., 2025), teachers often struggle to design truly interdisciplinary tasks. Advancing equity requires equipping teachers with appropriate approaches, though knowledge must ultimately be constructed through active student participation (Blomdahl, 2007). In this study, Art supports such participation by fostering creative engagement in understanding Technology.

3 METHOD AND DESIGN OF THE PILOT STUDY

The study is grounded in STEAM-based activities, using photography as an aesthetic medium to visualise technology. Photography involves deliberate composition; students actively choose what to include and emphasise through framing, cropping, and perspective (Lind et al., 2022). Reflecting on these images can provide valuable insights into their understanding. The study also incorporates children's and young adult literature as an accessible entry point to scientific concepts. Fictional narratives can support the interpretation of key phenomena (Egidius, 2002) and offer new perspectives on technology (Edvardsson, 2024). As a form of knowledge distinct from scientific discourse (Johansson, 2005), narrative can make abstract ideas more tangible, connect personal and global contexts, and foster curiosity while bridging everyday and disciplinary language

3.1 *Context and participants*

The students taking part in the study are enrolled in their third semester, specialising in technology education, grades 4–6 in Sweden. This module aims to provide a foundational understanding of technology by integrating practical activities with didactic perspectives. The student group is heterogeneous, comprising individuals of varying ages and educational backgrounds. A few students have completed their schooling in another country, some have recently graduated from Swedish upper secondary school, and others bring extensive work experience.

3.2 *Ethical considerations*

We obtained informed consent from all participants, ensured anonymity by removing names and other identifiers, used only participant-generated photographs that avoided recognisable individuals and identifiable locations, and reproduced no copyrighted content from the children's books beyond what was necessary for analysis under fair use/fair dealing principles.

3.3 *Three Phases of exploratory work*

The study is structured into three phases, with Phases 1 and 3 including questions about students' educational backgrounds, leisure interests, and conceptions of technology. The purpose of these phases is to explore whether the students' backgrounds and prior knowledge influenced their choice of technology and their ways of thinking about technology and technological artefacts. The first Phase of the project focused on identifying what the students associate with technology and technological artefacts. They were asked to photograph what they personally connect to technology. And they should take ten pictures. They were asked to select technology from their everyday environment, for example, in their homes or along their route to school or work. This took place at the beginning of the technology course, and the students had not yet taken part in any lectures or workshops involving technological content before being asked to take the photographs.

Before Phase 2, relevant children's literature was distributed to the students. To identify suitable titles, the university librarians were consulted. They compiled a list of recommended books appropriate for pupils aged 9 - 12. The selected books needed to be suitable for discussion from a technological perspective, resulting in a mix of fantasy, adventure, and detective fiction. The students were free to choose which of the books they wished to read. To support their reading, they were provided with a set of guiding questions to answer as they read. These questions concerned, for example, the narrative setting and the role technology played in the plot. During Phase 2, the books were discussed in a Zoom seminar. The students shared their reflections on the stories they had read. The seminar functioned as a semi-structured interview, allowing students to speak freely based on their reading experiences and the guiding questions provided. We participated as facilitators to encourage deeper elaboration of their responses and to ensure that the discussion remained focused on the topic. In Phase 3, the students were once again asked to photograph ten technology meanings from their everyday lives. However, instead of responding to questions about their age, background, and leisure interests, they were given more analytically oriented questions. They were asked to reflect on whether their perceptions of

technology had changed and whether they had become more attentive to its presence in their daily lives.

4 RESULTS

Across all three phases, participants most often represented technology as concrete artefacts. Tables 1–3 summarise the artefacts identified in the initial photo study (Phase 1), the book-based discussion (Phase 2), and the final photo study (Phase 3). In the tables, "E" marks electrified artefacts, meaning objects that require an electrical supply to function. In Phase 1, participants photographed everyday artefacts, many of which depended on electricity (Table 1). Electrified artefacts accounted for 52% of the identified items, including a computer, microwave oven, coffee maker, escalator, payment station, and self-scan system (Table 2). Non-electrified artefacts were also present (e.g., backpack, coffee cup, sneakers, tent), but participants more often highlighted technologies associated with electrical systems and automated services (Table 1).

Table 1

Photo study starts (Phase 1)

Backpack	Payment station (E)
Coffee cup	Roller conveyor belt (E)
Coffee maker (E)	Self-scanner (E)
Computer (E)	Sliding door
Crane	Sneakers
Crochet blanket	Hand blender (E)
Display with AI information (E)	Tent
Electric whisk(E)	Vacuum cleaner bags
Escalator (E)	Washing machine(E)
Instruments on stage	Writing pad
Microwave oven (E)	

E = Electrified artefacts, 52 %

During the book discussions, participants continued to focus mainly on artefacts (Table 2). The proportion of electrified artefacts remained high (52%), including cell phones, computers, computer games, GPS devices, lamps, televisions, and technologies connected to the "space hotel" and "space probe" (Table 2). Alongside these, participants also noted hand tools and mechanical components (e.g., hammer, screwdriver, hinge, bicycle valve), suggesting that the narrative sometimes also supported attention to non-electrified, everyday technologies (Table 2). The quotations illustrate how participants negotiated the boundary between "technology" and "magic" when the narrative introduced fictional elements. One participant framed the "agent" and the "magic pill" as potentially technical by reinterpreting them as devices. "...in the second part, it's a little more about the agent... which you can see as some kind of medical device if you want." Another participant questioned whether the story presented technology or "magic": "... it's like the technology is magic more than technology..." A third quotation shows how one participant

anchored technology in familiar artefacts within the storyline, particularly bicycles and tools. "The technology is quite everyday... bicycle or bicycles are central to the story... it is about bicycle thieves who sabotage bicycles... someone uses tools... screwdriver, hammer, hinge... and... TV... computer games..." Together, these excerpts show that participants primarily used artefact recognition as their entry point, even when the book invited more speculative interpretations (Table 2).

Table 2

Technology said to have been seen during the seminar. Book discussion (Phase 2)

Bank vault	Lamps (E)
Bicycle valve	Magic pill
Bicycles	Pipe post device
Cell phone (E)	Power button
Computer (E)	Screwdriver
Computer game (E)	Space hotel (E)
Glass elevator (E)	Space probe (E)
GPS (E)	Telephone (E)
Hammer	Television set (E)
Hinge	

E = Electrified artefacts, 52%

In Phase 3, participants again photographed only artefacts, but the composition shifted (Table 3). Electrified artefacts dropped to 16%, with the set dominated by non-electrified household tools and everyday objects (e.g., cheese slicer, garlic press, scissors, screwdriver, key, clock, waste sorting bin) (Table 3). Electrified items were less common and included a ceiling lamp, fluorescent tubes, and a digital alarm clock (Table 3). This change indicates that participants broadened what they considered worth documenting as "technology" in everyday life, even though their representations remained artefact-focused.

Table 3

Photo study ending (Phase 3)

Bottle capper	Garlic press
Ceiling lamp (E)	Gas tube
Cheese slicer	Hooks
Clock	Key
Comb	Scissors
Digital alarm clock (E)	Screwdriver
Easter clip plastic	Stair railing metal
Element	Vacuum cleaner bags
Fluorescent tubes (E)	Waste sorting bin
Frying pan	

E = Electrified artefacts, 16 %

Tables 1–3 show two consistent features in the data. First, participants represented technology predominantly through artefacts across all phases. Second, the share of electrified artefacts remained high in Phases 1 and 2 (both 52%) but decreased markedly in Phase 3 (16%), indicating a shift toward noticing non-electrified, everyday technologies after the book-based, reflective work.

4.1 *Analysis*

The images share a common emphasis on artefacts embedded in everyday routines and social relations. They depict essential objects that enable individuals to perform tasks more quickly and ease daily life. The variation lies in the types of functionalities and efficiency highlighted by the participants. One participant directs attention toward domestic chores such as shopping, cooking, and cleaning, while the other photographed objects like a coffee cup, a drum set, and a crocheted blanket, items associated with pleasure and enjoyment in everyday life. The participant who photographed household technology describes technology as something that saves time and enables tasks to be carried out more easily and efficiently; technology is thus framed as both functional and efficiency-enhancing. In contrast, the participant who photographed other everyday objects associated with enjoyment argues that technology not only provides comfort but also serves to make life more enjoyable and accessible. Technology is understood as fulfilling needs while simultaneously generating desires.

When the participants were asked a second time to photograph what they associate with technology (Phase 3), the most notable shift occurred in the participant who had previously focused solely on electrical devices. Instead of coffee makers, hand blenders, and computers, the new set of images includes a garlic press, a cheese slicer, a screwdriver, and a key. The participant explains that the book and discussions about the nature of technology contributed to a transformed, expanded understanding of what technology can be. Becoming attentive to the broader concept of technology was described as a novel experience that shifted the focus from exclusively electrical devices to analogue tools. What remains consistent is the interpretation of technology as something that supports everyday life by making tasks easier. What becomes more explicitly articulated in Phase 2, however, is that technology is also a form of convenience we become acutely aware of and feel a need for when it is not available. One participant noted that simply posing the question, "What is technology?" directs attention in a particular way and sharpens one's "technical gaze." This participant already had a strong interest in technology and therefore did not rely on the literature to broaden their perspective; instead, the question itself stimulated reflection and discussion.

4.2 *Disclosure*

The authors used generative AI tools for language-level support during drafting (e.g., translation and suggestions to improve grammar and clarity). The authors conducted, verified, and take full responsibility for all data extraction, analyses, and interpretations.

5 DISCUSSION AND IMPLICATIONS

This pilot study explored what pre-service teachers count as "technology" when they engage with children's literature through an iterative, aesthetically oriented task. The data points to what we have chosen to call technical blindness. Technical blindness in this context refers to participants most often identifying technology as visible artefacts and, less often, describing the knowledge, processes, or socio-ethical dimensions that shape artefacts and their use. Such starting points matter because they influence what future teachers are likely to prioritise in classroom talk, task design, and assessment. Nordlöf et al.'s (2022) framework and the A in STEAM helped us interpret our data. Participants' responses largely reflected "use" of technology. They rarely mobilised technological scientific knowledge or socio-ethical technical understanding, which aligns with prior research showing wide variation in teachers' conceptions of technological knowledge (Norström, 2014). One plausible explanation is that everyday life supports functional use, running on electricity, without requiring explanations of construction, mechanisms, standards, or consequences, leaving students with limited conceptual tools for noticing technology beyond objects. The task also created moments of dilation. When participants needed to justify their selections, some moved from naming artefacts to reasoning about function, constraints, and alternatives. This supports the view that technological knowledge becomes visible through explanatory and design-oriented reasoning rather than through the artefact itself (de Vries, 2016). In these cases, the STEAM-infused, dialogic structure helped expose assumptions and opened space for more developed interpretations.

Narrative and aesthetic experience mainly served as a shared entry point. The story world supported engagement and provided a common reference for discussion, but it could also reinforce artefact seeing if participants treated the book as a set of "props." Broader conceptions emerged more reliably when instructions directed attention to disciplinary questions, how something works, which systems it depends on, what trade-offs it involves, and what consequences follow. This suggests that aesthetic materials can support "technology beyond artefacts" only when teacher educators explicitly connect interpretation to technological knowledge practices and contextual judgement. The findings point to using artefact identification as a first step that requires explanation and context; otherwise, it risks leading students to focus only on the artefacts. Technology educators can counter technical blindness by assessing breadth across technical, analytic, and socio-ethical dimensions. Many learners know how to use artefacts, but lessons in technology education must also help them learn how to explain, reconstruct, and evaluate them.

This pilot has several limitations: a small sample, a single institutional context, and a short time frame, all of which affect transferability. The analysis could also have examined why deeper conceptual shifts (e.g., socio-ethical or systemic thinking) did not emerge despite the STEAM-based design. It remains unclear whether photographs of technology can capture more than artefacts. Although children's literature might support broader conceptual understandings, participants still documented only artefacts despite narrative prompts and seminars. This reinforces the central finding: students most readily identify technology as artefacts. Future research should scale the design, compare contexts, vary genres and media (e.g., film, games, multimodal texts), and use longitudinal approaches to assess whether broader conceptions persist and influence teaching practice.

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What is the Problem with Girls in Technology? A WPR Analysis of Intervention Research

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Abstract

Efforts to increase girls' engagement in technology and STEM are widespread, yet the "problem" these interventions address is often taken for granted. This scoping review examines how out-of-school technology and STEM interventions represent this problem and how these representations shape assumptions, subject positions, and intervention logics. Twenty publications identified through ERIC were analysed using Bacchi's "What's the Problem Represented to be?" (WPR) framework. The analysis identifies five recurring problem representations. By making these problem representations explicit, the study shows how different framings are associated with distinct assumptions and distributions of responsibility, directing attention either towards engagement conditions and institutional practices or towards individual learners. The study contributes to research on technology education and gender equity by showing how interventions not only respond to, but also actively construct, the problems they seek to address, thereby shaping what becomes visible and which equity strategies are pursued.

Key Words: Technology Education, Informal Learning, Gender Equity, Interventions, Scoping Review, WPR

1 BACKGROUND

Across national and international settings, technology-related learning continues to display gendered patterns in engagement and recognition, despite school and policy commitments to equity (European Parliament, 2022). Informal learning environments sometimes provide conditions that formal schooling may struggle to consistently offer, such as voluntary engagement, extended time for design and exploration, access to specific tools and expertise, and opportunities for recognition (Allen & Peterman, 2019; Kolb, 2014; Rogoff et al., 2016). These environments are often positioned as offering flexible and longer engagement, as well as access to tools, expertise, and recognition practices that are not always available in formal schooling (Allen & Peterman, 2019; Fernández-Limón et al., 2018; Kolb, 2014; Rogoff et al., 2016). As such, these settings are often framed as spaces capable of broadening engagement and challenging dominant norms in technology and STEM (Pesch et al., 2025). Intervention research, such as that mentioned, offers a wide array of approaches and reported outcomes, but sometimes leaves the

underlying problem definition implicit. When focusing specifically on girls' engagement, it is often treated as the object to be changed. Meanwhile, the rationale behind interventions varies across access to tools and opportunities, legitimacy and recognition of technology, identity and belonging, or measured attitude differences (Archer et al., 2015; Davenport et al., 2020). Informal interventions may reproduce narrow problem framings; for instance, programmes can implicitly construct girls as lacking confidence or interest, or treat gender as an individual-level explanatory variable without analysing how engagement conditions are produced (Archer et al., 2025; Dawson et al., 2024; Duan et al., 2021).

1.1 Gender and informal learning

Gender is treated in this study as a social and relational construct produced and negotiated through institutional, cultural, and material practices. While intervention studies may operationalise gender through binary categories (girls/boys), this review recognises that such categorisation simplifies complex processes of identity formation and power relations. The use of binary categories in the analysed publications is therefore examined as part of the problem representation itself, rather than assumed to be self-evident. Informal or out-of-school learning refers to organised learning activities taking place outside compulsory schooling structures, such as camps, clubs, science centres, museums, and community programmes. These settings typically involve voluntary engagement, flexible time structures, and different recognition regimes compared to formal schooling.

1.2 Aim and research question

The overall aim of this study is to examine how out-of-school technology and STEM interventions construct the “problem” of girls' engagement and how these constructions shape equity-oriented intervention logics. The study addresses the following research question:

How do out-of-school technology and STEM interventions represent the “problem” of girls' engagement, and what assumptions, subject positions, and intervention rationales follow from these representations?

2 METHODOLOGY

This section outlines the methodological approach used to analyse how interventions define the “problem” they address. It begins with an overview of the review design and explains the reasoning behind combining a scoping review with the 'What's the Problem Represented to be?' (WPR) approach. A scoping review was chosen as a tool to explore the different conceptual frameworks within intervention research rather than to measure effect sizes. It then specifies the inclusion and exclusion criteria used to ensure the data are relevant to technology education across informal and non-formal settings. Finally, it details the ERIC search strategy, screening process, and data-charting and coding procedures used to move from the initial record set to the included publications and to generate the analytic categories reported in the results.

2.1 *The WPR framework*

The WPR framework was used as the study's analytical lens. WPR examines how problems are constructed in policy and programme texts by asking what the problem is represented to be, which assumptions underpin it, what is left unproblematic, and what effects are produced. The WPR approach supports a systematic analysis of framings like the ones just described by examining how a "problem" is produced in text, what assumptions sustain it, what is left silent, and what effects follow from the representation (Bacchi, 2009, 2011, 2012) but as pointed out by Rönnblom & Edwards (2025), familiarity with the underlying epistemology and understanding how the social world operates are crucial when using WPR questions as an analytical tool. This helps to avoid the mistake of perceiving problems as obviously there.

When problem representations remain unarticulated, key features of technology education may risk remain unproblematised, including how technological knowledge is defined and valued, how assessment and credentialing signal competence, and how engagement norms shape recognition. This review, therefore, explores how technology-related interventions represent the problem they address and what those representations make visible or invisible in relation to equitable technology education. Using a scoping review with a WPR analysis, the study aims to map dominant problem representations across girls-centred and mixed-gender publications and considers their implications for how equity is pursued through technology-related learning interventions.

2.2 *Search strategy and study selection*

Searches were conducted in ERIC (Education Resources Information Center) using the string (girl* OR female* OR women OR gender) AND (STEM OR "technology education" OR engineering OR robotics OR computing OR programming OR camp OR club OR out-of-school OR informal). This search returned 482 records. Applying limits to peer-reviewed publications with full-text availability reduced the dataset to 77 records for screening. Reliance on ERIC may limit the inclusion of discipline-specific studies, exclude relevant work published in other languages, and narrow the international scope. The findings, therefore, primarily reflect dominant problem representations within education-focused and English-language research, while alternative formulations in other disciplinary or linguistic contexts remain outside the scope of this analysis.

Study selection proceeded in three stages. First, title and abstract screening excluded 5 records as clearly outside the scope. Second, full-text screening was conducted on the remaining 72 records. At this stage, 52 publications were excluded for not meeting the inclusion criteria (e.g., absence of an out-of-school setting, lack of a technology/STEM focus, or no gender-related analysis). This process resulted in a final sample of 20 publications, comprising 10 girl-centred studies and 10 mixed-gender studies that included gender-related analysis.

2.3 *Inclusion and exclusion criteria*

Studies were included if they met all of the following criteria:

- Reported an intervention or programme framed as technology- or STEM-related (e.g., STEM, engineering, robotics, computing, information literacy).
- Targeted girls or young women or included mixed-gender groups with analysis explicitly addressing girls'/women's experiences or outcomes.
- Took place in, or were led by, an out-of-school setting (e.g., science centres, museums, camps, clubs, community programmes, or comparable informal/non-formal contexts).
- Were published within the last 20 years and provided sufficient detail on aims, context, and activities to support WPR analysis.

Publication types included peer-reviewed journal articles, conference papers, and substantial research or evaluation reports. Opinion pieces and purely descriptive accounts without analytic claims were excluded. Exclusion criteria were categorised as: not out-of-school, no gender-related analysis, not intervention-related, or insufficient description for WPR analysis.

2.4 *Data charting and analysis*

In the first stage, each publication was charted in relation to context, design, stated rationale, reported outcomes, explicit equity framing, and key phrases used to describe the problem. The data were systematically organised according to the following categories: full citation; country/region; intervention aims; stated rationale; activity description; technology/STEM domain; reported outcomes for girls/females; key problem representations and assumptions about girls' learning; implicit deficit framing; stated equity framing; and WPR notes, including effects, silences, and how the problem is produced. In the second stage, the data were analytically organised into the following categories: reported outcomes for girls/females, key problem representations, assumptions about girls' learning, implicit deficit framing, stated equity framing, and WPR notes. WPR coding was then applied to identify the problem representations (explicit or implicit), the underlying assumptions, the subject positions made available to girls, the discursive and material effects of these representations, the silences within the literature, and the intervention logics implied. Codes were developed through an iterative process that combined deductive and inductive elements. Initial coding was guided by the WPR framework (e.g., problem representations, assumptions, and effects), while recurring patterns across studies were identified inductively and grouped into broader categories. Through repeated comparison across the dataset, these codes were refined and consolidated into five recurring problem representations present across both girls-centred and mixed-gender publications.

To support transparency, the full dataset can be found here:

<https://data.mendeley.com/preview/zwijs6b2fst?a=b37018c0-bfd8-468f-8409-c6abb582231b>.

The dataset consists of two tables used for stage two in the scope, intended to support transparency in the WPR analysis. Table 1 lists the Girls-centred publications (n=10), and Table 2 lists the Mixed-gender publications with gender-related analysis (n=10).

2.5 Disclosure

Generative AI was used for language-level support (e.g., grammar and clarity suggestions) during drafting. All substantive analysis, coding decisions, interpretations, and data extraction were performed and verified by the author.

3 RESULTS

This section addresses the research question and examines how problem representations are constructed across the 20 included publications. The publications span multiple national contexts. Girls-centred studies are primarily found in North America (United States and Canada), with one study from Puerto Rico. Mixed-gender studies extend this range to Türkiye, Finland, Israel, Romania, Lithuania, Cyprus, and the United States. Overall, the dataset reflects a concentration in North American contexts alongside a broader, though less dense, European and transnational representation.

3.1 *Girls-centred publications*

Across the girls-centred publications (Adjapong et al., 2016; Fadigan & Hammrich, 2005; Gonsalves, 2014; Greene, 2022; Hernández-Matías et al., 2023; Lyon & Jafri, 2010; McPherson, 2014; Mosatche et al., 2013; Silva & Scott, 2023; Wiest, 2008), the problem is consistently represented as structural. These studies emphasise underrepresentation, stereotypes, unequal access to authentic science and technology practices, limited role models, and restricted access to cultural capital and the hidden curriculum. For example, Adjapong et al. (2016) frame the problem as misrecognition and limited access to authentic experiences; Hernández-Matías et al. (2023) highlight stereotypes and lack of access to mentors and opportunities; and McPherson (2014) identifies unequal access to informal learning and exclusionary norms. Within these representations, girls are positioned as capable participants whose opportunities are constrained by conditions rather than by deficits in ability or interest. The intervention logics associated with these representations focus on expanding access, supporting identity development, and enabling recognition.

3.2 *Mixed-gender publications*

In the mixed-gender publications (Baran et al., 2016; Bergstrom et al., 2016; Demir et al., 2021; Gorghiu et al., 2018; Halonen & Aksela, 2018; Hill et al., 2018; Hite & Taylor, 2021; Macklin et al., 2018; Sasson, 2014; Savva & Trimis, 2005), the problem is more often constructed through comparison, measurement, or prediction. In some studies, girls are included but not analysed separately (e.g., Baran et al., 2016; Macklin et al., 2018; Savva & Trimis, 2005). In others, gender differences are explicitly reported. Demir et al. (2021) report lower positive STEM attitudes among females, with being female retained as a negative predictor. Bergstrom et al. (2016) find

that females are less likely to persist in astronomy and may feel less welcome. Halonen and Aksela (2018) report small differences in confidence and time orientation, while Hite and Taylor (2021) note that girls more often cite a female teacher as influential. At the same time, several studies report counter-patterns. Gorghiu et al. (2018) find females scoring higher across all items, Sasson (2014) reports higher inquiry skill scores for girls, and Hill et al. (2018) show strong interest among girls, particularly in rural contexts. These findings indicate that gendered differences are not consistent but vary across contexts. Within these representations, girls are more often positioned as a category to be measured or compared, and, at times, as a predictive variable. Corresponding intervention logics tend to focus on attitudes, motivation, or persistence rather than engagement conditions.

3.3 *Cross-cutting representations and implications*

Across all 20 publications, five recurring problem representations are identified: (1) unequal access to engagement and resources; (2) boundaries around what counts as technology and who belongs; (3) discontinuities in networks and access to the hidden curriculum; (4) technology as knowledge production and credibility; and (5) gendered differences in attitudes or interests. The findings show that different problem representations are associated with different assumptions and distributions of responsibility. When the problem is constructed as structural, girls are positioned as capable participants, and responsibility is directed towards intervention design and institutional conditions. When constructed through differences in attitudes or persistence, responsibility is more likely to be located at the level of the individual. In this way, the analysis demonstrates that how the “problem” is represented shapes what becomes visible, what remains unexamined, and which intervention strategies are pursued. This directly addresses the research question by showing how assumptions, subject positions, and intervention rationales follow from different constructions of girls’ engagement in technology-related learning contexts.

4 DISCUSSION

The results address the research question, but rather than treating problems as given, the analysis makes visible how interventions construct the issues they aim to address, and, in doing so, orient both research and practice towards particular forms of change.

A distinction between girls-centred and mixed-gender publications is clear, but it is most useful when understood as a difference in focus. The girls-centred studies are primarily framed in terms of access, recognition, and legitimacy. Girls are here positioned as capable participants whose opportunities are shaped by engagement conditions, which directs attention towards intervention design, mentoring, and the organisation of learning environments. For educators, this highlights the importance of how activities are structured: who gets access to tools and time, how roles are distributed, and whose contributions are recognised. In contrast, mixed-gender studies more often operationalise gender as a comparative variable. Here, differences in attitudes or engagement are foregrounded, and “girls” may appear as a category to be measured rather than as participants situated within specific classroom or programme dynamics. This shift does not necessarily imply deficit framings, but it can make the production of those differences less visible in everyday practice. At the same time, the findings challenge simplified narratives of “girls’ low interest.”

Several studies report small or no differences, while others show that girls perform as well as or better than boys or express a strong interest in technology and/or STEM. For both researchers and teachers, this suggests that interest and capability are not absent but may be shaped by how engagement is offered. Differences in attitudes, therefore, can be understood not only as learner characteristics but as outcomes of interaction, task design, and recognition practices.

The role of “authenticity” is another interesting topic in the material. Interventions often emphasise authentic practice, tools, real-world tasks, and industry-like practices as inherently motivating. However, the analysis indicates that authenticity can also reinforce existing boundaries around what counts as technology and who belongs. For teachers, this raises practical questions: Which forms of practice and content are being valued? Whose experiences are included or excluded? Treating authenticity as something that can be negotiated and expanded, rather than assumed, can open up more inclusive forms of engagement. Some girls-centred interventions extend this further by positioning technology as a site of knowledge production and public engagement, for example, through media-making or editing activities. These approaches foreground issues of authorship, credibility, and representation, suggesting that technology education can involve not only learning to use tools but also contributing to public knowledge. This may broaden the purpose of technology education and provide different ways for individuals to feel a sense of belonging.

Across the dataset, different problem representations are associated with different distributions of responsibility. When girls' engagement is framed in terms of engagement conditions, responsibility is directed towards intervention design, teaching practices, and institutional arrangements. When it is framed in terms of attitudes or interests, responsibility is more likely to be found at the individual learner level. For both researchers and educators, this distinction is consequential, as it shapes whether efforts focus on redesigning environments or on changing learners. These findings suggest the value of shifting attention towards conditions for engagement instead of trying to increase interest. Measures of attitudes and interests remain relevant, but they may be more meaningful when interpreted in relation to the conditions surrounding them. Without this, there is a risk that interventions reinforce individualised explanations while leaving structures that affect them unchanged.

The analysis can be seen as highlighting both tensions and complementarities. Girls-centred spaces may support identity development, learning, and leadership, particularly where engagement otherwise has been limited. At the same time, they might serve as compensatory measures if dominant practices remain unchanged in mixed settings. Mixed-gender initiatives can normalise girls' engagement in these settings but may also hide inequalities if these processes are not examined. In technology education, a key question is not which approach to adopt, but how different approaches can be combined to address belonging, recognition, and girls' inclusion in more sustained and systemic ways.

5 CONCLUSION

This study shows that out-of-school technology and STEM interventions do not merely address a problem; they actively construct it. These constructions shape what becomes visible and where

responsibility for change is assigned, especially between structural factors and individualised explanations. Although limited in scope, the analysis identifies clear, recurring patterns. By making these framings explicit, the study seeks to create space for more reflexive intervention designs in the future.

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Raising Sustainability Consciousness: A Call to Action for the PATT Community

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Abstract

Following a funded research initiation project, The Blindspot Declaration (2025) was developed by a multidisciplinary group of academics in response to educational concerns about the acknowledgement of technologies in sustainability discourse and vice versa. One of the Declaration's key concerns relates to technology blindness – around how technologies are intricate to our lives yet remain unproblematised and largely in the background of our worlds.

This paper reports on foundational work leading to the project, beginning with an overview of global sustainability conditions and followed by a brief overview of literature from both technology education and sustainability education. These analyses informed the development of the Declaration and prompted the authors to also reviewing how the PATT community has engaged with sustainability issues over time by investigating proceedings from PATT between 2003-2025. The paper outlines the main findings and concludes by presenting the Declaration's call to action as a point of reflection for raising sustainability consciousness within the PATT context.

Key Words: Technologies, Sustainability, SDGs, Technology Blindness, Education, Blindspot Declaration

1 INTRODUCTION - SHARED PERSONAL AND PROFESSIONAL CONCERNS

The authors share a concern about the extent to which technology education is addressing matters of sustainability. However, we also share a curiosity about the extent to which sustainability education is recognising the roles of technologies in sustainability challenges. In talking and working with colleagues from fields other than technology education we realised that we were far from alone in our concerns around technology-related aspects of sustainability education.

As a result of these concerns, we established a funded research initiation project which involved reviewing international reports and research, literature overviews, consultations, and a two-day symposium of ten academics held in June 2025. The major achievement of this project was The Blindspot Declaration (The Blindspot Group, 2025), an initiative that seeks to address what we

call technology blindness. Fuller detail of the developments is reported in parallel conference papers of Svensson et al. (2026) and Keirl and Svensson (2026).

As a contribution to better understanding technology-sustainability education relations, this paper reports on some of the foundational work to the project beginning, away from education, with reports on global conditions regarding sustainability and then taking a brief overview of literature from the fields of technology education and sustainability education. It was this work that prompted the authors not only to bring the Blindspot Declaration to PATT43 but also to cast an eye over PATT's own engagements with sustainability issues over the years. Our basic findings are reported in the paper. We then move to the Declaration's call to action and consider its potential in supporting the PATT community in raising sustainability consciousness.

2 THE GLOBAL PICTURE – AND A SHIFTING VOCABULARY

It is eleven years since the 193 full member states of the United Nations issued their 2030 Agenda for Sustainable Development, a '...shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership.' (UN, 2015/2024).

Each year since 2015 the UN has published a report on the progress of the 17 SDGs, and each report is a mixture of concern and cautious celebration. The latest report (UN, 2025) continues a trend of deepening concern. As the UN's Secretary-General says; 'Nearly half are moving too slowly and, alarmingly, 18 per cent are in reverse.' (UN, 2025:2). The UN independent scientists' report (UN, 2023) noted that '...the world is far off track...' regarding the SDGs and advocates interconnections offering '...opportunities to act in an integrated way to release positive synergies and achieve the SDGs' (UN, 2023:xviii). The scientists called for even greater efforts across many fronts and across disciplines, arguing for science that is '...multidisciplinary, equitably and inclusively produced, openly shared, widely trusted and embraced, and "socially robust" and relevant to society'. (UN, 2023:xxvii).

By the United Nations own critical measures, the situation is not good and while the SDGs offer one schema to work with, other perspectives are informative. As we reviewed these perspectives an evolving vocabulary became apparent. Whilst the many faces of sustainability challenges might once have been seen as discrete *problems*, the word is inadequate in reflecting complexity. Our field is familiar with the work of Rittel & Webber (1973) and *wicked problems*: open, real-life, problems that are ill-defined, self-adjusting and lack one clear solution. Such problems are interlinked in both expected and unexpected ways. They are difficult to even define or delimit and appear to have become increasingly common (Andersson et al., 2019).

The world's ever-more complex (and alarming) sustainability challenges are often referred to as *crises*. 'Climate crisis' is commonly heard, or we hear of a 'species extinction crisis' (see e.g. IPBES, 2019; Saban & Wiens, 2025). Globally, we now witness crisis upon crisis – some quick (pandemic, war) some slow (climate change, loss of biodiversity, ocean degradation) – and, when multiple crises overlap, coincide or interplay they have the capacity to trigger further crises. According to Tooze (2022), we are now living the *polycrisis*. As Tooze puts it: 'A problem becomes a crisis when it challenges our ability to cope and thus threatens our identity. In the

polycrisis the shocks are disparate, but they interact so that the whole is even more overwhelming than the sum of the parts.’ (Tooze, 2022). For a critique of the term ‘polycrisis’ see Lähde (2023).

Elhacham et al. (2020) characterise ‘...the human-induced epoch of the Anthropocene’ when they quantify human-made mass (‘anthropogenic mass’) and compare it to the overall living biomass on Earth. They nominate a *crossover point* (2020 ± 6) when: ‘On average, for each person on the globe, anthropogenic mass equal to more than his or her bodyweight is produced every week’.

Lenton et al. (2023) have compiled a substantial analysis with proposals for action regarding 26 Global Tipping Points. Here, *tipping point* does not equate negativity. Rather, it suggests that every tipping point of danger can be mirrored by a tipping point of opportunity.

Finally for our global picture, we drew on Søgaard Jørgensen et al. (2023) contributing to an impressive collection on evolution, sustainability and the Anthropocene. The authors discuss whether the accelerating change and complexity of current global challenges (the polycrisis) constitute a form of trap for humanity. They develop the biological concept of evolutionary traps in the context of humans and, thus, discuss *anthropocene evolutionary traps* (‘...phenomena manifesting at the global scale of human society, i.e. with dynamics occurring at least across multiple continents, causing one or more human practices to become maladaptive’ [Søgaard Jørgensen et al., 2023]) They present 14 traps subdivided as five global, five technology and four structural and suggest that 12 of these could be well advanced and, as with tipping points, very hard to reverse. Detail of this research cannot be reported here but, for information, the five technology traps are: infrastructure lock-in; chemical pollution; existential technology; technological autonomy; and, dis- and mis-information.

We offer this sketch of the global situation and its shifting vocabulary to illustrate the concerns around the sustainability issues that the planet faces. Significantly, whether looking at the 17 SDGs or taking other perspectives, what can be continually witnessed is the uncritical and superficial acceptance of particular technologies, a blind faith in technological solutionism, or the failure to foreground in any way the technologies and technological practices that underpin the very issues which the SDGs seek to confront. In sum, there is little acknowledgment of the implicit role of technologies in almost all human activity. In such ways, technology blindness is modelled.

3 LOOKING FOR RECIPROCITY BETWEEN TECHNOLOGY EDUCATION AND SUSTAINABILITY EDUCATION

A different aspect of the Blindspot Declaration foundation work conducted a 2005-2024 low-level literature *overview* (in research terms, neither rigorous nor reliable) of the fields of sustainability education (four journals; four handbooks) and technology education (three journals; three handbooks) along with seven educational research (e.g. curriculum, pedagogy) journals. Viewing drew largely on article/chapter titles, abstracts and, where possible, indexes. In the case of academic journals, the relevant websites allowed ready searches of, at least, all editions for this century. Using single and combinatory forms of *sustainable*, *sustainability*, *technology* and *education*, sources were examined for the extent to which the fields of sustainability education and technology education had addressed the other in some reciprocal way. For example,

reciprocity would be evidenced if the two fields were being positioned in an integrative or comparative way but not if one was merely an adjunct to the other.

No occurrences of reciprocity were found. Unsurprisingly, occurrences of *sustainability* and *technology* do occur in very particular, context-specific use or in very general (uncritical) use. As one might expect, journals/handbooks focussing on either technology education or sustainability education would not have reciprocation with the other as a high priority.

Turning more specifically to the field of technology education, several examples are illustrative (though, obviously, not conclusive). One example is the one chapter/paper (addressing the SDGs) of 40 in the four volumes profiling technology education internationally (CETE, 2016-2024). A search of the International Journal of Technology and Design Education using its own subject categories of 'Environmental and sustainability education' and 'Sustainability' offers only 37 articles for the period 2000-2025. Similar occurrences appear for the 2006-2025 editions of Design and Technology Education: an International Journal. Of two Handbooks of Technology Education, the Springer edition (de Vries, 2018) offers one chapter dedicated to sustainability (of 65) while Bloomsbury (Gill et al., 2023) has no chapters (of 30).

None of the four sustainability education journals (2005-2025) contained an article relating to technology education. For the same period, none of seven professional education journals contained an article on technology and sustainability education (see list of journals below References).

Technology education did show an increased interest in education for sustainable development 2005-2010 (possibly reflecting the UN Decade of Education for Sustainability 2005-2014). To our knowledge, only one text (Stables & Keirl, 2015) has taken a more holistic approach to the issues. Meanwhile, sustainability education continues to overlook the considerable potential of interacting with technology curricula (see e.g. Scoffham & Rawlinson, 2022). So far as interdisciplinarity is concerned, there are emergent positives see Focht et al., 2019; Saetra, 2023; John, 2025).

This brief overview of literature is intended to be informative and could well be a starting point for generating data for deeper research and action. Issues of technology blindness and sustainability awareness are very much holistic concepts which cannot be well addressed by the current educational research literature relating to our field. Knowing the global picture and having a sense of our concerns being echoed in the educational research literature we decided to look at PATT's engagements with sustainability-related issues.

4 ANALYSIS OF PATT PROCEEDINGS 2003-2025

In order to reflect on the PATT conference proceedings over the last 20 years, we conducted a basic quantitative word-frequency analysis. We used the archive that have been established by LJMU Open Journals online (<https://openjournals.ljmu.ac.uk/PATT/issue/archive>). First, we validated the number of occurrences of the selected term, *sustainability*, *sustainable*, *environment*, *ethics/ethical*, and *value/values*, in the proceedings as a whole, to investigate whether and to what extent sustainability and related words has been included in the proceedings presented between 2003 and 2025 (Table 1). We were not able to analyse the PATT38 Rauma

2021, since it was uploaded as a journal document in the Techne series and not as a pdf of the conference proceedings.

Measuring word frequency does not capture contextual nuances; rather, it highlights patterns in language use that reveal interests and priorities. This indicates the extent to which the nexus between technology, sustainability and education has been explored within the research field represented by the PATT community.

Table 1

Basic quantitative word-frequency analysis of papers in PATT proceedings 2003-2025

Proceedings	Nr of papers	Sustainability	Sustainable	Environment	Ethics/ Ethical	Value/ Values
PATT13 Glasgow 2003	46	65	87	85	14	253
PATT18 Glasgow 2007	53	6	15	39	2	48
PATT20 Tel-Aviv 2008	27	43	15	52	5	30
PATT25 London 2011	54	39	65	129	17	98
PATT26 Stockholm 2012	57	22	0	53	28	198
PATT27 Christchurch 2013	64	*841 (516=325)	259	352	35	189
PATT29 Marseille 2015	62	96	119	115	21	260
PATT32 Utrecht 2016	56	26	81	128	19	193
PATT34 Philadelphia 2017	44	7	13	46	4	230

PATT36 Athlone 2018	69	147	121	187	18	203
PATT37 Msida 2019	42	9	14	51	10	232
PATT39 StJohn's 2022	56	38	55	125	20	220
PATT40 Liverpool 2023	78 (+ 13 posters +3 workshop)	60	116	200	19	378
PATT41 Nanjing 2024	52	10	25	100	52	146
PATT42 Montreal 2025	41	40	67	67	38	119

*This conference proceedings included a page-footer including the word *sustainability*

The word frequency analysis shows large differences in the occurrence of the words 'sustainable' and 'sustainability' in the conference proceedings. These words appear between six and 350 times. This can be seen as an indication that the topic is of interest to the field, but with clear peaks and troughs in terms of emphasis. What is the significance of this for understanding and developing the relationship between technology and sustainability in education? Could this relationship be more clearly and consistently represented in the PATT proceedings? There is a correlation on some of the peaks at PATT proceedings in relation to global initiatives like the UN Decade of Education for Sustainability 2005-2014, as we can see in the increased number during PATT27 Christchurch 2013 and PATT32 Marseille 2015. We also interpret the fact that the theme of the conference in Christchurch was *Technology Education for the Future: A Play on Sustainability* which contributes to an increased frequency of the words 'sustainable' and 'sustainability'. We can compare this with 'values' that consistently have a relatively even and high frequency, except on two occasions (PATT18 Glasgow 2007 and PATT20 Tel-Aviv 2008). We can't say from this word frequency analysis that within the technology education research field there is not proper attention given to sustainability, but is the relationship between technologies and sustainability in the foreground and is it investigated in a critical way? Maybe we need to adopt a more holistic approach to 'get out of our pond'.

Since we also are interested in the connection between technology and the SDGs (UN 2015/2024) we also searched for occurrences of the term in the proceedings. The first time SDG occurs is in the PATT39 (2022) proceedings. It is mentioned two times in one of the proceedings. In the proceedings from PATT40 (2023) SDG is mentioned totally nine times in one proceeding and in one poster. Also, in the PATT42 (2025) SDG is mentioned three times in one proceeding. We

interpret the low frequency of mentioning SDGs in the conference papers as an indication of a problem with connecting technologies to the global picture of sustainability issues.

Further conclusions can only be drawn once a deeper analysis of the context in which the words we have identified appear has been conducted.

5 REFLECTIONS

There are, perhaps, few surprises in what we have shared above. The global situation is serious, complex and challenging. Historically, professional educators have been trapped in their silos and cannot easily break free, either intellectually or in their teaching, and take new directions. Communities such as PATT may be well-intentioned, but they can be constrained by circumstances, such as history, orthodoxies of the field, subject content, curriculum frameworks, policy, educational trends and/or chasing new technologies.

All 17 of the SDGs (along with any other intentional act on the world by whoever) are necessarily entwined with technologies. No single profession or group can manage the challenges. From the many perspectives taken by the Blindspot Group, holism, complexity, multidisciplinary, and dynamics all speak out. If technology blindness is to be addressed and sustainability awareness and action are to be amplified, then the UN scientists' invitation warrants a response. How might we develop '...opportunities to act in an integrated manner to unlock positive synergies and achieve the SDGs' (UN, 2023:xviii)?

6 GETTING OUT OF THE POND...

Neither unlocking positive strategies nor achieving the SDGs need be seen as hopeless or impossible. Here, as the UN report says, is an opportunity to act. As we have suggested in a parallel paper (Keirl & Svensson, 2026), volition is a key, if underrated, player when considering technologies. The same applies to sustainability - as Lenton et al. (2023:3) affirm: '... (positive global tipping points) are seeds of systemic change, able to cascade into global impact if nurtured with solidarity, resources, and political will.'

If, as educators, we share such a view we may be professionally conflicted by all that holds us back. This can mean a significant personal as well as professional challenge but, as players in a professional community such as PATT (a small pond perhaps) we can join others in bigger ponds, or perhaps create new ponds, or even move between ponds to help overcome technology blindness. Making such moves is neither easy nor implausible.

In seeking new ways to approach the challenges of technology blindness the multidisciplinary group who developed the Blindspot Declaration included a call to action '...for research-informed, responsible and responsive technology-sustainability education that:

- recognises that many sustainability challenges are technology challenges;
- articulates expansive understandings of technologies in sustainability education;

- is inter-disciplinary and trans-boundary in bringing technology education and sustainability education into play across curricula;
 - foregrounds transformative ethical-critical pedagogies and literacies to deepen knowledge and understanding about technologies-sustainability relationships;
 - embraces imagination, holistic thinking and systems thinking;
 - addresses risk, uncertainty and ambiguity through ethically-framed precautionary, long-term and reflective thinking;
 - acknowledges humility and educates for constructive hope and emotional resilience;
 - is contextually grounded, culturally aware and action-oriented;
 - informs policy making that does not shy away from discussing ethics, values and moral dilemmas;
 - itself models principles of sustainability.’
- (The Blindspot Group, 2025)

Such a call is certainly broad-ranging, but its parts offer focal points that contribute to a greater collective whole – a positive synergy. The location for such a synergy is in the interplay – the nexus - of all three of: technologies, sustainability and education. This, it seems to us, invites opportunities for reflection. First, on our own, personal thinking and values; second, on our professional practices – our research and our teaching (and our conferences); and third, on how we might relate to and act with others – other disciplines, other professionals, other jurisdictions. From such reflections might emerge a realisation that we are far from alone and that change for the better is possible and we believe that the PATT community has a role to play in raising sustainability consciousness and overcome technology blindness.

7 ACKNOWLEDGEMENT

The foundational work of The Blindspot Group was funded by Riksbankens Jubileumsfond, Research initiation, F25-0004

8 AFFIRMATION

This paper is original work, and the authors take full responsibility for its content.

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10 RESEARCH JOURNALS REVIEWED FOR THIS PAPER

Journal of Sustainability Education
 International Journal of Sustainability in Higher Education
 Journal of Education for Sustainable Development
 International Journal of Sustainability Education
 International Journal of Education
 International Journal of Educational Research
 European Educational Research Journal
 Journal of Teacher Education
 Teaching and Teacher Education
 Journal of Curriculum and Teaching
 International Journal of Curriculum and Instruction

The Journey from Liverpool to Norrköping: Taking Action to Challenge Technology Blindness Concerning Sustainability

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Abstract

The paper is written in the spirit of finding new ways of supporting PATT colleagues in their sustainability work, to model strategies of multidisciplinary academic collegiality and, above all, to try to do better for the planet.

In conversation at PATT40 in Liverpool, the authors discussed a shared concern – the perception of an absence of technological discourse regarding sustainability and a reciprocal absence of sustainability discourse regarding technologies. This paper describes the authors' initial conversations, the strategies undertaken to build a collegial network, applying for funding, and the outcomes to date of the project.

The first stage of the journey involved identifying the problem through literature reviews, exploring international reports and discussing the issue with colleagues from beyond the PATT community. Three conclusions quickly emerged. First, that our initial concern was justified; second, that a multidisciplinary approach was essential; and third that funding would be needed to facilitate deeper and broader discussions with others. We developed a draft of the problem and a call to action. These became the first version of the Blindspot Declaration. The work behind the Declaration gave the basis for both a funding application and a one-page document with which to approach potential participants. Professors external to the field of Technology Education were invited to critique the draft as well as to nominate colleagues who might identify with its intentions. Over time, a group of co-participants was identified for their academic alignment with the concerns and their willingness to take action in line with the Declaration. In June 2025, ten academics from a range of disciplines and countries met for two days to discuss, refine and (mostly) ratify the Declaration. The Declaration is written to stimulate ongoing discussions, critique, and actions – together, addressing technology blindness concerning sustainability.

Key Words: technology blindness, sustainability, multidisciplinary, education, Blindspot Declaration

1 IT ALL STARTED WITH A CUP OF COFFEE

The PATT40 conference in Liverpool 2024 was the starting point for the journey we want to report. Participating in PATT conferences offers a fantastic opportunity to gain insight into ongoing technology education research in different countries. Although the name of the conference suggests that it focuses on student attitudes, it is actually the attitude of the research field that is being measured at these conferences. During the conference in Liverpool, Svensson and Keirl had a nagging feeling that we had overlooked something, if we were to judge current research in our field by the presentations. Therefore, we decided to meet for a coffee to talk about this concern, and we ended up at the former School for the Blind building – round the corner from the conference.

We perceived a problem: a lack of research on technology education in relation to sustainability. Shouldn't this be a more central perspective at the conference, especially given what is happening to societies on Earth today? Sustainability is a key topic in technology curricula in many countries around the world, highlighting the potential of technology to solve sustainability challenges, by developing sustainable technology solutions. Nevertheless, we do not see technology education being problematised or critically examined through research. We know that many technological 'solutions' often bring new technological problems. Historical faith that global problems can be met by technological solutions is no longer itself sustainable (Saetra, 2023). This should be central and, we feel, could be given due consideration in the technology education research presentations at PATT conferences.

During our conversation, we also discussed whether a conference on sustainability education research would be connected to technology. Despite technology being ubiquitous in everyday life and societal systems, we believe that it remains largely unquestioned and in the background in sustainability education. What opportunities are there to bridge the perceived gap in technology education research concerning sustainability, and maybe also the other way around, of technology in sustainability education research?

To better understand and address the identified problem, we concluded that it was not enough to discuss it within our own research environment. Instead, we needed to adopt a multidisciplinary approach and broaden our perspective and try to 'get out of the pond'. After our café meeting in the old School for the Blind building, a number of questions for continued conversations and further development emerged:

- How can we identify individuals from different disciplines who are interested in discussing these issues?
- How can we create opportunities to meet these people and fund such a meeting?
- What could the outcome be? A book, articles, or something else?

2 RECOGNISING THE NEED TO EXPRESS OUR CONCERNS CLEARLY

To capture the ideas, and to provide some initial focus and structure, Svensson and Keirl met in London and developed a statement, a succinct (one-page) summary of our thinking, to make it easier both for us and for a stranger to read and reflect on. Although the final text is limited to one page, producing it was far from straightforward, as it required both thorough background research and careful consideration of wording over several weeks. Our journey to arrive at the statement included assessments of the state of play of sustainability education and technology education along with broad-ranging discussions around (amongst others) global tipping points (Lenton et al. 2023), sustainability goals (UN, 2015/2024), Artificial Intelligence (Bengio et al., 2023), evolutionary traps (Søgaard Jørgensen et al. 2023), and conceptions of 'human/posthuman' (Bostrom, 2003; 2009) – all as informing the backdrop of our key educational concerns. Fuller details of these assessments and discussions appear in Svensson and Keirl (2026).

We came to call the statement a 'declaration' and gave it the title: *Making Technology Visible in the Ongoing Debates about Sustainability*. This initial version of the Declaration became important in the next part where we looked for critical friends from disciplines different to our own.

3 CRITICAL FRIENDS

To be sure that we weren't just living in our own little bubble, the next stop on our journey was to consult two professors external to technology education research to critique the concept and discuss the relevance and timing of the Declaration. One of these was Tim Ingold, Emeritus Professor of Social Anthropology at the University of Aberdeen, with an interest in comparative questions of environment, technology and social organisation. He also has an interest in the role of animals in human society, on issues in human ecology, and on evolutionary theory in anthropology, biology and history. The other was Arjen Wals, Professor of Transformative Learning for Socio-Ecological Sustainability at Wageningen University. He also holds the UNESCO Chair of Social Learning and Sustainable Development with a research interest in designing learning processes and learning spaces that enable people to contribute meaningfully towards sustainability.

The Declaration document was sent to them as a stimulus document, and they were both invited to an online meeting to critique the Declaration and discuss an initial idea about applying for funding to expand the group to deepen collaboration and action. The purpose was to establish a group that shared mutual concerns regarding planetary futures with reference to the relationship between technologies and sustainability. These critical friends were also helpful in nominating other possible collaborators in the project.

We are extremely grateful for the time and thoughts given by these two colleagues, one of whom was unable to continue to work with the project because of other research commitments. The other continued as a member of the expanded group.

4 ESTABLISHING A GROUP

The journey continued and multidisciplinary others were approached, some of them suggested by Wals and Ingold, and some who Svensson and Keirl had identified as having interesting research profiles with potentials to contribute to the multidisciplinary perspective - two of whom are Christenssen and Svanström, co-authors of this paper. Those who expressed interest and were keen to meet for an introductory session were invited to an online meeting. The Declaration was sent out in advance, and they were asked to reflect on it and to provide comments and criticism during the meeting. Some declined to join (for various reasons – workload or, for a couple, having moved on in their research interests), but suggested others who they thought might be interested. The work of establishing a group developed through 'ripples on the water'. At the online meetings the authors, as initiators, were joined by one or two of the researchers we had contacted. Two of the participants described their experience of the first contact as follows:

When I was first contacted about participation, I responded only because I already knew one of the initiators. I was somewhat sceptic when I met the two initiators for a first online meeting on the Declaration. I explained that this was not the first Declaration with similar intentions that I had seen and even participated in formulating and that I was only interested if there could be a participatory process around the document and that its content would be allowed to evolve over time. This was well received, and participants have been allowed to co-design the process. (Participant A)

Being invited into the Blindspot group was, for me, both a very unexpected challenge and a (surprisingly) enriching experience. Coming from outside the field of technology education, I initially felt uncertain about how I might contribute. Much of the early discussion left me wondering what “they” really meant by “technology”. Yet this position as an “outsider” became a productive vantage point, at least for me. (Participant B)

Following the online meetings with the group that represented a broad spectrum of disciplines, theoretical and philosophical positions such as designers, anthropologists, scientists, engineers, sustainability educators and technology educators, it became increasingly important to secure funding to arrange a physical meeting with the full group as soon as possible.

5 DESCRIPTION OF FUNDING APPLICATION

Securing funding can be challenging, but fortunately the Riksbankens Jubileumsfond (<https://www.rj.se/en/>) had issued a call for proposals aimed at research initiation. This call gave us the chance to apply for funding to organise a two-day symposium for in-depth discussions by the expanded group as well as to establish a research network and make contacts that could lead to new research in the humanities and social sciences. In preparation of the application, Svensson and Keirl conducted a comprehensive literature overview of the state of the art internationally for the fields of sustainability education and technology education. UN documents, reports and research texts were examined for the extent to which each field had addressed the other in some reciprocal way (Svensson & Keirl, 2026). The proposed symposium activities were described in

the application, together with profiles of the ten participants, their qualifications, and their relevant publications.

Preparation and work with an application is time-consuming and you never know if you will succeed. The first attempt was rejected but in the next try there was a positive decision for the application to host a symposium in June 2025 in Gothenburg. The journey could continue.

6 PREPARING FOR A SYMPOSIUM

To prepare the symposium, Svensson and Keirl had a (two-day) preparatory meeting when a detailed program was finalized. Resources (research publications, texts, topic notes) were identified and made available to the participants in advance of the meeting. The purpose of the resources was to offer some common ground and research sources to the symposium participants and provide discussion points for the physical meeting. Examples of these materials included stimulus notes on topics such as ‘Initial sketches from online meetings’; ‘One model – Notes on New London Group’; ‘Ways of ‘seeing’ technologies’, research papers, the sources included in the funding application, and the list of proposed symposium objectives described in the application:

The proposed symposium objectives were to:

- (i) unpack and review, in practical ways, the concepts of sustainability, technology and education;
- (ii) discuss the relationship between technology, sustainability and education;
- (iii) broaden the view of what knowledge about technology and sustainable development means from an educational perspective;
- (iv) develop a platform for researchers and educators from participating universities in different countries to share experiences and develop strategies in the provision of technology and sustainable development education;
- (v) share research findings and identify questions and issues, which can form a basis for future collaborations.

Participants shared, in advance, brief descriptions of their research interests, as well as three to five of their own publications. The idea with this is to make the start-up and getting-to-know-each-other process at the two-day symposium in Gothenburg in June smoother. All material was uploaded on a shared platform used by all participants. The programme was finalised, the hotels booked, and travel arrangements made and this part of the Blindspot journey was complete, and we were ready to move on to the next, very significant, step.

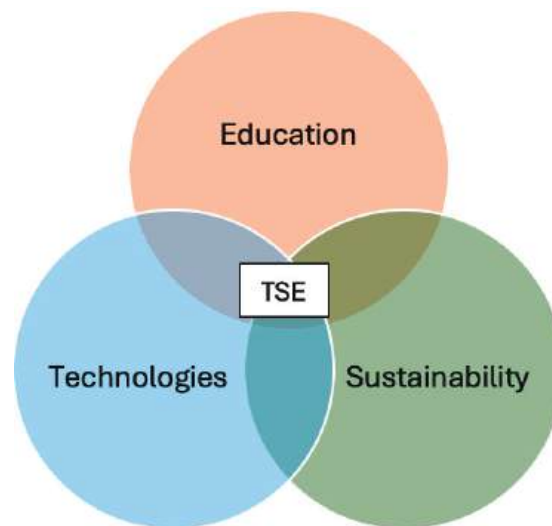
7 THE GOTHENBURG SYMPOSIUM

In June 2025, ten researchers met in Gothenburg for a symposium with an intensive program which enabled interesting discussions and exchanges of experience regarding technology and sustainability in education as described in the initial Declaration. A few questions formed the

basis of our discussions during the first day of the two-day symposium; Is the word sustainability sustainable? How visible are technologies? What are the educational blockers and enablers? The questions are linked to the three central parts of the Declaration, which are visualised in Fig. 1. The central intersection, or nexus, is at the core of the group's continued work.

Figure 1.

Illustrating the nexus between technologies, sustainability and education that is the focus of the Blindspot Declaration.



In the end of the first day, the group went back to the Declaration and looked at the technologies-sustainability-education nexus. What can we agree on in relation to our different starting points and experiences? To further develop the Declaration, we worked in pairs to analyse the three components in the nexus, both separately and together during the second day.

When sharing critical responses to the Declaration, it emerged that even this group had different understandings of technology. There were dissenting views and discussions concerning technologies' different roles in various situations, the embodied multiple values and the often undemocratically distributed power. Also, the different roles of education in formal and informal settings were questioned, particularly in relation to technology and sustainability education. Different cultural, academic and linguistic perspectives influenced the opinions, contributing to a deeper and more holistic understanding. One of the participants reflected on the exchange and processes that took place during the symposium as follows:

As the group collectively explored the ethical, societal and sustainability-related dimensions of technology, I began to recognize resonances with my own research on risk, hope, sustainable development, and climate literacy, as well as my work on values and ethics in science education.

The process itself was very inclusive. Each participant generously shared their expertise, and there was a strong collective commitment to ensuring that all voices (including those - me - less familiar with technology education) were invited into the conversation. An activity

early in the meeting, where we worked in rotating pairs to discuss and articulate ideas on large sheets of paper, was particularly powerful. It encouraged clarity of thought, shared concerns and helped articulate the core of our discussions.

Through this collaborative work, I moved from initial confusion toward a deeper understanding of technology as fundamentally value-laden and intertwined with sustainability challenges. I was very happy to find that my perspectives on risk, uncertainty, hope, and teacher education could meaningfully support the development of the Declaration. (Participant A)

After two intensive days, we ended the symposium with a list of potential activities to help us realise all the things expressed in the Declaration. We wanted to avoid the Declaration becoming just another piece of writing that is not put into practice. Therefore, the group affirmed that the one-page Declaration could be both meaningful and a valuable starting point for more far-reaching work with an expanded, multidisciplinary group of researchers and teachers.

We seek to broaden a network of critical, creative and concerned individuals from multiple backgrounds to develop fresh perspectives and knowledges for deeper understandings of technology blindness issues (The Blindspot Group, 2025).

8 FINAL REVISION AND RATIFICATION

Immediately following the symposium finished, Svensson and Keirl worked to accommodate the aggregated critiques and improvements into the declaration. The final version was sent out to the participants for a) ratification; b) confirmation of willingness to put their name to it; and c) to confirm the collective name of the Group and the title of the Declaration.

The final outcome from the Gothenburg symposium was that nine authors (collectively, The Blindspot Group) put their names to The Blindspot Declaration. One participant did not feel able to sign the Declaration in its final form as they could not identify fully with its content.

9 EMERGING DEVELOPMENTS - WHAT'S NEXT? – WHERE TO NEXT?

The symposium marked not the end of the journey, but a crossroads where different paths met, and new common paths were discussed - well described by one of the participants:

Contributing to a project with such an important mission, and seeing how interdisciplinarity genuinely strengthened it, left me inspired and hopeful about the continued work ahead. (Participant A)

Since the physical meeting, the research group has initiated regular online meetings to deepen conversations and identify local and international strategies for developing and expanding an interdisciplinary educational research community (but also envisaging including policy-makers and concerned professionals and others), around the nexus and the Declaration's Call to Action. The group is gradually expanding, with researchers who were initially contacted but unable to

participate in the symposium now joining the meetings. One of the nine signatories of the Declaration has also temporarily stepped back from further activities due to workload. A website has been set up to disseminate the Declaration, to expand the multidisciplinary research network further and to provide information about bringing technology education and sustainability education jointly into play across research fields and curricula. International conference papers building on the call to action are in preparation to be presented. Special editions of research journals and an academic text are under discussion.

10 CRITICAL REFLECTIONS

A strong foundational network of researchers is now established and is dedicated to continuing the development of new perspectives, knowledges and understandings around technology blindness issues. We are well aware about the continued effort that is required to maintain momentum and to achieve strong action. This point is illustrated by one of the participants:

Even after the meeting in Gothenburg and several online meetings, it is clear that words and conceptions take time to create a mutual understanding around. What seems perfectly clear to one person is vague to another and a word may mean different things in different contexts. This makes a multidisciplinary process like this both rewarding and challenging at the same time. If this confusion can be harnessed for learning, it can be very useful for all participants. I believe that we have managed to do this to some extent but have not yet reached all the way. (Participant B)

From the first coffee at the former School for the Blind in Liverpool 2023 to today's date, the driving force in our journey has been an effort to address technological blindness (see also Keirl & Svensson, 2026). Technology blindness is one aspect of the phenomenon of technology being likened to the 'elephant in the room' for all societies. We believe that the Blindspot Declaration could provide a foundation for developing new perspectives on how technologies and sustainability can be more effectively incorporated into education in various disciplines and across curricula.

The journey continues!

Acknowledgement

The foundational work of The Blindspot Group was funded by Riksbankens Jubileumsfond, Research initiation, F25-0004

Affirmation

This paper is original work, and the authors take full responsibility for its content.

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Creativity in Design & Technology

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Abstract

The background to this paper was a 2002 seminar that brought together various stakeholders, including teacher trainers, local authority advisors and inspectors, professional associations, government departments, and secondary school teachers. This collaboration aimed to investigate whether creativity was indeed in crisis within the design & technology classroom.

The purpose of this paper is to investigate and analyse the opportunity for creativity in design and technology learning in England. The methodology used was a thematic document analysis focused on the English National Curriculum from 2002 to the present day.

The key finding is that across the four pedagogical approaches to teaching design and technology, there are many opportunities to encourage creative activity. However, this paper asks: has anything truly changed since 2002?

The seminar's findings were published in 2002 as *Creativity in Crisis* by Nuffield Design & Technology and the Design and Technology Association.

Key Words: Creativity, Design & Technology, Curriculum Development

1 INTRODUCTION

In recent decades, there has been a rising interest (Craft, 2003, 2005; Grey & Morris, 2024) in addressing creativity in schools among both politicians and academics, with many (Sharp & Le Métais, 2000) attributing this shift to the findings of the NACCE report (Robinson, 1999). During his tenure as leader of the opposition, the current Prime Minister (Starmer, 2023) expressed his commitment to ensuring that children continue to study a creative arts subject or engage in sports until they reach the age of 16. The most recent Programme for International Student Assessment (PISA) report from 2022 has included a measure of creative thinking alongside mathematics, reading, and science, further underscoring the significance of creativity in education. The rising interest in creativity in schools or the drive to build 'creative capital' (Sharp & Le Métais, 2000) is partly driven by the desire to ensure economic competitiveness in a global economy. Whilst

the motivation for creativity in education can clearly be understood from an economic perspective, there are other reasons for its inclusion too, such as human flourishing.

This paper begins by identifying four different types of creativity. It then considers design & technology pedagogy in the light of these sorts of creativity. The third part compares and contrasts the place of creativity in the design & technology programmes of study introduced in the National Curriculum in 2007 (Qualifications and Curriculum Authority, 2007) and 2013 (Department for Education, 2013) and the resulting changes to the GCSE (General Certificate of Secondary Education) public examinations. The fourth part reports the recommendations for design & technology made by the recent Curriculum and Assessment Review (Francis, 2025). Part five discusses the place of creativity in design & technology in the light of the preceding four parts and asks whether anything has changed in this regard since the Creativity in Crisis report was published in 2002.

The authors hope that the findings from this paper, focusing on the English national curriculum, will be of interest internationally when considering opportunities for creativity within their own curricula.

2 METHOD

Document analysis was the methodology used. A thematic analysis was used to read, interpret, compare, and contrast the English National Curriculum documents (Qualifications and Curriculum Authority, 2007; Department for Education, 2013) from the original report in 2002 to the present day, 2026.

2.1 Disclosure Statement

Artificial Intelligence (AI) technologies were used solely to enhance the clarity and structure of the written text. All scholarly contributions, theoretical perspectives, and analyses were produced by the authors.

3 FOUR DIFFERENT SORTS OF CREATIVITY

A useful place to start is the distinction between different kinds of creativity, as developed by Beghetto & Kaufman (2016) and summarised in Table 1.

Table 1*Beghetto & Kaufman's 4 Cs of Creativity*

Creativity Type	Description	Evaluation & Impact
Big-C	Work that transforms a field of expertise	Global, professional
Pro-c	Robust ideas that add to the existing field	Professional community
Little-c	Everyday, localised problem solving	Local community
Mini-c	Novel and personally meaningful learning	The individual

Beghetto & Kaufman, 2016

An example of Big-C creativity is Einstein's equation $E = mc^2$, which changed the way scientists think about the relationship between energy and matter and enabled society to understand and utilise nuclear power. Another is Duchamp's urinal in an art gallery, which changed what society sees as 'art', and without this, it is unlikely that Damien Hirst's shark in formaldehyde would have been created. Pro-C creativity is exemplified by the day-to-day work of scientists, such as synthetic chemists, who develop new compounds and materials in accord with the prevailing paradigm of how atoms bond with one another. Such compounds and materials are often quite remarkable and add to the existing field's knowledge base. 'Little-c' creativity describes innovations in everyday life that solve localised problems and are considered new and valuable by a local community. Mini-c creativity refers to the everyday little 'Eureka' moments of developmental learning. In this model, 'Mini-c' insights are based on Vygotsky's (1976) conception of learning as a dynamic process of knowledge construction. Hence, personal insights are creative acts in the learner's mind as they construct novel, personally meaningful interpretations of experiences. Therefore, 'Mini-c' is a beneficial way of thinking about creativity in the context of design & technology learning, where the emphasis is on developing personal expression through producing a particular outcome and personal growth. Such creativity refers to activities and outcomes that are creative with regard to the individual who has devised and implemented them, in that they mark significant achievements that they have not managed before. How these sorts of creativity might be made manifest in design & technology is our next consideration.

4 DESIGN & TECHNOLOGY PEDAGOGY - THE POTENTIAL FOR CREATIVITY

A prevailing paradigm in design & technology pedagogy is the use of four approaches: making without designing, designing without making, design and making and exploring technology

(Beaumont & Steeg, 2024). The first three of these are particularly relevant to our discussion of creativity in design & technology and the sorts of creativity considered above. Clearly, Big-C and Pro-c are unlikely to feature in the design & technology classroom, but this may not be the case for Little-c and Mini-c, as discussed below.

4.1 *Creativity in making **WITHOUT designing activities***

In this activity, the teacher identifies a simple artefact, the making of which will teach specific making skills and provide hands-on experience using tools to manipulate specific materials. The teacher provides the artefact's design and clear, explicit instructions for making it. Examples of such artefacts include a spinning top, a decorated arm band, and a simple kite. All these items are likely to appeal to students starting secondary school in England (age 11/12). In one sense, there is no creativity here in that all the design decisions that lead to the nature of the artefact have been made by the teacher. The students simply follow instructions, but in doing this, they move from a situation in which there is a set of starting materials to one in which something has been produced, what we might call 'constructional creation'. Whilst not Mini-c, this activity builds knowledge and skill and provides confidence in the making aspects needed to pursue designing AND making activities.

4.2 *Creativity in designing **WITHOUT making activities***

In this activity, the teacher introduces students to a new material or technology and asks the question, "What could you use this for to make the world a better place?" The teacher is clear from the outset that the students will not make their idea, but will present it in terms of four criteria: technical feasibility, meeting people's needs or wants, being acceptable to society, and being viable for sale in an existing or new market. Usually, the students work in small groups and are required to present and justify their ideas to the rest of the class. This was the basis of the Young Foresight Initiative (Barlex, 2012) and proved highly successful in developing creativity, communication, and presentation skills in learners aged 11 - 14 years. Taking the novel material QTC (a stress sensitive conductor; in a relaxed state it is good insulator but the more it is stressed by compressing, stretching or twisting, the more it conducts) groups of students devised a wide range of products including: clothing that changes colour as you dance, car tyres that sense their internal pressure, an epileptic fit detector, a self-weighing suitcase, an arthritis treatment device, keep fit apparatus, a depth sensitive submersible and an internal heart beat monitor. This activity is clearly an example of Mini-c, and the ideas themselves have the potential to be seen as beneficial to particular communities and hence move into Little-c territory.

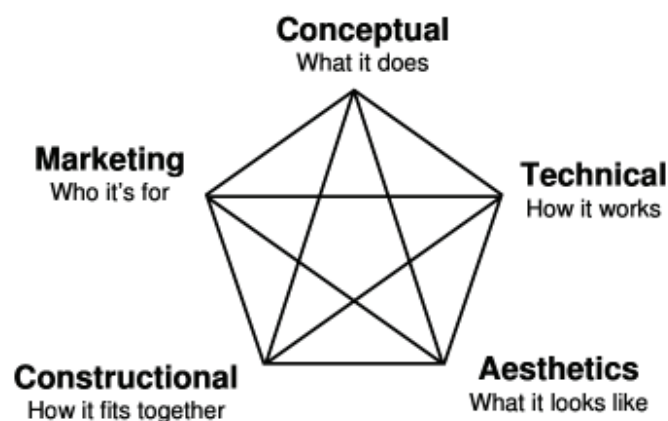
4.3 *Creativity in designing **AND making activities***

In this activity, the student has to design an artefact to address a particular need or want, then make the artefact they have designed. The creativity involved may be considered in terms of the design decisions the student makes (Beaumont & Steeg, 2024). These can be seen as involving five features: conceptual (the sort of item to be designed), technical (how the item will work), aesthetic (what the artefact will look like), constructional (how the item will be made) and stakeholder (the requirements of users, but possibly buyers, sellers, manufacturers as well). This is often represented as a design decision pentagon, as shown in Figure 1. The connections across

the pentagon are important as decisions made at one vertex can affect those made at others. For students aged 11 - 14 years, it is usually the teacher who makes the conceptual decision and then supports students in making the other sorts of decisions. It is worth noting that giving complete free rein here is unwise and that some teachers restrict each of the remaining four vertices of the decision pentagon to three possibilities. So, three different ways of working, three different aesthetic drivers, three different sorts of material, three possible users. Taken together, these possibilities give rise to $3 \times 3 \times 3 \times 3$ different designed outcomes - 81 in total. Given that the variety of outcomes is seen as an indicator of the level of creativity operating within a classroom, this approach to designing and making assignments may be seen as enabling and promoting Mini-c creativity in design & technology. A test of the level of creativity encouraged in a designing and making activity is to view all the outcomes at the same time, which gives a gestalt impression. If the majority look very similar, then Mini-c creativity has not been achieved for most students. A large number of unfinished pieces may indicate that students were overly ambitious in their creative intentions. It is worth noting that in England, older students (14 - 16 years) are required to make the conceptual design decision, deciding on the sort of item they will design and make in response to a given context.

Figure 1

A design decision pentagon (Barlex, 2007)



The extent to which this pedagogy can be used in response to the statutory requirements requires that these are considered in some detail, and it is to this that the paper now turns.

5 DESIGN & TECHNOLOGY IN THE ENGLISH NATIONAL CURRICULUM 2007 AND 2013

5.1 In Key Stage 3 (students aged 11 - 14)

Two key differences immediately stand out when comparing the 2007 and 2013 Programmes of Study (PoS). Firstly, the 2007 PoS is far more extensive than the 2013 PoS. The 2007 PoS consists of 7 pages (9 if one includes the attainment targets) embellished with graphics, photographs and explanatory notes. The 2013 version is minimalist in the extreme, consisting of just 3 pages and no illustrative material. Secondly, while food is included in the body of the 2007 PoS alongside

other materials in the 2013 PoS, it has a separate section, Cooking and Nutrition, devoid of any mention of designing and making with food. This is mitigated to some extent by the specific mention of using ingredients in the Subject Content's Make section. Both PoS consider design as a key activity, but the level of detail differs significantly. In the 2007 Key processes section, design is described with eight supplementary statements accompanied by five explanatory notes (altogether some 329 words), whereas the 2013 statement on design consists of five bullet points (some 97 words).

This minimalist approach has consequences in the way the materials to be used in design & technology are described. Hence, the 2013 PoS reads: select from and use a wider, more complex range of materials, components, and ingredients, taking into account their properties; just 19 words. This is in stark contrast to the detailing of using food, textiles, resistant materials and systems and control in the 2007 PoS, which totalled 261 words. The 2013 PoS is essentially materials agnostic, leaving the choice of materials to play out in the classroom according to teacher preference. In terms of creativity, the 2007 PoS includes a section titled Creativity in the Key Concepts section and several acknowledgements of its significance throughout the documents, as shown in Panel 1.

Panel 1

Statements concerning creativity in the Design & Technology 2007 National Curriculum Programme of Study

On Page 2

In design and technology, pupils combine practical and technological skills with **creative thinking** to design and make products and systems that meet human needs. ... They learn to **think creatively** and intervene to improve the quality of life, solving problems as individuals and members of a team. They apply their **creative thinking** and learn to innovate.

On Page 5

... **respond creatively** to briefs, developing their own proposals and producing specifications for products

On Page 9 in the Attainment Targets

Level 7 - They investigate form, function and production processes as they **respond creatively** to briefs.

Level 8 - They identify conflicting demands on a product and **respond creatively** to briefs,

On Page 10 in the Attainment Targets

Level 6 - They **respond creatively** to briefs,

Exceptional performance - **Responding creatively** to briefs, they are discriminating in their selection and use of information sources to support their work. They interpret and **apply knowledge and understanding creatively** in new design contexts.

On Page 10 Bold pull out statement

Pupils combine practical and technological skills **with creative thinking** to design and make products and systems that meet human needs

In contrast, there are just three statements concerning creativity in the design & technology 2013 PoS as shown in Panel 2. Perhaps this is not surprising given the minimalist approach of the 2013 PoS, but it would seem that the previous emphasis on creativity has diminished.

Panel 2

Statements concerning creativity in the Design & Technology 2013 National Curriculum Programme of Study

On Page 1 In purpose of study Using creativity and imagination, In Aims develop the creative , technical and practical expertise On Page 2 in Subject Content Through a variety of creative and practical activities

5.2 In Key Stage 4 (students aged 14 - 16)

There is no specified PoS for design & technology at Key Stage 4. Instead, in England, the Office for Qualifications and Examinations Regulation (Ofqual) regulates qualifications, examinations, and assessments. They set the Assessment objectives (AOs), which are the same across all versions of each qualification, regardless of the provider. Ofqual (2015) laid down the assessment framework for design & technology in terms of four assessment objectives. Their weighting across the two assessment items – a non-examined assessment (NEA) and a written paper, each worth 50% of the marks, is summarised in Table 2.

The nature of the NEA was significantly different post 2013 to its equivalent in the intervening years. Before 2013, students tackled a design and make task set by the Awarding Organisations; they provided a materials specific design brief. Post 2013, the Awarding Organisations provided a description of a situation and its context, and students were required to identify for themselves a feature in that context that could be addressed by designing and making a product. The students were required to develop their own design brief. The NEA became known as a contextual challenge, and students could choose from a wide range of materials and components to meet it.

Table 2

Distribution of marks according to assessment objectives (AO) and assessment items in GCSE D&T

Objective	Weighting	NEA	Written Paper
AO1 Identify, investigate and outline design possibilities to address needs and wants	10%	10%	0%
AO2 Design and make prototypes that are fit for purpose	30%	30%	0%
AO3 Analyse and evaluate: Design decisions and outcomes, including prototypes made by themselves and others Wider issues in design and technology	20%	10%	10%
AO4 Demonstrate and apply knowledge and understanding of: Technical Principles Designing and making principles	40%	0%	40%
Totals	100%	50%	50%

Adapted from (AQA, 2022)

The Awarding Organisations, in response to Ofqual requirements, significantly increased the amount of subject matter students were required to learn to tackle the written paper, despite the minimalist approach adopted in 2013. This ‘knowledge richness’ was justified by Michael Gove, the then Minister for Education, by citing Daniel Willingham’s research into cognitive science as evidence that the ‘knowledge-rich’ focus of the national curriculum was the key to educational success. It is worth noting that the Creativity in Crisis Report (2002) acknowledged the importance of teaching knowledge and skills as a precursor to creative activity. The written paper required that candidates answer different types of questions. Beaumont and Steeg (2024) argue that it is important, therefore, that they have significant experience in answering such questions well before they sit the written paper. They suggest that one way to provide such an experience is through homework activities, which not only give practice in answering different types of questions but also explicitly teach the nature of particular types of questions and strategies for answering them. This is particularly important for those questions that require extended written answers and cover more than one item in the specification – synoptic questions. The range of question types candidates might face in the written paper is summarised in panel 3.

Panel 3

Possible written paper question types

- To remember names of, for example, materials, types of materials, properties of materials, uses of materials, tools and their uses, components, types of components, and their behaviour. In some cases such questions may be presented as multiple-choice questions in which the candidate is given a choice of possible answers from which to choose the correct one.
- To identify a true statement from a selection of statements
- To provide descriptions of processes
- To provide justifications and/or explanations for technical, aesthetic, and manufacturing decisions
- To use their knowledge and understanding of design movements and designers to comment on and discuss products of various kinds
- To answer synoptic questions, discussing a particular issue from several points of view using examples and content from different parts of the specification. This might involve using knowledge and understanding from science to consider issues such as pollution, global warming, and resource depletion
- To complete partly finished scale drawings
- To interpret graphical information given in the form of, for example, pie charts, bar charts, or line graphs
- To calculate costs from given information
- To convert from imperial to metric units
- To use information in diagrams and tables to calculate features such as percentages, length, area, volume, angle, and mass
- To use information in diagrams and tables to calculate component values and behaviour in mechanical, electrical, and electronic systems.

Taken together, the nature of the NEA and the increase in the amount of material tested in the written paper significantly changed the assessment of design & technology.

6 POSSIBLE CHANGES IN 2026

In November 2025, the final report of a Curriculum and Assessment Review for schools in England, entitled ‘Building a world class curriculum for all’ (Crown Copyright 2025), was published. The review, chaired by Professor Becky Francis, is a significant development and has a stated intention to maintain and build on the knowledge-rich approach and the coherent structural architecture established by earlier curriculum work. The Review examined in depth the issues facing individual subjects and provided recommendations for Government action. The recommendations for design & technology are shown in Panel 4.

Panel 4

Francis Review recommendation for design & technology

We recommend that the Government:

Rewrites the D&T subject aims to be more aspirational, and clarifies the purpose of study to focus on the subject's distinct body of knowledge and capabilities, with a particular focus on Key Stage 3.

Refines the D&T curriculum and GCSE subject content to:

- Explicitly include how to achieve sustainable resolutions to design challenges.
- Embed the teaching of social responsibility and inclusive design explicitly within the curriculum, as appropriate to the key stage, throughout the design process.
- Support the development of critical decision-making skills about material selection.

Ensure that realising designs remains integral to pupils' experience of D&T.

7 DISCUSSION

This paper has identified Mini c (Beghetto & Kaufman, 2016) as the sort of creativity that might be encouraged in the way design & technology is taught. It has considered the extent to which creativity featured in the (Qualifications and Curriculum Authority, 2007) and (Department for Education, 2013) National Curriculum versions of design & technology Programmes of Study and the resultant public examinations. Finally, the paper has reported the recommendations made to the government by the recent Curriculum and Assessment Review (Francis, 2025).

Where do the changes at KS3 and KS4 in the move from 2007 to 2013 leave us in terms of requiring students to be creative? Although mentioned less in the 2013 PoS, the nature of the Contextual Challenge at Key Stage 4 may be seen as requiring more creativity than previously and preparing students for this in KS3 might mitigate the reduced emphasis of creativity in the 2013 PoS. However, the increased demands on learning subject content needed for success in the written paper may also be felt at KS3, using up time that might otherwise be spent preparing students for success in the Contextual Challenge.

Without doubt, designing without making activities have the potential to develop Mini-c creativity (Beghetto & Kaufman, 2016). However, Patricia Murphy, in the Creativity in Crisis report, notes that its effectiveness in supporting creativity depends on the teacher's view of knowledge and how this influences their pedagogy. Those teachers who see themselves as having knowledge which they have to transmit to students were unlikely to give the students the intellectual freedom to develop their own ideas and become creative. So, there are two problems here. The first is the extent to which teachers build designing without making into their teaching, and the second is whether they are predisposed to a view of learners as passive receivers of information, knowledge and skills or inclined to a view of learners as constructing rather than receiving meaning and understandings within a social context.

Similarly, design and making activities have the potential to develop Mini-c creativity and also act as precursors for the contextual challenge of the NEA. However, analysis of some designing and making activities reveals that they are, in fact, very much making activities with few, if any, design decisions made by the students. The teacher has to give students a certain amount of decision-making autonomy and manage how they use it. Teachers who view learners as passive recipients of information, knowledge, and skills are unlikely to use designing and making activities effectively to develop creativity.

What is likely to be the impact of the recommendations for design & technology on the government from the Curriculum and Assessment Review (Francis, 2025)? Rewriting the D&T subject aims to be more aspirational, which might well lead to an explicit requirement to include the development of Mini-c creativity. Clarifying the purpose of study to focus on the subject's distinct body of knowledge and capabilities again might endorse creativity, but it will be important that this also deals with the intrinsic nature of the subject - to intervene effectively and creatively in the made world - and doesn't overinflate the required body of knowledge.

With regard to the situation now and that in 2002 when the Creativity in Crisis report was written, one is tempted to quote Alphonse Karr: "Plus ca change, plus c'est la meme chose."

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Exploring Student Attitude Development in Engineering and Arts/Humanities Design Activities

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Abstract

Design-oriented activities are a central pedagogical strategy for integrating science, technology, engineering, the arts, and mathematics (STEAM). Among these, engineering and arts/humanities design represent two distinct approaches with differing instructional processes and philosophies. Prior studies show that students' motivations and affective responses vary across these approaches, influencing their attitudes towards technology education. Grounded in the PATT (Pupils' Attitudes Towards Technology) framework—which addresses interest, perceived difficulty, gender roles, curriculum value, and career aspirations—this study systematically reviews research on engineering and arts/humanities design within technology education. Using keyword searches in major journals and a coding scheme developed for this study, PATT-related literature was analyzed. Descriptive results and key findings are synthesized to inform future research and instructional practices in technology-based curricula.

Key Words: Design-Oriented Activities, PATT, Engineering Design, Arts and Humanities Design, Technology Education

1 INTRODUCTION

The maker culture and practical learning have a long history, including craft education, manual training, and applied arts curricula. These traditions remain essential in contemporary technology education, with varied instructional activities shown to foster positive student attitudes. Recent trends in transdisciplinary curriculum development highlight design-oriented strategies to cultivate students' problem-solving competencies (e.g., English, 2016; Kelley & Knowles, 2016; Tzeng et al., 2024). Engineering design emphasizes rational, logical processes to achieve optimal solutions. In contrast, arts and humanities-based design promotes open-ended, non-prescriptive approaches that foster divergent thinking and creativity (Brown & Wyatt, 2010; Razzouk & Shute, 2012; Runco, 2007). While both are grounded in design-based learning, students may develop different motivations and experiences depending on the design approach, shaping their engagement in technology education. The PATT (Pupils' Attitudes Towards Technology) framework offers insight into students' attitudes across dimensions such as interest, difficulty,

gender roles, curriculum value, and career aspirations. Analyzing how these dimensions vary across design-oriented activities provides a basis for informed curriculum design. This study examines research on engineering and arts/humanities-based design in technology education, focusing on their implementation and influence on students' attitudinal development.

2 LITERATURE REVIEW

2.1 *Design-Oriented Activities*

Technology education encompasses a range of learning activities, from hands-on and experiential tasks to engineering design focused on problem-solving and systems thinking, as well as arts and humanities-based design emphasizing creative expression, cultural context, and aesthetic judgment. These activities differ in instructional goals, pedagogical processes, and cognitive demands, shaping distinct student experiences and attitudes. Despite the growing emphasis on design-oriented strategies in interdisciplinary STEAM curricula, research often lacks clarity in distinguishing the structural and pedagogical differences among these approaches.

Engineering design-based curricula highlight rational problem-solving processes (Burke, 2014; Bybee, 2013; Dym et al., 2005; Hynes et al., 2011). According to the Next Generation Science Standards (NGSS Lead States, 2013), engineering design involves: (1) defining problems within constraints; (2) evaluating solutions; and (3) iterative testing and optimization. For novice learners, particularly those unfamiliar with engineering, identifying core problems, understanding constraints, and applying scientific and mathematical principles present significant learning challenges (Atman et al., 2007; Mentzer et al., 2014; 2015).

In contrast, arts and humanities-based design emphasizes imaginative and affective processes (Brown & Wyatt, 2010; Razzouk & Shute, 2012; Runco, 2007). As defined by IDEO, this design process includes: (1) empathy and inspiration; (2) conceptual development and visualization; and (3) iterative ideation, prototyping, and refinement. The open-ended, trial-and-error nature of such design can be frustrating for students with weak conceptual understanding, and teachers may struggle to manage outcomes due to divergent student ideas (Fukui & Sasaki, 2022; Skorinko et al., 2012).

Effective implementation of these two approaches requires addressing their inherent challenges: engineering design should not be constrained by limited materials or environments, while arts/humanities-based design must be sufficiently structured to avoid excessive divergence that impedes creativity and higher-order thinking. These considerations are essential for cultivating innovation competence.

This study focuses on two types of design-oriented activities in technology education—engineering and arts/humanities-based design—each characterized by defined processes and demands for higher-order thinking. Activities based solely on experience, imitation, manual operation, or skill acquisition are excluded. Instead, the focus is on instructional activities involving problem definition, conceptual development, and reflective iteration.

2.2 *Attitudes Towards Technology*

Students' attitudes towards technology are a central focus in technology education research. The Pupils' Attitudes Towards Technology (PATT) instrument has been widely used to measure students' perceptions and experiences. Developed by Raat and de Vries in the 1980s, early studies showed that cognitive and affective responses to technology were influenced by gender, conceptual understanding, and prior experience (Raat & de Vries, 1985; Boser & Daugherty, 1998).

Later efforts to standardize and revalidate the instrument identified several key dimensions. Ardies et al. (2013), through reconstruction and factor analysis of the PATT scale, confirmed subdimensions such as Career Aspirations, Interest in Technology, Tediousness, Perceived Difficulty, and Perception of Technology as a Subject for Boys or for Both Boys and Girls.

Grounded in these theoretical and empirical foundations, this study adopts these dimensions as its analytical framework. By incorporating students' subjective experiences in design-oriented curricula, the study explores how these attitude dimensions relate to learning motivation and perceptions across technology, engineering, and arts/humanities-based activities.

3 **METHODOLOGY**

This study followed systematic content analysis procedures (Tzeng & Yu, 2024). Literature was retrieved using keywords related to student attitudes towards technology, with a focus on studies utilizing attitude measurement instruments. Content analysis was conducted based on the instructional features of technology curriculum activities. Descriptive statistics and key analytical findings were reported to inform future research in technology education.

Three journals were selected: Design and Technology Education: An International Journal (DTEAJ), International Journal of Technology and Design Education (IJTDE), and Journal of Technology Education (JTE). Searches using the keywords "attitude," "perception," "attitude towards technology," "Attitudes Towards Technology," "PATT," "PATT-USA," "PATT-SQ," and "PATT-NL" yielded 50 articles from DTEAJ, 802 from IJTDE, and 11 from JTE, totaling 863 articles.

From these, 29 studies using the PATT instrument were identified. Applying inclusion criteria related to design orientation and attitude dimensions, studies not involving engineering or arts/humanities-based design activities were excluded. After screening, nine articles were retained for analysis. Since only IJTDE and JTE contained studies of both design orientations, DTEAJ articles were excluded.

A three-digit coding system was used: the first digit indicated the journal, and the next two indicated the article number. IJTDE was coded as "1" (101–107) and JTE as "2" (201–202).

The analysis was conducted collaboratively. One author retrieved articles and compiled metadata (title, abstract, DOI) using Microsoft Excel. Initial categorization by design orientation and attitude dimension was followed by review and verification by a second author. Final coding and analysis were completed through joint discussion.

4 RESULTS

The analysis consisted of two parts: (1) the distribution of publication years for design-oriented activity studies, and (2) a cross-comparison of design orientations and technology attitude dimensions.

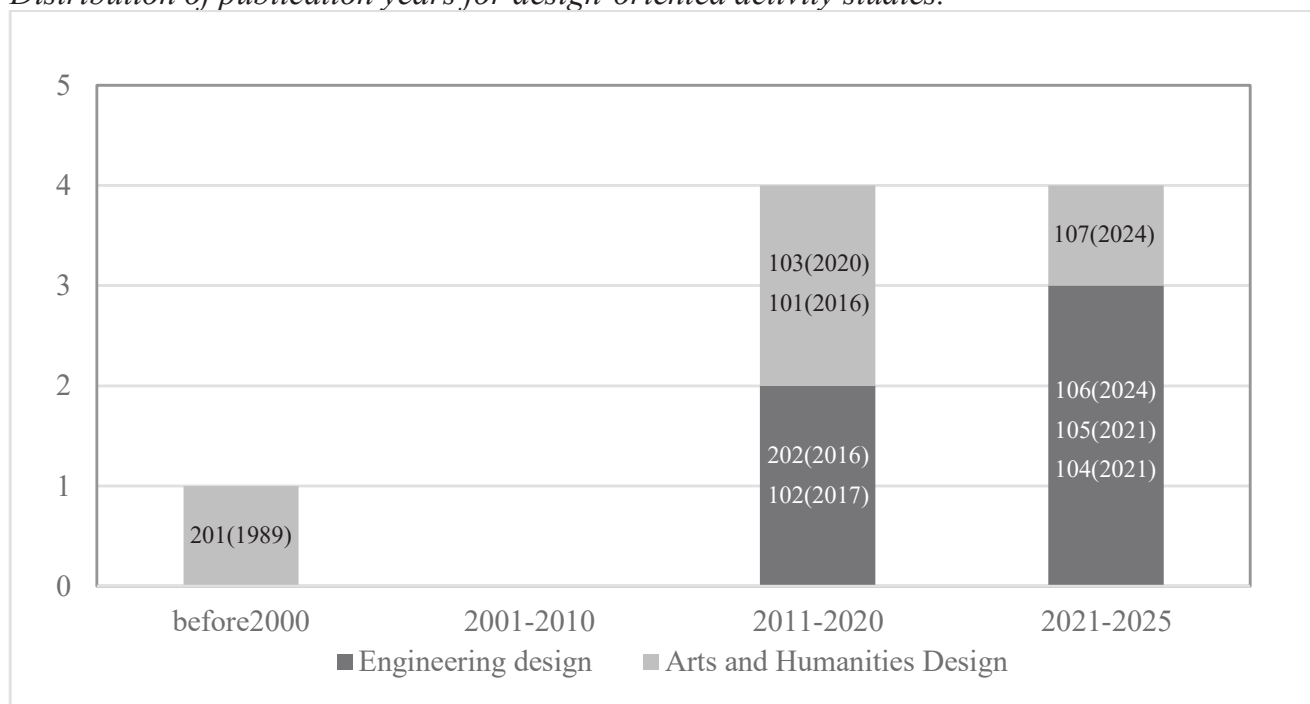
4.1 *Publication Year Distribution of Design-Oriented Activity Studies*

Figure 1 presents the distribution of publication years. One study was published before 2000, none between 2000 and 2010, four between 2011 and 2020, and four between 2020 and 2025. Among them, five focused on engineering design and four on arts and humanities-based design.

Engineering design studies first appeared in 2016, with the highest number published between 2021 and 2025. Arts and humanities-based design studies first emerged in 1989, with most published between 2011 and 2020.

Figure 1

Distribution of publication years for design-oriented activity studies.



Note: Article codes are arranged chronologically. Engineering design: 102, 104, 105, 106, 202; Arts and humanities-based design: 101, 103, 107, 201.

4.2 Cross-Analysis of Design-Oriented Activities and Technology Attitude Dimensions

As shown in Table 1, differences emerged in the distribution of PATT-related dimensions between engineering design and arts/humanities-based design studies.

Engineering design studies addressed all seven PATT dimensions: six focused on *Interest*, four on *Gender Role* and *Career Aspiration*, three on *Importance*, two on *Boredom*, and one each on *Difficulty* and *Curriculum*. In contrast, arts/humanities-based design studies covered only four dimensions: two on *Interest*, and one each on *Gender Role*, *Importance*, and *Career Aspiration*.

Table 1

Cross-analysis of design-oriented activities and technology attitude dimensions

Dimensions	Engineering design	Arts and humanities-based design
Gender role/ role pattern	102,104,105,202	201
Importance/consequences	104,105,106	201
Difficulty	104	
Interest	102,104,105,106,107,202	107,201
Boredom/ tediousness	104,202	
Curriculum/ Curricula	106	
Career aspiration	104,106,107,202	107

Note: Articles 101 and 103 referenced the PATT instrument but did not classify items by dimension. Article 102 partially applied the PATT dimension framework.

5 DISCUSSION AND SUGGESTIONS

This systematic review compared the research landscape of two design orientations—engineering design and arts/humanities-based design—in relation to students’ attitudes towards technology (PATT). Two key findings are highlighted.

First, in terms of publication trends, the earliest study appeared in 1989. No studies were published in the 2000s, but interest has grown significantly since 2011, with four articles

published from 2011–2020 and another four from 2020–2025. This indicates the increasing prominence of design-oriented activities in technology education research.

Second, while the number of studies for each design orientation was similar, engineering design studies addressed a broader range of PATT dimensions. These included *Interest*, *Gender Role*, *Career Aspiration*, *Importance*, *Boredom*, *Difficulty*, and *Curriculum*. For instance, del Olmo-Muñoz et al. (2021) investigated six dimensions and found that engineering design strategies effectively reduced students' perceived difficulty and increased girls' interest in technology, demonstrating broad positive attitudinal impacts.

In contrast, arts/humanities-based design studies primarily examined *Interest*, *Gender Role*, *Importance*, and *Career Aspiration*, with no discussion of *Difficulty*, *Boredom*, or *Curriculum*. For example, Autio (2016) reported that although Finnish girls showed increased acceptance of everyday technologies, gender stereotypes in career aspirations persisted—suggesting that general exposure to technology may not sufficiently address deeper gender-related attitudinal gaps, unlike targeted engineering design interventions.

In sum, design-oriented activities have become a key pedagogical strategy in shaping students' attitudes towards technology over the past three decades, with engineering and arts/humanities design representing two primary trajectories. Current research shows a strong emphasis on *interest*, with less focus on *difficulty*. Engineering design studies tend to demonstrate integrative impacts across multiple dimensions and show promise in reducing gender disparities. In contrast, research on arts/humanities-based design remains limited, particularly in addressing students' cognitive challenges and curriculum-related experiences. Future work should explore students' difficulty and negative perceptions during the design process to strengthen transdisciplinary STEAM curriculum development. This article was originally written in the author's native language. Artificial intelligence tools were subsequently employed to assist with English translation and linguistic editing..

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Logics of Sustainability in Swedish Technology Education

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Abstract

In the global north of today, it is common to view technological progression as a means of achieving a sustainable future. This is true also in technology education. That is, sustainability is seen as dependent on technological progression – endlessly developing technologies. In this study, I explore how sustainability teaching in Swedish upper-secondary technology school is articulated in the Technology course syllabus and in six interviews with technology teachers about sustainability. I aim to understand why ideas of technological progression have such a grip on views sustainability in technology education. I use *logics of critical explanation* to explain and articulate the discursive structures that make this social practice possible. I pay attention to social logics (the characteristics of a practice, e.g. certain views on teaching), political logics (how practices are normalised or contested), and fantasmatic logics (how fantasies are used to defend or change practices). The findings show logics that support the hegemony of technological progression both in the syllabus and among the teachers. This happens through the articulation of an imagined future where technology is portrayed as the way to sustain modernity. These logics render arguments against technological progression and engineering-inspired teaching approaches invisible. I argue that such a practice risk creating a fixed view of teaching sustainability in technology education, while alternative ways of teaching sustainability are left unexplored. It also risks fortifying the instrumental idea of technology education as an education for the industry.

Key Words: Technology Education, Sustainability, Technology Teachers, Discourse Theory, Logics

1 INTRODUCTION

Today, it is common to view technological solutions as a means of achieving a sustainable future (e.g. *AI for Climate and Nature Initiative*, n.d.; Carlsson, 2025; Government Offices of Sweden, 2025a, 2025b; Walker, 2025), which can be explained by a global hegemonic discourse of ecological modernisation (Dryzek, 2013; Knutsson, 2018). This technologically optimistic view is also visible among Swedish upper secondary technology teachers (Westin & Berge, 2026). Such an idealisation of technological progression (the continuous development of technology) as the solution to all the problems we come upon, is also known as technological solutionism (Morozov, 2013). Solutionist answers to sustainability and environmental issues carries the risk

of reinforcing existing socioeconomic and environmental crises, which could have dire consequences globally (Heikkurinen, 2024; Hornborg, 2021; Knutsson, 2018).

2 LITERATURE REVIEW

In previous research regarding sustainability in technology education, there is a consensus arguing for shifting technology education towards more sustainable values and methods. Back in 2000, Petrina did a literature review regarding research on teaching methods in technology and design education and described the discourse of technology education as based around “technocentric design and technological problem solving methods”, and unsuitable for a sustainably oriented technology education (2000, p. 210). This technocentric focus seems to be continuously adopted and yet criticised (Elshof, 2015; Knutsson, 2018; Pavlova, 2011). For example, Pavlova (2011) criticises the intense focus on “eco-design” and proposes education for sustainable development (ESD) to be more noticeably included in technology education, as a way of reaching a change in values (Pavlova, 2011). Several earlier studies have concluded that such a technocentric focus may be explained by a technology education steeped in neoliberal ideology and market logics (McGarr & Lynch, 2021; Spendlove, 2025; Westin & Berge, 2026). Further arguments for a heavier focus on sustainable values, and the way values are imbued in technology, suggests this may be way of breaking with unsustainable practices in technology education (Hallström & Ankiewicz, 2024; Keirl, 2015; Pavlova, 2011; Spendlove, 2025). Keirl (2015) highlights the non-neutrality and cultural situatedness of technological artifacts and argues for a technology and design education centred around ethical considerations and a sustainable discourse, while Spendlove promotes an “activism and value driven pedagogy” (2025, p. 53).

Despite the risks associated with an overreliance on technological solutions, and despite the arguments and suggestions for a more sustainable technology education, technocentrism seems to have a continuously steady grip on the teaching of technology, even in the face of a climate crisis (Westin & Berge, 2026). To enable explanation for such seemingly inexplicably gripping social practices and discourses, *Logics of critical explanation* (Glynos & Howarth, 2007) has been developed. Variants of this approach has earlier been utilized to explain, for example, how Swedish youths couple substance use with different possible futures (Dennermalm, 2025) and how the degrowth movement is able to sustain a steady membership base in spite of societal norms of economic growth and capitalism (Hurtado Hurtado & Glynos, 2025). This approach is, as far as I know, not yet utilised in the study of teaching and views thereof.

In this paper, I explore the logics behind why teachers idealise technocentric teaching in Swedish upper-secondary technology education. My aim is to create an understanding for how and why such seemingly unsustainable practices are upheld. My research question is:

What logics are constitutive of articulations of sustainability in technology education?

3 METHODOLOGY

3.1 Data collection

To explore this, I collected data that consisted of six interview transcripts, as well as the syllabus for the technology subject in upper secondary school (Skolverket, n.d.). The syllabus was revised in 2025, but in this paper, I only focus on the one that was active at the time of the interviews (i.e. spring/summer 2024). I conducted interviews with six upper secondary technology teachers, which were recorded and transcribed, in total 364 minutes. The interviewed teachers work at the technology programme at their respective school, teaching technology courses. The selection of participants was based on reachability and availability. To ensure some diversity of experience and opinion, teachers were chosen from 6 different schools in 6 different cities. The interviews were conducted in a semi structured style (Brinkmann & Kvale, 2018). The interview guide contained questions around sustainability in their teaching and in the technology syllabus, and the teachers' personal perspectives on sustainability. All names are fictitious. The interview transcripts and the syllabus were analysed together.

Table 1

Participant information

Teacher	City	Years in teaching	Educational background	Interview length
Anna	A	15-20	Engineer	58 min
Bella	B	10-15	Teacher	55 min
Carl	C	5-10	Engineer	1 h 15 min
Daniel	D	15-20	Engineer	1 h 09 min
Eva	E	30-35	Other	49 min
Farouk	F	10-15	Teacher	1 h 00 min

3.2 Logics of critical explanation

I use Logics of critical explanation (Glynos & Howarth, 2007), to explain how and why the teachers describe and talk about the teaching practices regarding sustainability in technology education the way they do. This approach is grounded in the understandings of articulation and discourse as introduced by Laclau and Mouffe:

We will call *articulation* any practice establishing a relation among elements such that their identity is modified as a result of the articulatory practice. The structured totality resulting from the articulatory practice, we will call *discourse*. (Laclau & Mouffe, 2001, p. 105)

The logics approach allows for an exploration of a certain practice, for example the articulated views of the teaching of a subject, by providing a “grammar or vocabulary – with which we can both explain and criticize the practices and regimes that constitute our concrete objects of analysis.” (Glynos & Howarth, 2007, p. 132). This “grammar”, consisting of social, political, and fantasmatic logics, enables an understanding of the discursive structures that makes a social practice possible, by answering the questions of what it is, how it is, and why it is, respectively (Glynos & Howarth, 2007). Together these logics are used to explain and articulate the characteristics of a practice (social logics), processes of normalisation or contestation of a practice (political logics), and underlying fantasies, that is affective reasonings, for resistance to, or characterisation of, changes in practice (fantasmatic logics) (Glynos & Howarth, 2007). Such logics are not found or deduced by the researcher in an effort to reveal some truth about the collected data but should instead be viewed as the interpretations of the analyst, which “are constructed, tested and reworked by the analyst in relation to a diverse range of empirical data” (Glynos et al., 2021, p. 70).

In this paper I view discussions and deliberations around sustainability as potential moments of dislocation, when the contingency of the social order is made visible (Glynos et al., 2025; Glynos & Howarth, 2007; Laclau & Mouffe, 2001). This may create opportunities for the teachers to either defend or rearticulate the practices of teaching the technology subject, that is, activating political and fantasmatic logics. In other words, issues of sustainability may create a difficulty to reconcile the idea of technology as unproblematic with its destructive sides. In such moments, certain logics are activated and articulated, either to cover over flaws in the practice or to challenge the current ways of doing things.

3.3 *Data analysis*

The analysis started with open reading of the data, both interview transcripts and the subject syllabus, with a focus on articulations of the character of the technology subject and the teaching of technology. Special attention was paid to references of the inclusion of sustainability in the teaching. What followed relates to the iterative process of construct-test-rework of explanatory logics as described above. In this process of constructing and articulating the logics that structured the discourses of sustainability teaching, I looked for and identified articulations of:

- (i) Social logics of technology teaching. The foundational discursive structures of technology teaching and its relation to sustainability. Drawing on both the subject syllabus and the teacher interviews.
- (ii) Political logics, showing how these social structures were politicised in moments of dislocation and how the constitution of the social logics was defended or criticized, creating conditions of possibility or vulnerability (Glynos & Howarth, 2007). From here on, the analysis drew only on the teacher interviews.
- (iii) Fantasmatic logics, explaining the grip of certain social logics. How fantasies were used as a way of covering up flaws in the social logics made visible in moments of dislocation.

4 RESULTS

4.1 *Social logics*

The results show that the discourse around teaching sustainability in technology education is constituted through three social logics of ‘technological progression’, ‘technological commodities’, and ‘technological projects’, that many times are active simultaneously and work together. These logics are constructed through a focus on developing skills necessary for the continued development of technology, often in the form of products and services. Sustainability is articulated as a part of this teaching.

In the Technology syllabus it is stated that the students should learn to develop “new technology that contributes to a more sustainable society” (Skolverket, n.d., p. 1). Further down in the document, part of the subject content is described as focusing “on the technology of the future and a sustainable society” (Skolverket, n.d., p. 2). These are two of very few places in the syllabus where sustainability is mentioned explicitly. All these statements connect sustainability with future technology, the development of new technology, or technological solutions. I view these as articulations of a logic of ‘technological progression’ – the way of solving the issues of sustainability is, in the syllabus, through continued technological development. This logic is mirrored also among the teachers:

But I'm passionate about environmental issues, and I'm passionate about technology, and believe that technology is the solution to the [sustainability] problems, at least part of the solution, to the problems we face... (Daniel)

In this quote, the teacher (Daniel) articulates the logic of ‘technological progression’ through a passion for technology, leading to the logical conclusion that technology is “the solution”. However, the additional “at least part of the solution” suggests that the logic of ‘technological progression’ being politized with regard to sustainability.

This logic is also articulated elsewhere pertaining to the sustainability of technological products:

... a project called ‘From idea to product’ and then, then we connect the products to the sustainable society, and, er, work from several perspectives or they get to work with their, their products, the products they develop. (Anna)

Here, the teacher (Anna) articulates a connection between technological products and sustainability, similar to the phrasing in the syllabus – that is, signifying a logical connection between reaching sustainability and the creation of new technology. Because of the explicit focus on projects and products, I interpret this quote as articulating logics of ‘technological commodities’ and ‘technological projects’. Even though projects are not particularly emphasized in the syllabus – a small part of the technology syllabus states that students should be “given the opportunity to work in projects” (Skolverket, n.d., p. 1) – the idea that project work is essential to technology is predominant among the teachers, as illustrated in the quote by Anna. It is perceived as a way of teaching skills necessary for ‘technological progression’. Projects are

articulated as different challenges, competitions, and development projects, and a way of combining sustainability with entrepreneurship and the development of some kind of technological product, leading to the commodification of technology:

Yes, *Blixtlåset* [added emphasis] is an innovation competition that Siemens organizes [...] the sustainability criterion is now a requirement since 3 years [...] the product or service must in itself be sustainable or contribute to sustainability (Bella)

Through working in projects, different kinds of important skills are brought into the teaching, for example entrepreneurship, which centres development projects (the logic of ‘technological projects’) and the commodification of technology (the logic of ‘technological commodities’) and innovative thinking, which leads to progressing technology (the logic of ‘technological progression’) and thus sustainability.

4.2 *Political logics*

Despite the relatively stable discourse of technological progression and commodities, described above, the social logics are destabilised when the topic of sustainability is discussed. This can be seen in the quote by Daniel above, where technology is “*at least part* of the solution [added emphasis]”. In such moments of dislocation (Glynos & Howarth, 2007), a political logic of ‘non-technological solutions’ is activated, where technology is articulated as more problematic:

... we don't just have to think about everything we can develop to continue living the way we do. I also think that a big part of sustainability is to rethink and think about how much we consume. How can we consume less? So, we also try to talk to our students about that. (Anna)

I view the above quotation as meaning that development cannot be the only way, as a critique of the predominant focus on technological progression. This logic is characterised by articulations of discussing alternative possibilities with the students, and as such the social logics are challenged. However, a second political logic of ‘innovative products’, based the development of new technology, is articulated as a way of hiding the disruption caused by the sustainability impasse:

... but we can actually steer it in a different direction, we can develop technology that helps us, that makes it easier for us [...] easier in everyday life to think sustainably and to live sustainably. (Anna)

I view the quote above as providing a condition of possibility (Glynos & Howarth, 2007), a way of sustaining the social logics by articulating them as necessary from a sustainability perspective.

4.3 *Fantasmatic logics*

To further cover up the dislocation of sustainability, two fantasmatic logics of ‘passion in teaching’ and ‘hero innovators’ are activated, providing an affective grip to the social logics. In

these fantasies, technology students are described as practically minded, and uninterested in theoretical abstractions:

They have chosen technology for a reason. It is because they want to do practical technology, solve technical problems practically and things like that. (Farouk)

In the context, I interpret the statement above as equating practical stuff with fun, and thus in the same movement equating theoretical stuff with boring. This brings joy to the students, and to the teachers themselves, while at the same time providing opportunities for the students to focus on the skills promoted by the social logics:

Because I don't believe in lecturing. I could have stood and talked about metallurgy and energy technology and chemical engineering, biotechnology [...] but if I don't have rewarding practical tasks for them to sort of try that engineering role out in some way, then I don't feel that it's valuable. (Carl)

The teachers show passion, that their teaching is focussed on practical things:

... but to stand and, and sort of babble on about sustainable development and the Brundtland report and like the climate issue too much, well, they were just, I think, weighed down by that. Instead, you have to transform it into innovation [...] develop a product or service that contributes to sustainability. (Bella)

In the above quote, the teacher (Bella) articulates this logic by suggesting that practically working with product development is natural and well received by the students. In fact, she goes even further, articulating theoretical ruminations as leading to negative emotions among the students, something that is unwanted, possibly even harmful. Thus, this teacher's solution is to focus on innovation, activating also a second fantasmatic logic of 'hero innovators'. The teachers describe engineering as the main objective of technology education, and that engineers generally work in projects developing new and innovative technology with capabilities to solve sustainability, thus articulating engineers as very important in the sustainability project. The teacher (Bella) takes pride in that the teaching is removed from abstract discussions about the Brundtland report and climate change, and at the same time posits innovation as the thing that will provide a way forward. The fantasy of 'hero innovators' is further articulated by a focus on technology as crucial for upholding modern living standards. To achieve this, and simultaneously achieve sustainability, new and innovative technologies are crucial:

We are used to a certain standard and a certain level [...] and we are quite comfortable, so to continue to develop technology that, that makes it possible, that makes it easier for us to live sustainably in everyday life. And that's where engineers play a very important role. (Anna)

5 DISCUSSION

In conclusion, I view the fantasmatic logics presented above as crucial in understanding why ideas of technological solutionism and technological progression are so predominantly articulated. These logics enable teachers to construct and rationalise ideas of technological progression and commodification as positive developments. Through this, technological progression becomes a logical choice in the teaching since it provides an infrastructure for how to contribute to the sought after preservation of modernity. The teachers connect technological progression to a beatific future scenario where people can continue living a modern life. Implicit in the idea of technological progression as connected to modernity lies the threat of something else. I understand this as contributing to the creation of a modern-unmodern dichotomy. This provides only two possible outcomes, two ways of reaching sustainability; We can either develop new technologies, uphold and progress modern living standards with green technology, or sacrifice modern life. Through this discursive movement, teaching in a way that maintains students' interest and simultaneously helps to preserve modernity becomes naturalised, and the grip of the social logics is sustained. The social logic of 'technological commodities' enables a way of distributing such sustainable technologies, and the 'hero innovators' are portrayed as people who can fill the roles put forward the social logics. These fantasmatic logics enable teachers to cover over arguments against technological solutions and engineering-inspired approaches (the political logic of 'non-technological solutions'). I argue that this leaves alternative ways of teaching sustainability unexplored and fortifies the idea of technology education as an education for the industry, rather than an education for long term sustainability.

I view this study as a way of dislocating technology education from its current hegemonic practices, creating an opportunity for reflection on the way sustainability is dealt with in the subject. However, more research is needed to find ways of breaking this grip and rearticulating technology education around sustainable values and methods. I believe bringing teacher and students perspectives into such a reimagining of the technology subject to be necessary. One way of potentially realizing such reflection would be to use the results from this study as grounds for a discussion around, and exploration of alternative teaching practices in technology education with a focus on sustainability. This could, for example, be done in the form of workshops with technology teachers, where the results from this study are discussed and used for generating ideas. A second alternative could follow a similar setup, but include both students and teachers together.

6 AI DISCLOSURE

No artificial intelligence (AI) tools were used in the preparation of this manuscript. All writing, data analysis, and interpretation were conducted entirely by the author without assistance from AI technologies.

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Contradictions and Trust Erosion: How Generative AI Mediates Pupils' Educational Experience

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Abstract

The use, or perceived use, of generative AI (GenAI) has spread throughout society, including among secondary education pupils. The availability of this technology affects education as a whole, and technology education in particular, as the subject that may have to lay the foundation for pupils' understanding of AI. There have been numerous studies on how teachers and pupils perceive GenAI, as well as research into its use. However, there has been little study of how the changes in education due to GenAI impacted pupils' overall school experience. The present paper reports on the open-ended answers ($n = 807$) from a survey completed by Swedish upper secondary pupils in May 2024 ($n = 1266$). Through an inductive qualitative content analysis, main and subcategories were identified. Cultural-Historical Activity Theory (CHAT) is used as a lens to conceptualise how GenAI mediates education. The pupils' responses reveal that GenAI mediates pupils' activity systems both through direct use and through institutional reactions to its presence. My analysis identifies several contradictions as pupils and teachers navigate the existence of GenAI as an available tool. These contradictions have eroded several dimensions of trust. The strongest of these is the teachers' trust in pupils, but also affected are pupils' trust in their peers, pupils' trust in the educational system's ability to provide fair education and grading, to compensate for individual difficulties, and to provide an education that adequately prepares them for the future. Implications include the need for schools to address the consequences of their responses to GenAI and the importance for technology education to provide structured education and support for the use of GenAI.

Key Words: Generative AI, Cultural-Historical Activity Theory, Upper Secondary Education, Trust

1 INTRODUCTION

Most of us notice a given form of trust most easily after its sudden demise or severe injury. We inhabit a climate of trust as we inhabit an atmosphere and notice it as we notice air, only when it becomes scarce or polluted. (Baier, 1986, p. 234)

Trust, as Baier notes, is something intangible that we often take for granted. However, trust holds our society together. Trust is imperative for social cohesion and fundamental to the functioning of society (Van Maele et al., 2014). In education, trust is a crucial factor in learning as it affects pupils' achievements (Bormann et al., 2021; Schneider et al., 2014). Trust is also an essential factor in improving cooperation between pupils and between pupils and teachers, which helps the system function (Bormann et al., 2021), and reduces teacher burn-out (Van Maele & Van Houtte, 2015). But trust in education is not only crucial for education itself; the trust built in education lays the foundation for the continued trust that underpins our society (Bormann et al., 2021; Niedlich et al., 2021). It is therefore concerning that teachers report losing trust in students due to Generative AI (GenAI) (Kloker et al., 2024).

The Swedish context for this study is important. Sweden has long had an image as a forerunner in digitalisation, but in recent years a political backlash against digitalisation in education has emerged. Global organisations have promptly issued guidance on how to handle generative AI in education (UNESCO, 2023), frameworks for the competencies needed by teachers (Cukurova et al., 2024) and pupils (Miao et al., 2024), and for teaching AI literacy (European Commission & OECD, 2025). In Sweden, a commission tasked with investigating and proposing courses of action for AI was explicitly barred from making any proposals relating to education (Statens offentliga utredningar, 2025). A recent report proposing a new curriculum for education mentioned AI mostly in passing and, overall, removed much of the digital competency education (Regeringskansliet, 2025). The Swedish National Agency for Education responded by advising against using home exams and recommending that schools devise a plan to address GenAI, but, without political direction, there are limits to the support the agency can provide.

This paper draws on activity theory and trust to examine tensions arising in education due to GenAI and suggests that technology education is key for addressing these tensions.

2 LITERATURE REVIEW

2.1 *Trust in education*

Trust is a relational aspect between individuals, often described as the willingness on the part of one or several trustors to be vulnerable to a trustee that can not be completely controlled or predicted (Bormann et al., 2021). In organisations, including educational institutions, trust flows both upward and downward within the hierarchy (Joubert & Strever, 2025). However, this is an asymmetrical bidirectionality – pupils are more vulnerable than teachers in losing the trust of the other party. A loss of a teacher's trust can harm a pupil's achievements and motivation (Bormann et al., 2021). Trust is increasingly recognised as a significant factor in teaching, as trust increases pupil participation and achievement, and an experience of a lack of trust decreases the likelihood of pupil engagement in learning processes (Van Maele & Van Houtte, 2014).

In addition to trust affecting relationships on the individual level, there is the notion of institutional trust, the individual's trust in institutions such as education or government. The foundation for institutional trust, which is important for a functioning society, is built in education, with pupils learning to trust the educational institutions (Niedlich et al., 2021).

Institutional trust relies on, among other things, the institution’s transparency, fairness and effectiveness (Niedlich et al., 2021). As GenAI has led to less trust for pupils among teachers (Kloker et al., 2024), some argue that we need to move away from distrusting pupils to “a pedagogy of distrust” (Joubert & Strever, 2025, p. 73) that fosters positive critical thinking.

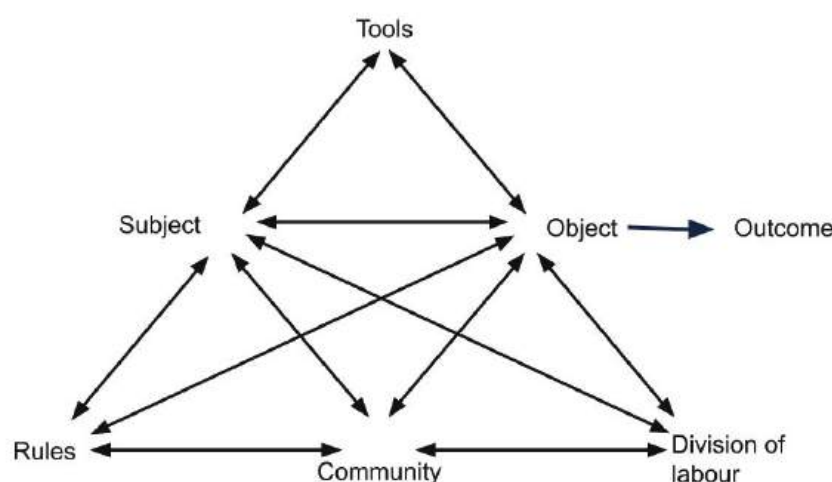
2.2 *Cultural-historical activity theory*

In this paper, I draw on cultural-historical activity theory (CHAT) to map how GenAI has mediated pupils’ educational experiences and to identify contradictions that may explain tensions observed in schools as a result of GenAI. CHAT builds on Vygotsky’s theories, which were expanded by Leont’ev and later by Engeström (Engeström & Sannino, 2021). A central concept in CHAT, stemming from Vygotsky, is mediation: artefacts (cognitive or physical) can affect and enable more complex mental operations (Cong-Lem, 2022). According to Engeström, an activity system is a complex interweaving of a subject, the object of an activity, the mediator, and the context consisting of rules, community and division of labour, as shown in Figure 1 (Engeström & Sannino, 2021).

Another central concept in CHAT is contradictions that appear in or between activity systems, and which can be the driving force behind change and development of activity systems (Engeström & Sannino, 2021). Contradictions can be divided into four levels: within nodes, between nodes, between a new version of the activity system and the old, and between activity systems (Sannino & Engeström, 2018).

Figure 1

Activity system diagram, from Engeström & Sannino (2021)



3 METHODOLOGY

3.1 *Data and participants*

This paper is part of a larger study on upper secondary pupils' attitudes and use of GenAI for their schoolwork, which builds on interviews (n=13) and a survey (n=1266) conducted with Swedish upper secondary school pupils aged 15-20 in spring 2024. Two earlier papers from this study report on the interviews (in review) and the quantitative analysis of the survey responses (Hugerth & Hugerth, 2026), respectively. This paper presents an analysis of responses to the optional open-ended question, 'How has AI affected you and your studies?' in the survey, from 807 of the 1266 respondents. We had explained that for this set of questions, the type of AI that we were interested in was GenAI, for which the pupils were given a list of 20 examples available at the time, including ChatGPT, Microsoft Copilot, Snapchat MyAI, Claude, Midjourney.

3.2 *Analysis*

The responses, after ensuring no personal information was contained within, were analysed using inductive qualitative content analysis with the QCAmap tool (*Qcamap.Org*, n.d.). The unit of analysis was set to a coherent thought, meaning a sentence can contain several units if several thoughts are strung together, or a unit can contain several sentences if a respondent elaborates on an idea. Second, the analysis had to follow the rules for the coding frame of unidimensionality, mutual exclusiveness, exhaustiveness, and saturation as explained by Schreier (2012). Categories were revised, redefined and joined at several points during the initial coding process, and the coding restarted. Finally, the main categories were derived from the full set. QCA made visible the distribution of sentiments, then Cultural-Historical Activity Theory (CHAT) was used to explore the possible underlying contradictions that manifest in the pupils' responses.

3.3 *Ethical considerations*

This study was approved by the Swedish Ethical Review Board on December 5th 2023 (dnr: 2023-06629-01) and follows the guidelines of the Swedish Research Council (Vetenskapsrådet, 2024). All respondents are anonymous, and all data are stored on the research data storage provided by Stockholm University.

No GenAI has been used in the writing of this paper, except as a sounding board while developing the initial idea for the paper.

4 RESULTS

Through inductive coding of pupils' responses, categories and subcategories were identified. On the top level, these can be divided into positive (42%), neutral/unspecific (35%) or negative changes (23%). The relative frequencies of these categories and subcategories are shown in Table 1, along with brief descriptions. The majority of responses are positive or neutral, but in this paper the negative responses reveal more clearly the tensions caused by GenAI, and are the main focus.

Table 1*Relative distributions of categories from QCA*

Positive changes	Process support (31%)	GenAI as study support, for inspiration, information, and perspectives.
	Positive results (3%)	Positive results in learning, grades and stress levels.
	Unspecific positive (7%)	Uninformative expressions that convey little beyond a positive sentiment (e.g. “good”)
Neutral changes	No or neutral change (27%)	No changes, or changes without positive or negative signalling.
	Faster Schoolwork (3%)	Comments without positive or negative sentiment, or contradictory sentiments (easier to cheat, easier to do schoolwork without learning)
	Unspecific neutral (4%)	Uninformative statements that do not convey a positive or negative sentiment.
Negative changes	Negative for process (16%)	Worse conditions for doing schoolwork. Less trust from teachers.
	Negative results (4%)	Worse learning outcomes, grades, and increased stress levels.
	Negative, system level (3%)	Negative effects due to others’ use of GenAI, which may affect non-users’ grades. In addition, a decrease in trust in the school system and a loss of its relevance.
	Unspecific negative (<1%)	Uninformative expressions that convey little beyond a negative sentiment (e.g. “bad”)

4.1 CHAT-analysis

Two concepts in CHAT are of special interest for this analysis. First, the central idea of mediation, and second, the concept of contradiction in and between nodes and systems. Pupils’ responses show that GenAI mediates their education in several ways, whether they use GenAI or not, as evidenced by this pupil’s response: “I don’t use AI, but I have been affected by it. For example, you’re not allowed to write any texts at home. You also get less information about certain written assignments as teachers don’t want to reveal too much since pupils can then use AI”. Here, the pupil reveals that GenAI’s existence as a tool, even if not used, mediates the rules under which pupils work. Pupils receiving what they perceive as worse information and assessment conditions indicates a contradiction in the system between the tool and rule nodes.

Primary contradictions are evident in the rules node: First, the differences in responses indicate that schools have responded very differently to GenAI, with some removing home exams while others have not. In schools where assessment practices haven't changed, a contradiction is indicated in the misalignment between the rules for assessment and the expectations of fair grading: "Other pupils use AI for their assignments, while you yourself work harder in the usual way, but they get the same or better grades". On the other hand, the changes of rules for assessment create another contradiction when those rules contradict the requirements on schools for varied evaluations, as well as for ensuring each pupil's needs are met, for example this pupil with Autism spectrum disorder: "I can for example not sit in a smaller room with fewer pupils or take breaks, because there is no trust in the pupils. This I think hits hardest against pupils with extra needs."

Many of the negative effects reported by pupils concern reduced teacher trust in pupils and its consequences. "Because of AI like chatgpt all teachers become paranoid", comments one pupil. "You get accused of AI when the teacher judges that you use words that you shouldn't know, instead of supporting that the pupil is interested," writes another. Clearly, GenAI has eroded interpersonal trust between pupils and teachers, indicating secondary contradictions between the subject-community nodes, both between pupils and teachers and between peers.

The contradictions in the rules node can themselves be understood as consequences of GenAI. With the availability of GenAI as a tool, a contradiction appears between tool and division of labour, as it becomes possible to let GenAI do all the work and still get the same outcome (when focusing on grade as the outcome, which many pupils do in their comments) as someone who does the work themselves, as illustrated by the quote earlier, and by: "Chatgpt does all my assignments for me and carries my grade". Another contradiction between rules and tools can be seen as an unforeseen consequence of the rule change in this response: "It's really damn annoying that you have to write everything on DigiExam, so I've started cheating more by writing the text beforehand and then bringing a note and copying it".

Education can be seen as interacting activity systems with partly shared objects. In previous research (Hugerth & Hugerth, 2026), I have shown that pupils have been left largely on their own in handling GenAI. Pupils' use of GenAI comes from outside the educational system, but is used for educational purposes, and can be seen as an activity system that partly shares objects with schools: both pupils and schools want education to adequately prepare pupils for their future, and they want fair grades. While education is more than these, they are what pupils mainly comment, and therefore these will serve as an example. There is a misalignment between the pupils' and the school's goals: schools prioritise control of assessment, whereas pupils often prioritise their own grades and acquiring knowledge they deem aligned with their future needs. The quote from one pupil below illustrates the contradiction between the pupil's activity system and their school's activity system:

"Since we're no longer allowed to work on texts at home, I can't continue developing my writing ability with access to the internet, where I can look up words I can't think of and get more time to fine-tune. Instead I have to write in locked mode and under time pressure, which brings a lot of stress and worry. It also feels like it becomes less

like how we'll write when we enter working life. Would a boss deny you access to the internet when you write a report? It also feels like we're falling behind when the school so strongly prohibits the use of AI. Because it's a tool that looks like it will become really big, and then it should be prioritised that we learn to use it in a good way."

The quote also illustrates the previously mentioned contradiction between tools and rules, as well as the contradiction that pupils expect to be taught the skills they will need to meet future employment demands, and school has not yet adapted to technological advancements and, in the pupils' eyes, fails to meet its responsibilities. The positive responses among the students may also be indicative of similar contradictions: The students' positive experiences may not align with teachers' didactic designs, and may not be conducive to the object that the teacher has planned for (learning), and their positive experience may be such due to existing contradictions that create stress and where students perceive a lack of support.

5 DISCUSSION

As noted by Baier in the epigraph to the introduction, trust is often overlooked until the atmosphere of trust is polluted. In the analysis above, I have described several contradictions that have appeared, or at least been revealed, by the existence of GenAI in education. What is striking in the analysis is that no action seems to escape erosion of trust. If the school maintains its old assessment practices, including home assignments, this will erode trust in its ability to ensure fair grading. If it does change practices, it erodes trust in its ability to ensure fair assessments aligned with future needs. Similarly, pupils report feeling eroded trust in their teachers, whether or not they use GenAI.

As noted earlier, trust flows both upwards and downwards in a hierarchical structure (Joubert & Strever, 2025), and while the most common comment by pupils relates to eroding trust from teachers, there is also evidence of a lessening trust upwards, towards the teachers' abilities to provide adequate education and fair grading, with GenAI as a factor, as well as sideways as trust in one's peers is affected. The pupils' distrust seems not primarily to be an interpersonal trust issue, but rather an institutional trust-erosion issue, as what they criticise is a systemic failure to ensure adequate education to prepare them for future studies and work, and fair grading to ensure pupils compete fairly for further education positions. This institutional trust erosion is concerning, considering the importance of trust not only for pupil engagement in education (Van Maele & Van Houtte, 2014) and the effects on pupil achievement (Bormann et al., 2021), but also because of its role in our broader society (Niedlich et al., 2021).

What does this entail for education? While the negative responses are not a majority, there is still a sense of all courses leading to trust erosion. Trust needs to be, and can be, rebuilt through transparency and good teaching. The foundations of institutional trust – transparency, fairness and effectiveness (Niedlich, et al., 2021) – needs to be rebuilt. In reestablishing trust in education, technology education may have to play a key role. While technology as a subject does not bear sole responsibility for guiding pupils on GenAI, it plays a key role. To reestablish institutional trust, schools need to prioritise transparency and guidance about GenAI and its use, which

requires an understanding of GenAI. By providing education on AI, including GenAI, technology education can be the foundation on which schools can build. This was one of the findings from our AI literacy development project (Hugerth & Elderstig, 2024). Technology, like other subjects, also needs to rebuild trust in its ability to provide fair assessment and grading that do not disadvantage people, which may require us to work towards aligning pupils' and schools' objects and focusing less on the products that may invite GenAI use and more on the processes that lead to that product. Finally, Joubert & Strever's "pedagogy of distrust" (2025), and the idea of moving the distrust from the interpersonal level to promote a common distrust directed at technology and information streams can be fruitful in repairing trust in education – but that, too, requires basic technology education about GenAI.

5.1 *Limitations*

This paper is based on a snapshot in time and a limited number of responses to an optional question. Due to space limitations, this paper focuses on trust rather than exploring other contradictions that may be indicated in the data. It is possible that the trust erosion seen in this paper is not representative, or that it is of a transitory nature. Further studies on this subject, especially those that track changes in trust over time, are needed to determine whether the trust erosion caused by GenAI is temporary or permanent and to assess the consequences for education and society.

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From Quantitative Findings to Qualitative Insights: Understanding Educational Logics in Makerspaces within an Extended 4C Framework

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Abstract

Building on a quantitative survey of 147 makerspaces in Germany that examined educational goals and methodological practices within an extended 4C skills framework, this paper presents a qualitative follow-up study. The preceding study revealed a strong emphasis on action-oriented goals such as technical skills and creativity, a comparatively lower relevance of computational thinking, and a predominant use of open formats such as open making and project-based learning. While these findings describe central patterns across makerspaces, they leave open questions regarding the educational rationales and interpretations underlying these priorities. The aim of this study is to deepen and contextualize the quantitative findings by reconstructing educational logics in makerspaces through guided expert interviews with Maker educators. The qualitative study follows an explanatory mixed-methods design and examines how skills within the extended 4C framework are conceptually understood, pedagogically justified, and enacted in practice. A central contribution of this paper is the development and theoretical grounding of an interview guide derived from the extended 4C framework and systematically linked to the results of the preceding quantitative study. The paper presents the methodological design, the structure and validation of the interview guide, and reflections from its pretesting. By linking quantitative patterns with qualitative insights, the study contributes to a more differentiated understanding of competence development and educational practices in makerspaces within technology education.

Key Words: Maker Education, Maker Space, 21st Century Skills, Technology Education

1 INTRODUCTION

Makerspaces are open, predominantly informal workshop and learning environments in which making takes place as a creative, action-oriented practice at the intersection of technology, craftsmanship, and digital fabrication technologies. They function as physical and social spaces

that enable collaborative experimentation, problem-solving, and the iterative development of artefacts (Blikstein, 2013; Halverson & Sheridan, 2014; Schön et al., 2019). In educational contexts, makerspaces are increasingly discussed as learning environments of technology education, even though conceptual understandings, objectives, and didactic classifications remain inconsistent (Rothe et al., 2025; Wiemer & Rothe, 2024).

Makerspaces are increasingly framed as educational institutions and associated with a form of Maker Education that remains loosely defined. Their educational value is frequently postulated (Rothe et al., 2025; Wiemer & Rothe, 2024) but often either attributed *ex post* or examined within individual intervention studies. Empirical studies that systematically capture educational goals, content, and methodological practices from the perspective of the actors themselves are still rare. One exception is Iwata, who explicitly links makerspaces to 21st century skills (Iwata et al., 2025). Otherwise, research has focused primarily on the investigation of practical implementation (e.g., Westerhof et al., 2023; Núñez-Solís et al., 2023; Pijls et al., 2023) or has taken a more conceptual and descriptive approach (e.g., Halverson & Sheridan, 2014; Martin, 2015; Schön & Ebner, 2020).

At the same time, makerspaces are predominantly informal learning environments of technology education that are generally not bound to curricular requirements and whose educational offerings are often organized in open, project-based, and voluntary formats (Blikstein, 2013). This creates fundamental uncertainty about how educational content, goals, and skills are interpreted in practice.

Against this background, the question of the implicit educational logics of makerspaces comes into focus. This refers to the actors' self-understanding regarding educational goals, conceptions of skills, and methodological approaches, as well as the assumptions guiding their pedagogical practice without necessarily being explicitly articulated.

To obtain an initial systematic overview, actors in makerspaces were surveyed quantitatively in a preceding study (Wiemer & Degen, 2025). An extended 4C framework served as the analytical point of departure, as makerspaces are frequently linked in the literature to so-called 21st century skills (Iwata et al., 2020, 2025) or, more broadly, to aspects such as general technological understanding or general problem-solving ability (Ioannou & Gravel, 2024; Rayna & Striukova, 2021).

Building on this, the perspective on actors in makerspaces is deepened through a qualitative continuation of the existing research. Building on these findings, the qualitative analysis examines how actors conceptually frame and pedagogically justify the identified skill priorities and methodological patterns. The focus lies on deriving central guiding questions from the extended 4C framework. Specifically, the study investigates:

- (i) How are the components of the extended 4C framework interpreted by the actors?
- (ii) How are the identified methods enacted in practice?
- (iii) Why are certain skills and methods prioritized over others?

The present paper describes the first step toward addressing this research question by presenting the theory-driven development of an interview guideline aimed at reconstructing implicit educational logics in makerspaces, and by reflecting on its functionality and initial analytical potential based on a pretest interview. The central contribution of the paper is primarily methodological: it demonstrates how quantitative findings can be systematically transferred into a qualitative data collection instrument.

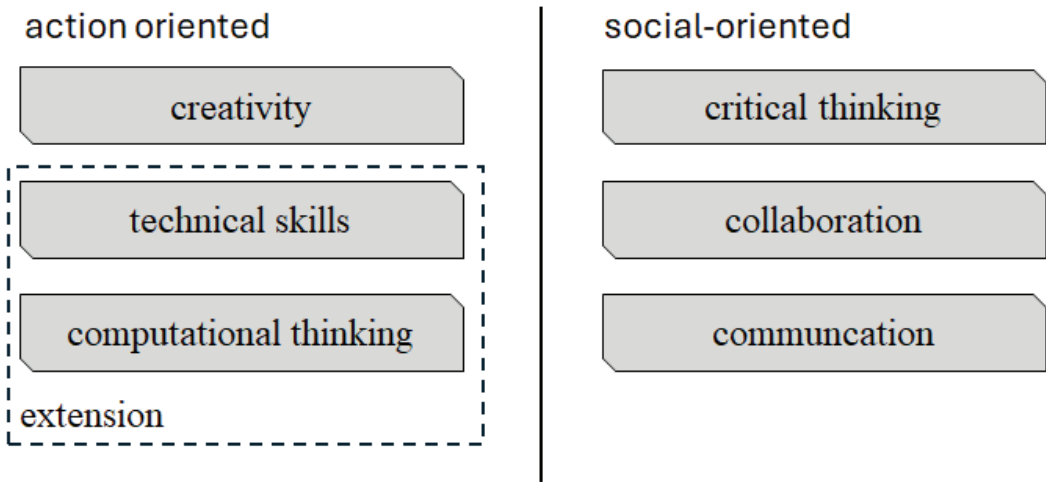
2 THE EXTENDED 4C AND THE QUANTITATIVE PRECEDING STUDY

2.1 The Extended 4c in Detail

An extended 4C framework serves as the analytical frame, encompassing creativity, critical thinking, collaboration, and communication, and extended by technical skills and computational thinking (Wiemer & Degen, 2025). The 4C form part of the broader concept of 21st century skills, which the OECD conceptualizes as skills for future participation (OECD, 2018, 2020) and which are often associated with makerspaces (Iwata et al., 2025). The extension results from additional skills that have also been linked to makerspaces in various studies, such as technical skills or computational thinking (e.g., Ioannou & Gravel, 2024; Rayna & Striukova, 2021).

Figure 1

The Extended 4C Framework in Relation to the Preceding Study



In the analysis, the different skills are divided into two main categories: action-oriented skills and social-oriented skills (Gessler & Sebe-Opfermann, 2022). Action-oriented skills include creativity, technical skills, and computational thinking. These skills refer to the ability to act independently, solve problems, and develop new ideas. Social-oriented skills include collaboration, communication, and critical thinking and refer to the ability to work effectively with others, communicate, and collaboratively develop solutions. This distinction makes it possible to examine prioritization patterns within makerspaces and to discuss them with the actors (Wiemer & Degen, 2025).

2.2 *Key findings*

The quantitative preceding study (Wiemer & Degen, 2025) examines educational goals and methodological practices in makerspaces in Germany, with a particular focus on institutions offering programs for children and adolescents. Using a standardized online questionnaire, data were collected from 147 makerspaces, corresponding to approximately 29% of the estimated population of open workshops in Germany. The study was designed as an exploratory investigation.

The results show that makerspaces predominantly perceive themselves as educational spaces, regardless of their formal institutional affiliation. Institutions with targeted programs for children and adolescents rated educational goals higher than those without such programs, particularly regarding technical skills. Across the entire sample, action-oriented skills were rated as significantly more important than social-oriented skills—both in terms of self-assessed goals and perceived skill promotion within educational programs. Among the individual skills, technical skills and creativity emerged as the most strongly emphasized goals and, at the same time, as those most intensively promoted in practice. In contrast, computational thinking received comparatively lower ratings. This pattern appeared consistently in both goal assessment and the evaluation of actual skill promotion.

Regarding methodological approaches, the study identified a clear preference for open and weakly structured formats. Open making was the most frequently used method, followed by project-based learning, peer learning, and experimental formats. In addition to method frequency, the study also examined perceived associations between methods and skills. Open making was most strongly associated with creativity, while project-based learning was linked to collaboration and communication.

3 *METHODOLOGY AND RESEARCH DESIGN*

3.1 *Research Design*

Building on the described quantitative study and the research questions outlined in Chapter 1, qualitative interviews are used to address the research questions. Overall, the research on skills and methods in makerspaces follows a mixed-methods approach using a sequential explanatory design. In this design, findings from the quantitative study are deepened through interviews with selected respondents. (Döring, 2023). In the study, $n = 6$ experts from makerspaces are interviewed, as is common in such qualitative research designs (Helfferich, 2009). Typical factors that would necessitate a larger number of participants, such as biographical differences (Helfferich, 2009), do not apply in the case of focused expert interviews. In addition, as presented in this article, a pre-study with $n = 1$ is conducted, which examines not only substantive statements but also the suitability of the interview guide. Case selection follows a pragmatic approach, drawing on individuals who participated in the questionnaire study and agreed to take part in the interviews.

3.2 *Methodology for the interview*

The substantive development of the interviews is methodologically situated within the framework of the focused interview, whose point of departure is specific experiences, encounters, and situations (Reinders, 2011), or a “focus on a particular object” (Helfferich, 2009). At the same time, the interviews are expert interviews, which requires that certain additional aspects be considered in their design and implementation. The interviewees are not addressed as private individuals, but on the basis of their specific role-based and experiential knowledge. They possess action-guiding knowledge of makerspaces, are familiar with methodological decisions and organizational conditions, and are therefore understood as experts in this field (Helfferich, 2009).

The focused expert interview makes it possible to steer the conversation toward the thematic fields identified in the quantitative part, while simultaneously allowing space for justificatory, explanatory, and contextualizing statements by the interviewees, and for structuring the conceptual interpretations, decision-making logics, and pedagogical rationalities that guide the actors’ practices.

In contrast to open or narrative interview formats, a higher degree of structuring is appropriate in expert interviews (Meuser & Nagel, 2005). This accounts for the expectations of the interviewees, who typically understand the interview as a fact-oriented professional discussion. Accordingly, a guideline-based approach is adopted that systematically covers the central thematic areas. Attention is also paid to the design of the interview situation. Expert interviews must always be understood as communicative interaction situations in which roles, expectations, and potential asymmetries between interviewers and interviewees may arise. Against this background, the interviews are designed to align with the professional modes of communication of the interviewees and to make the clear goal orientation of the conversation apparent (Helfferich, 2009).

3.3 *Layout and structure of the interview guide*

Following Reinders (2011), the interview guide is structured into four functional phases: opening phase, warm-up phase, main phase, and closing phase. This structure serves both to guide the conversation and to ensure the comparability of the interviews.

The opening phase aims to establish a trusting interview situation and includes the presentation of the research project, explanations of the procedure, and organizational information. It also helps to reduce uncertainties and potential narrative inhibitions (Reinders, 2011). In the warm-up phase, the thematic entry is prepared. Questions about the interviewees’ activities, roles, and personal access to the makerspace activate experience-based knowledge and facilitate the transition to the substantive discussion. In the main phase the central thematic fields of interest are addressed. The interview guide specifies thematic focal points while allowing flexibility in the order and depth of questions, so that individual emphases of the interviewees can remain possible. The closing phase provides space for additional remarks and reflections (Reinders, 2011).

3.4 *Methodology for the analysis*

The interviews are analyzed using a comparative, theme-centered analysis of expert interviews following Meuser and Nagel (2005). The analysis does not aim to develop new theories inductively. Instead, it seeks to reconstruct action-guiding interpretative and justificatory patterns within the extended 4C framework that shape pedagogical practice in makerspaces. The qualitative analysis is designed as an explanatory step within the mixed-methods design and serves to contextualize and interpret the results of the preceding quantitative study (cf. Meuser & Nagel, 2005; Bogner, Littig, & Menz, 2014; Döring & Bortz, 2023).

After transcription and anonymization, the transcripts are divided into meaningful text segments and assigned to thematic fields. These thematic fields are primarily oriented toward the structure of the interview guide and the theoretical framework of the study, particularly the extended 4C framework. The purpose of this step is to organize the material in a way that enables a systematic comparison of expert statements. Within the thematic fields, relevant statements are paraphrased and condensed to their core meanings. While the substantive meaning of the statements is preserved, they are linguistically and conceptually abstracted. This step serves to reduce the volume of material and to extract the aspects central to the research interest, without losing the connection to the original material.

The condensed statements are then compared across cases within each thematic field. The aim is to address the research questions outlined in Chapter 1 and to identify similarities, differences, and recurring patterns of argumentation. The analysis therefore focuses on (a) the conceptual understandings of the individual skill dimensions, (b) the described methods, and (c) the justifications for prioritizing certain skills or methods. Through this systematic comparison, typical interpretative and justificatory patterns are reconstructed.

The cross-case comparison of the condensed statements within the thematic fields is planned as the next analytical step but is not yet implemented in the present paper. As this article focuses on the development of the interview guide and its testing in a pretest, the analysis at this stage primarily serves to assess the viability of the analytical procedure.

4 DEVELOPMENT OF THE INTERVIEW GUIDE

After an opening phase addressing organizational matters, the interview guide begins, in the warm-up phase, with a thematic block aimed at contextualization. This includes questions about the makerspace's self-understanding as an educational provider, target groups, and available resources. These aspects make it possible to situate statements on skills and methods within broader organizational and pedagogical contexts.

Figure 2*Introduction and description phase*

No.	Topic	Question
1	Welcome and introduction	Brief greeting
2		Introduction of the interviewer and the project
3		Explanation of the procedure
4		Information about participants' rights, data protection, and implications of participation
5		How long have you been active in this makerspace?
6		What is your role in the makerspace?
7		How did you come to work in the makerspace?
8		What fascinates or motivates you about makerspaces?
9	Description of the "own" makerspace	How would you describe your makerspace in three sentences?
10		How would you say your makerspace differs from others?
11		Do you understand your makerspace as an educational institution?
12		What do you base this assessment on?
13		Which target groups do you primarily and secondarily address?
14		Do you support girls through additional programs in your makerspace?
15		Which programs, workshops, or projects do you offer and implement in your makerspace?
16		How are your spatial facilities structured?
17		Which tools and machines are part of your core equipment?

In the subsequent main section, the substantive design of the interview guide is directly derived from the results of the preceding quantitative study as well as from the extended 4C framework. For each of the six skill dimensions of the extended 4C framework (creativity, critical thinking, collaboration, communication, technical skills, and computational thinking), a uniform three-step questioning principle is applied. In a first step, the interviewees' conceptual understanding is addressed. Open introductory questions aim to capture individual definitions and interpretations of the respective skill. Such questions are narratively stimulating and correspond to the practice recommended by Helfferich (2009) of opening thematic blocks with open, narrative-generating questions. In a second step, practical implementation is addressed. The interviewees are asked whether and how the respective skill is fostered in the makerspace and are invited to provide concrete examples from practice. This establishes a link between abstract conceptions of skills and concrete pedagogical action. In a third step, a reflexive deepening takes place, for example through questions about feedback, observations, or criteria by which the promotion of the respective skill is perceived. This step makes it possible to reconstruct implicit evaluative standards and pedagogical assumptions.

Figure 3*Questions regarding skills and methods*

No.	Topic	Question
18	Skills and methods	How would you define the term makerspace?
19		Which skills are intended to be fostered in your makerspace?
20		What do you understand by the term “making”?
21		What role does digital making play for you?
22		What role does analog making play for you?
23		Creativity a) What does creativity mean to you? b) Do you believe that creativity is fostered in your makerspace? c) What do you base this on, and do you have examples? d) How have you received feedback on this?
24		Critical thinking a) What does critical thinking mean to you? b) Do you believe that critical thinking is fostered in your makerspace? c) What do you base this on, and do you have examples? d) How have you received feedback on this?
25		Collaboration a) What do you understand by collaboration in the makerspace? b) Do you believe that collaboration is fostered in your makerspace? c) What do you base this on, and do you have examples? d) How have you received feedback on this?
26		Communication a) What role does communication play in your makerspace? b) Do you believe that communication is fostered in your makerspace? c) What do you base this on, and do you have examples? d) How have you received feedback on this?
27		Computational thinking a) What does “computational thinking” mean to you? b) Do you believe that computational thinking is fostered in your makerspace? c) What do you base this on, and do you have examples? d) How have you received feedback on this?
28		Technical skills a) What do you understand by technical skills? b) Do you believe that technical skills are fostered in your makerspace? c) What do you base this on, and do you have examples? d) How have you received feedback on this?
29		Which of the six skills (creativity, critical thinking, collaboration, communication, computational thinking, technical skills) do you consider most crucial for your makerspace?
30		Which of these are fostered the most in your makerspace?
31		Which of these skills would you personally like to foster more strongly?
32		Would you like to add a skill?

This three-step logic is applied to all skill dimensions and ensures both substantive comparability and openness to differing emphases. In line with quality requirements for qualitative interview guides, the guide relies on clearly structured, thematically clustered questions, as recommended for this type of interview (Helfferich, 2009).

The interview concludes with a closing phase that provides the opportunity to address additional aspects and to clarify any misunderstandings.

Figure 4*Closing phase*

No.	Topic	Question
33	Closing phase	What misconceptions about makerspaces do you frequently encounter?
34		What personally motivates you to be part of this makerspace?
35		Which aspects would you like to add?
36		Clarification of open questions
37		Thank the interviewee
38		Farewell

4.1 *Generative AI disclosure*

The authors used ChatGPT (OpenAI) exclusively to support the translation of the manuscript from German into English and for paraphrasing interview statements. No linguistic or stylistic editing of the manuscript was performed using AI tools. All AI-supported suggestions were critically reviewed, content-checked, and revised where necessary by the authors, ensuring that responsibility for interpretation, analysis, and presentation of the data remained entirely with the authors.

5 PRETEST AND METHODOLOGICAL REFLECTIONS

5.1 *Interview results regarding the methodology*

The interview conducted within the scope of this publication serves as a pretest to examine the applicability and methodological robustness of the developed interview guide as well as the intended analytical procedure. The aim is not to generate generalizable findings but to assess whether the theory-driven guide is suitable for reconstructing implicit educational logics in makerspaces and enabling a subsequent comparative, theme-centered analysis.

The pretest interview shows that the central thematic blocks of the guide could be addressed during the interview process. All dimensions of the extended 4C framework, except computational thinking, as well as questions concerning methodological practices, self-understanding as an educational provider, and prioritization logics, were taken up by the interview partner without the need for extensive follow-up questions or reformulations. This indicates that the questions are clearly formulated, practice-oriented, and aligned with the role-based and experiential knowledge of the interviewee. At the same time, the structure of the guide allowed sufficient openness for individual remarks.

From an analytical perspective, the collected material also proved suitable for the planned stepwise procedure. The segmentation of the transcript into meaningful text segments could be carried out consistently, and these segments could be assigned to the thematic fields derived from the interview guide and the theoretical framework. No relevant overlaps or ambiguities emerged that would have required an adjustment of the structure.

As the pretest is based on a single interview, the cross-case comparison envisaged in the research design is not yet implemented in this paper. Instead, the focus lies on examining the analytical coherence and feasibility of the procedure. Overall, the pretest confirms the methodological suitability of the interview guide and the planned comparative, theme-centered analytical procedure for subsequent expansion to the remaining planned interviews.

5.2 *Interview results regarding the content*

From the interviewee's perspective, the basic understanding of the makerspace is shaped by the idea of an open space of possibilities in which collective action, experimentation, and self-directed learning take center stage. The social character of the space is described as central, while

technical artefacts and digital tools are primarily understood as means for realizing one's own ideas. The makerspace is thus conceived less as a formally structured learning environment and more as a practice-oriented, collectively used space for action.

Regarding the skill dimensions included in the extended 4C framework, it becomes apparent that several of these concepts are associated with clear meaning structures from the interviewee's perspective. Creativity is explicitly addressed and described as the ability to question established routines and develop alternative solutions. Technical skills are also explicitly named and understood as a central prerequisite for autonomous work in the makerspace. These include the handling of tools and machines as well as basic knowledge in construction, fabrication, and software use. Social-oriented skills such as collaboration and communication are not formulated as explicit educational goals but are described as self-evident components of collaborative work.

In contrast, computational thinking occupies a special position in the interview. The term is initially unfamiliar to the interviewee and requires explanation during the conversation. In the description of practice, there are also no explicit references to informatics-related work in a narrower sense, such as formal models, data structures, or algorithmic abstraction. Against this background, computational thinking can be regarded as the only skill, in terms of the competence concept applied here, that cannot be understood as an explicitly intended or systematically fostered skill in the examined makerspace.

Overall, the pretest interview suggests, on an initial level, that from the actors' perspective, meaningful interpretations can be assigned to most of the skill dimensions included in the extended 4C framework, and that these are predominantly articulated in a practice-oriented, implicit manner without theoretical framing.

6 DISCUSSION AND OUTLOOK

The contribution does not yet aim to draw conclusions about educational logics in makerspaces. Rather, it outlines how the authors, based on the quantitative study they conducted and building on its findings, now undertake a qualitative deepening, explicitly describing and reflecting on the methodological development required for this transition. The focus therefore lies on the theory-driven development of a guideline-based expert interview derived from the extended 4C framework and the empirical patterns identified in the survey. The pretest results indicate that the structure of the guide is robust and that theme-centered segmentation and the assignment of statements to the intended analytical fields were consistently possible.

The next step involves the planned rollout with additional expert interviews. Only on this basis can the cross-case comparison envisaged in the research design be implemented in the sense of a comparative, theme-centered analysis, to systematically identify recurring interpretative and justificatory patterns and to contextually explain the quantitative findings. In this process, it will also be necessary to examine whether certain concepts—particularly computational thinking—remain implicit, are reinterpreted, or are in fact marginal in practice, and what implications this has for the interpretative classification of makerspaces as environments of technology education.

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Integrating Technical Expertise and Inclusive Pedagogy: A Conceptual Model for Vocational Technology Teacher Education in China

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Abstract

Vocational technology teachers teach technology-related subjects in vocational and technical institutions. Preparing “dual-qualified” teachers, those competent in both technical expertise and pedagogical practice, is central to current reforms in vocational and technical education in China. “Dual-qualified” (双师型) teachers possess both industry-based technical credentials and formal teaching qualifications. This educational approach aims to bridge the gap between industry practice and classroom teaching by integrating technical knowledge with effective pedagogy. Yet in the Chinese context, the process through which these competencies are developed and enacted within teacher education remain under-theorised.

This conceptual paper introduces a model that integrates technical expertise and inclusive pedagogy, understood as pedagogical approaches valuing learner diversity and authentic participation, into vocational technology teacher education. The model is developed through an integrative theoretical synthesis of literature on vocational technology teacher preparation, boundary-crossing learning, and sociocultural perspectives on learning transfer. It conceptualises teacher learning as participation in communities of practice spanning industry, university, and vocational institution contexts, where teachers recontextualise technical knowledge through participation, developing professional identity and pedagogical capacity.

This model positions vocational technology teacher education as a boundary space where learning, belonging, and knowledge integration co-evolve. It proposes that the development of dual-qualified teachers is best understood as occurring through inclusive communities of practice that connect technical and educational cultures. It provides a conceptual basis for future empirical research examining how boundary-crossing, learning transfer, and inclusion shape teacher learning and identity. The first phase will investigate pre-service teachers' experiences in Chinese technical normal universities, followed by studies of practicum partnerships and school–industry collaborations. These collaborations aim to co-design models that reflect inclusive, dual-qualified professional identities and strengthen connections between universities,

vocational schools, and industry. The paper contributes to international discussions on preparing vocational technology teachers advancing inclusive and innovative practices in diverse educational contexts.

Key Words: Vocational Technology Teacher Education; Dual-qualified; Boundary-crossing Learning; Transfer of Learning; China

1 INTRODUCTION

Across many education systems, vocational technology teachers are increasingly expected to be both technically competent professionals and effective educators. In China, this expectation is articulated through the policy emphasis on the “dual-qualified” (双师型) teachers (Huang & Li, 2025). Similar expectations can be found in other countries where teachers are often required to maintain close connections with industry while also meeting professional teaching standards (Esmond, 2021; Schmidt, 2019; Tapani & Salonen, 2019).

Despite the policy prominence of this “dual-qualified” model, its realisation in teacher education remains challenging (Huang et al., 2025). Vocational technology teacher preparation typically takes place across universities, vocational institutions, and industry workplaces, yet these components are often organised as parallel or sequential experiences, with limited conceptual guidance reported in some contexts regarding how learning across these settings is integrated (Eiríksdóttir, 2020). As a result, technical and pedagogical development are often approached as distinct domains. While established models of teacher competence, such as TPACK (Koehler & Mishra, 2009; Mishra & Koehler, 2006) and COACTIV (Baumert & Kunter, 2013), have advanced understanding of knowledge components, less attention has been given to how these forms of expertise are integrated through processes of participation and professional identity formation, particularly in vocational contexts where technology teachers navigate dual professional identities across industry and education.

At the same time, vocational technical classrooms in China are becoming increasingly diverse (Fan et al., 2024; Wang & Guo, 2019), making inclusive pedagogy, understood here as pedagogical approaches that support authentic participation and meaningful engagement for all learners (Florian, 2015), and address the non-discrimination of disadvantaged and underrepresented groups, a central concern. Yet inclusion is often discussed as an add-on rather than as a core condition shaping how technical knowledge and skills are taught, learned and transformed in practice-based settings.

These challenges point to the need for a conceptual framework explaining how vocational technology teachers integrate technical expertise and pedagogy across institutional and professional boundaries. This paper aims to address this gap by developing a conceptual model of dual-qualified vocational technology teacher development across boundaries, grounded in the Chinese context but addressing challenges shared internationally.

2 BACKGROUND

2.1 *The Chinese Context*

In China, the preparation of vocational technology teachers has been shaped by reforms aimed at strengthening the connection between education and industry (Zhu & Li, 2025). A central concept in these reforms is the “dual-qualified” (双师型) teacher, defined in policy as a teacher who possesses both formal teaching qualifications and recognised industry-based technical or professional credentials (Huang & Li, 2025). This model reflects a policy commitment to aligning vocational education with technological development, industrial standards, and workforce needs. Technical normal universities in China play a key role in this system. They prepare future vocational technology teachers through programs combining disciplinary or engineering-oriented coursework, pedagogical training, and practicum experiences in vocational schools (Zhang, 2014). In policy terms, dual-qualified teachers are expected to teach technical content, engage in the development and implementation of practice-oriented curricula, and supervise skill-based learning (Huang et al., 2025).

Despite the clarity of these expectations, implementation remains challenging. In many programs, technical preparation and pedagogical training are organised as separate strands, sometimes delivered by different departments with distinct academic cultures (Huang et al., 2025). As a result, pre-service teachers often experience fragmented learning in which the relationship between technical expertise, teaching practice, and professional identity remains implicit (Xue, 2025). At the same time, vocational schools in China serve increasingly diverse student populations, including growing numbers of students from low socioeconomic backgrounds or rural backgrounds (Koo, 2016; Ling, 2015). Teachers are therefore required not only to master technical content, but also to design learning environments and tasks that support engagement and participation. While policy documents emphasise both technical competence and pedagogy, less attention has been given to how these capacities are developed together in practice (Huang et al., 2025; Zhu & Li, 2025).

2.2 *International Parallels and Shared Challenges*

The challenges associated with the dual-qualified teacher model are not unique to China. In many countries, vocational technology teachers are similarly expected to maintain strong connections with industry while also meeting professional teaching standards (Zhou, 2023). In systems such as Germany, Finland, and Australia, teachers often enter the profession through pathways combining occupational experience with formal teacher education (Kuhlee, 2021; Schmidt, 2019; Tapani & Salonen, 2019).

International research has documented recurring difficulties in connecting workplace experience with classroom teaching and translating occupational knowledge into teachable forms (Eraut, 2009). It also highlights challenges in designing coherent learning trajectories across university, school, and workplace settings (Membrive et al., 2022). Although practicum and workplace learning are widely recognised as essential components of vocational teacher education, they are often experienced as peripheral rather than as integral to a coherent professional learning process (Myhre et al., 2025).

These developments point to a shared problem: while the dual-qualified teacher model is widely endorsed, vocational technology teacher education remains conceptually underdeveloped in terms of how learning across tertiary institutions, school, and industry contexts is understood and supported. Much of the existing literature focuses on program structures, qualification routes, or competency frameworks, while comparatively little attention is paid to the learning processes and identity transformations through which teachers become both technical professionals and educators (Vähäsantanen & Hämäläinen, 2019). This suggests a need to move beyond treating technical expertise and pedagogy as separate components, and instead to theorise their integration as a process of participation and identity formation across practice contexts. The following section introduces the theoretical perspectives that inform this conceptual reframing.

3 METHODOLOGICAL APPROACH TO CONCEPTUAL MODEL DEVELOPMENT

This study adopts an integrative theoretical synthesis of scholarship in vocational technology teacher education, boundary-crossing learning, sociocultural perspectives on learning transfer and professional identity, and inclusive pedagogy. While existing research has clarified policy frameworks, competency standards, and program structures, it has paid less attention to the learning processes and identity work through which technical expertise and pedagogical practice are integrated. This synthesis therefore aims to develop an explanatory framework for understanding this process across institutional and professional contexts.

Generative AI tool (ChatGPT) was used in a limited capacity to support language refinement. All conceptualisation, synthesis of literature, and analytical decisions were undertaken by the authors.

3.1 *Integrative Theoretical Synthesis*

The model draws on an integrative theoretical synthesis, an approach suited to complex educational phenomena that cut across institutional and professional domains (Jabareen, 2009). Four bodies of literature informed this synthesis, including research on vocational technology teacher education as a contextual foundation, and three complementary theoretical perspectives that structure the model. Research on vocational teacher education and dual-qualified teachers was examined to identify prevailing assumptions and structural challenges in teacher preparation (Huang et al., 2025; Lucas, 2014). Boundary-crossing learning theory provided a lens for understanding learning as movement, coordination, and negotiation across activity systems such as industry, university, and vocational institutions (Akkerman & Bakker, 2011). Sociocultural perspectives on learning transfer and professional identity explain how knowledge is recontextualised through participation rather than transferred as a decontextualised skill (Beach, 1999; Wenger, 1998). Work on inclusive pedagogy contributes insights into how participation, belonging, and recognition shape meaningful learning in practice-based settings (Florian, 2015).

3.2 *From Synthesis to Conceptual Model*

The synthesis involved identifying key recurring concepts—participation, boundary-crossing, learning transfer, professional identity, and inclusion—and examining their relationships across

contexts. Rather than treating these as discrete variables, the analysis focused on their relational dynamics within overlapping communities of practice. This process resulted in a conceptual model that frames dual-qualified vocational technology teacher development as participation in inclusive communities of practice spanning industry, university, and vocational institutions. The model positions boundary-crossing participation and learning transfer as central mechanisms through which technical expertise and pedagogical capacity co-develop, leading to the formation of a dual-qualified professional identity. The following section outlines the theoretical foundations that inform this model.

4 THEORETICAL FOUNDATIONS

The conceptual model developed in this paper draws on three complementary theoretical perspectives: boundary-crossing learning, sociocultural perspectives on learning transfer and professional identity, and inclusive pedagogy in practice-based learning contexts. These perspectives were selected from a broader synthesis of literature, in which research on vocational technology teacher education provided the contextual and empirical grounding for the model (Wedekind et al., 2025). Boundary-crossing learning theory conceptualises learning across institutional and professional contexts (Akkerman & Bakker, 2011); sociocultural perspectives explain how knowledge is recontextualised through participation (Beach, 1999); and inclusive pedagogy foregrounds the conditions that enable participation and identity development (Florian, 2015).

4.1 *Boundary-Crossing Learning*

Boundary-crossing learning theory conceptualises learning as movement, coordination, and negotiation across different social and institutional contexts (Akkerman & Bakker, 2011). In contemporary education systems, professional learning rarely occurs within a single, stable community of practice. Instead, learners, including pre-service and in-service teachers, are required to move between multiple activity systems, each with its own norms, tools, values, and ways of knowing (Wenger, 1998).

In vocational technology teacher education, such boundary-crossing is especially pronounced. Teachers-in-training must navigate transitions between university-based coursework, vocational school classrooms, and industry workplaces (Myhre et al., 2025). Each context represents a distinct culture of practice, characterised by different emphases: universities tend to prioritise theoretical and disciplinary knowledge, industry emphasises efficiency, standards, and problem-solving, while vocational institutions are more closely engaged with curriculum enactment, student learning, and assessment in practice-based settings. Boundary-crossing learning theory highlights that learning does not occur simply by moving between these contexts, but through the work of translating, coordinating, and reinterpreting knowledge and practices across them (Akkerman & Bakker, 2011).

From this perspective, boundaries are not merely obstacles to be overcome; they are also productive sites for learning and development (Akkerman & Bakker, 2011). Encounters with different practices and expectations can prompt reflection, reorientation, and the reconfiguration

of professional identity (Wenger, 1998). In the context of vocational technology teacher education, boundary-crossing provides a useful lens for understanding how technical expertise and pedagogical practice are brought into dialogue rather than remaining isolated domains (Vähäsantanen & Hämäläinen, 2019).

4.2 *Sociocultural Perspectives on Learning Transfer and Professional Identity*

Sociocultural theories of learning challenge the notion that knowledge is simply transferred from one context to another as a stable, decontextualised entity. Instead, learning transfer is understood as a process of recontextualisation, in which knowledge is reshaped through participation in new activities, relationships, and purposes (Beach, 1999). From this perspective, what matters is not whether individuals can apply what they have learned elsewhere, but how they learn to participate competently in new forms of practice.

For vocational technology teachers, this insight is particularly important. Technical knowledge acquired in engineering or occupational contexts does not automatically become pedagogical knowledge. Learning to teach technical subjects involves transforming ways of seeing, valuing, and using knowledge—through designing tasks, anticipating misconceptions, scaffolding skill development, and making judgements about what counts as meaningful learning in social practice (Billett, 2011; Williams, 2020).

Sociocultural perspectives also emphasise that learning is inseparable from identity formation (Wenger, 1998). As individuals participate in new practices, they do not merely acquire skills; they become different kinds of practitioners. In the case of vocational technology teachers, developing a dual-qualified professional identity involves learning to inhabit both technical and pedagogical worlds, and to see oneself as a teacher who can mediate between them. This identity work is central to understanding how integration between technical expertise and pedagogy is achieved in practice (Vähäsantanen & Hämäläinen, 2019).

4.3 *Inclusive Pedagogy in Practice-based Learning Contexts*

Inclusive pedagogy provides a further lens for understanding how participation and learning are organised in vocational and technology education settings (Florian, 2015). In this paper, inclusion is not understood primarily as a set of specialised strategies for particular groups of learners, but as a commitment to designing learning environments that support authentic participation, recognition, and belonging for all students (Ainscow et al., 2006; Florian, 2015).

Vocational and technical classrooms are characterised by substantial learner diversity, including differences in prior academic experience, motivation, learning needs, and future aspirations. Teaching in such contexts requires more than technical competence; it requires the ability to create learning situations in which students can engage meaningfully with practical tasks, collaborate with others, and develop confidence in their abilities (Tesmamu Mirre, 2024). Inclusive pedagogy thus intersects directly with questions of task design, assessment, classroom interaction, and the social organisation of learning.

Importantly, inclusion is also relevant to teacher learning. For pre-service and early-career teachers, inclusive learning environments within teacher education programs and practicum settings provide the conditions for risk-taking, experimentation, and identity development (Howes et al., 2005). From this perspective, inclusion is not an add-on to vocational technology teacher education, but a core condition that enables boundary-crossing learning and the recontextualisation of knowledge to occur.

4.4 *Toward an Integrated Perspective*

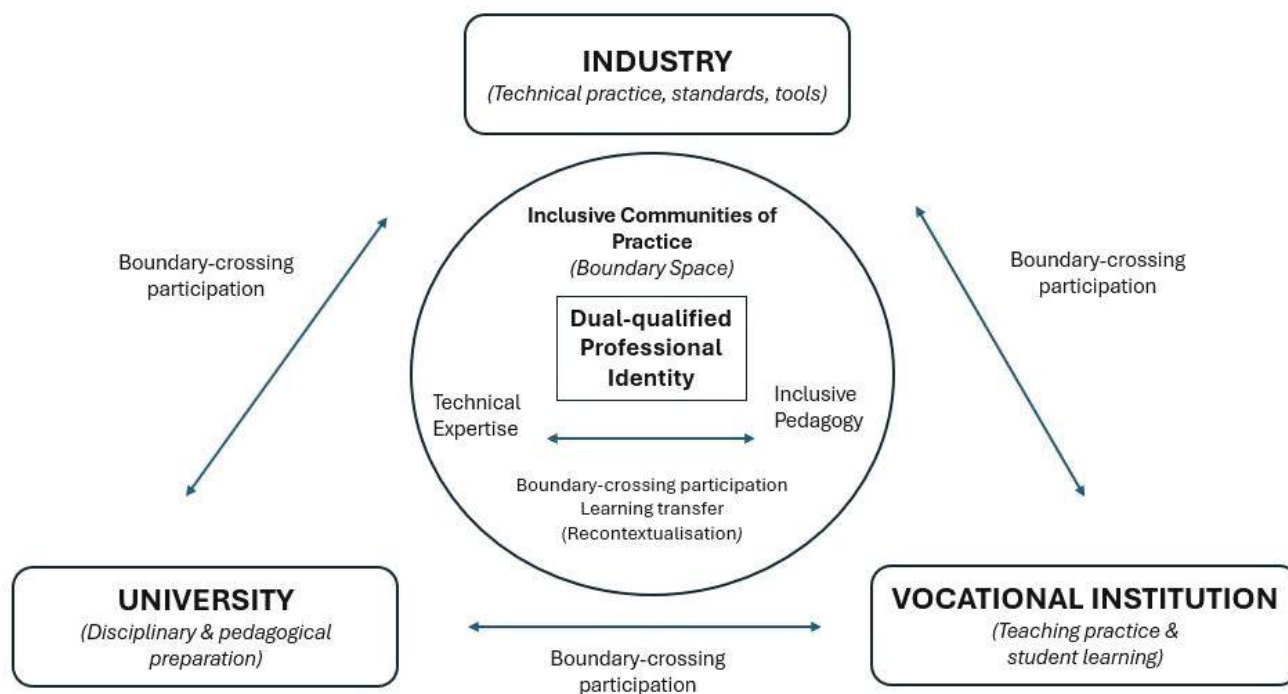
Each of these perspectives illuminates a different aspect of vocational technology teacher development. Boundary-crossing learning highlights movement and negotiation across contexts; sociocultural perspectives explain how knowledge and identity are formed through participation; and inclusive pedagogy foregrounds the conditions that enable meaningful participation. Taken in isolation, however, these perspectives offer only partial accounts. Brining these perspectives together enables a more comprehensive conceptualisation of vocational technology teacher development as a relational and boundary-crossing process in which participation, learning transfer, and identity formation are mutually constituted within and across institutional contexts.

5 THE CONCEPTUAL MODEL: DUAL-QUALIFIED TEACHER DEVELOPMENT ACROSS BOUNDARIES

This section presents the conceptual model of vocational technology teacher development developed through the theoretical synthesis outlined above. The model, illustrated in Figure 1, conceptualises the development of dual-qualified teachers not as the accumulation of separate technical and pedagogical competencies, but as a process of participation, integration, and identity formation across interconnected practice contexts. It positions teacher learning as occurring within and across three key contexts—industry, university, and vocational school—through boundary-crossing participation and learning transfer as recontextualisation, within inclusive communities of practice that function as a shared boundary space.

Figure 1

Conceptual model of dual-qualified vocational technology teacher development across boundaries



5.1 Three Interconnected Practice Contexts

As shown in Figure 1, the model situates vocational technology teacher learning across three major contexts: industry, university, and vocational institution. These contexts are not merely sites of placement or training, but distinct communities of practice characterised by different purposes, norms, and forms of expertise. Professional learning unfolds through movement between these contexts. However, they are not automatically aligned, and transitions often involve tensions and discontinuities. The model therefore treats these contexts as interconnected but differentiated, requiring active work to translate, coordinate, and integrate knowledge and practice across boundaries, for example, when industry-based practices are reinterpreted for classroom teaching during practicum experiences.

5.2 The Inclusive Communities of Practice as Boundary Space

At the centre of the model is inclusive communities of practice, conceptualised as a boundary space in which learning across contexts becomes possible. This does not represent a single institution, but a relational and pedagogical space created through partnerships, practicum arrangements, mentoring relationships, and collaborative work across university, school, and industry settings, such as joint supervision or co-designed training between institutions.

Here, inclusion refers to the creation of conditions for authentic participation, recognition, and belonging. These conditions are essential not only for students, but also for teachers. Inclusive communities of practice provide the social and pedagogical infrastructure that enables novice teachers to experiment, take risks, and negotiate emerging professional roles as they move across contexts.

5.3 *Boundary-Crossing Participation and Learning Transfer*

Within this boundary space, two interrelated processes drive learning: boundary-crossing participation and learning transfer as recontextualisation. Boundary-crossing participation involves coordinating meanings and practices across industry, university, and vocational school contexts, while learning transfer refers to the reshaping of technical knowledge through participation in teaching practice, for example when teachers adapt workplace procedures into teachable learning tasks. In the model, these processes function as the central mechanisms of professional learning within the inclusive community of practice.

5.4 *Integrating Technical Expertise and Inclusive Pedagogy*

A key feature of the model is the dynamic integration between technical expertise and inclusive pedagogy. Rather than treating these as separate domains, the model conceptualises their relationship as one of mutual shaping. Technical knowledge is transformed as it is taken up in teaching practice, while pedagogical approaches are informed and constrained by the nature of technical work and vocational tasks. This integration is enabled by participation in inclusive communities of practice, where teachers can experiment with translating technical knowledge into teachable forms and reflect on how pedagogical decisions shape students' access to meaningful participation, for instance by modifying technical tasks to support diverse learners' engagement.

5.5 *Dual-Qualified Professional Identity as an Emergent Outcome*

At the centre of the model is the development of a dual-qualified professional identity. This is not the result of holding two sets of credentials, but the emergent outcome of sustained participation across technical and educational worlds. Through boundary-crossing participation and recontextualisation within inclusive communities of practice, teachers come to see themselves as professionals who can integrate technical expertise and pedagogy in meaningful ways.

From this perspective, dual-qualified teacher development is a process of becoming rather than a state of having acquired predefined competencies. The model therefore positions vocational technology teacher education as a boundary space in which learning, belonging, and knowledge integration co-evolve.

6 IMPLICATIONS AND FUTURE DIRECTIONS

The conceptual model presented in this paper reframes vocational technology teacher development as a process of participation, integration, and identity formation across boundaries.

This extends existing work on teacher competence, which has often focused on knowledge domains and their relationships, e.g., TPACK (Koehler & Mishra, 2009), COACTIV (Baumert & Kunter, 2013) by conceptualising integration as a situated and relational process and by foregrounding the specific challenges of vocational contexts, where technology teachers navigate dual roles across industry and education. In this sense, the model is intended not only as an interpretive framework, but also as a foundation for a program of empirical research.

The first phase of this research will focus on pre-service teachers in Chinese technical normal universities, examining how they experience and navigate relationships between university coursework, vocational school practicum, and industry-oriented learning. A second phase will extend the focus to practicum partnerships and school–industry collaborations, investigating how these arrangements function as inclusive communities of practice and how mentoring and curriculum co-design support boundary-crossing participation and learning transfer.

Although grounded in the Chinese context, the model speaks to challenges shared across systems in which vocational and technology teachers are expected to bridge occupational and educational worlds. It therefore offers a conceptual lens for international dialogue on vocational teacher education and contributes to broader discussions on preparing teachers capable of advancing inclusive and innovative practices in diverse vocational and technical education contexts.

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Exploring MUFY Students' Perceptions of Gender Inclusivity and Engagement in Technology-Enhanced Learning

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Abstract

Digital learning is now embedded in MUFY classrooms, shaping how students interact with knowledge, peers, and educators. As technology becomes central to teaching, questions about gender inclusivity remain crucial, particularly in educational stages that influence entry into STEM and technology-related fields. This study explores the perceptions of Monash University Foundation Year (MUFY) Chemistry students towards gender inclusivity and engagement within a technology-enhanced learning environment. The MUFY programme is an internationally recognised Australian Year-12 qualification that prepares students for undergraduate studies. A structured questionnaire was administered, and responses were analysed using descriptive content analysis. Findings reveal encouraging trends as 89.6% of respondents believe male and female students are equally capable of succeeding in technology-enhanced learning environments, while 91.7% agreed that instructional materials reflected gender inclusively. Technology exposure appeared to increase interest, with 83.3% reporting enhanced curiosity about technology-related subjects or careers. It was good that 93.7% of students affirmed that educators encouraged creative and confident technology use for learners of all genders. Additionally, 89.4% indicated that coursework demonstrated how technology addresses real-world challenges across diverse communities. Nearly all respondents (97.9%) viewed gender equality in technology education as essential for building an inclusive future workforce. These results suggest that integration of digital tools can positively shape learners' confidence and interest in technology. The findings carry practical implications for curriculum development, digital resource design, and professional learning in MUFY programmes seeking to foster equitable engagement in technology fields.

Key Words: Technology, Gender, Inclusive, Engagement, Education.

1 INTRODUCTION

Over the past decade, technology has shifted from being a supplementary tool in classrooms to a medium through which students access content, collaborate, and express understanding. Recent

studies show that online resources and virtual platforms increasingly shape academic participation and student engagement across disciplines (Bennett & Maton, 2010; Wright & Akgunduz, 2022). This has not only changed instructional practice but has transformed the learner experience, with digital literacy becoming key academic competencies rather than optional skills (Zawacki-Richter *et al.*, 2020). As digital ecosystems continue to shape schooling, it becomes necessary to explore whether all students feel supported and represented in these spaces. Gender equity remains an important focus within technology education, given the longstanding concern that female learners are less likely to pursue technology-related pathways (Wang & Degol, 2017; Wang *et al.*, 2023). While early exposure to technology has been linked to increased interest in Science, Technology, Engineering, and Mathematics (STEM) fields, the *quality* of that exposure matters. For example, classroom interactions, representation in learning materials and educators' encouragement can all influence whether students perceive technology-rich spaces as welcoming or exclusionary (Casey *et al.*, 2023; Perez-Felkner *et al.*, 2024). These dynamics may be subtle, yet they hold power in shaping confidence, identity, and aspiration in technology related domains (Master *et al.*, 2021).

In the Monash University Foundation Year (MUFY) programme, students make decisions that impact their future academic pathways. It is at this stage that beliefs about capability and belonging can either support or hinder students' willingness to pursue technology-related disciplines. Globally, women in technology are creating impact but classroom experiences continue to play a decisive role in fostering inclusion (UNESCO, 2017; Parmaxi *et al.*, 2024). When young people see technology applied to broad social contexts rather than confined to traditional male-associated fields, interest tends to widen across gender lines (Casey *et al.*, 2023; Li, 2022). Much of the current debate in technology education emphasises equitable access to tools and infrastructure. However, access alone does not guarantee engagement or development of identities (European Commission, 2020). A student may log into a platform daily, complete the required tasks, and yet never feel that the world of technology includes them. As a result, educator behaviour and curriculum design still matter more than ever. As Wang *et al.* (2023) highlighted, perceptions of belonging and confidence are as influential as skill mastery in shaping technology-related aspirations. This implies that the classroom remains a social space before it is a digital one.

1.1 Theoretical Framework

This study is guided by a gender theoretical framework that understands gender as a socially shaped and context-dependent construct, rather than a fixed biological trait. From this perspective, students' experiences with technology are influenced by cultural expectations, classroom practices and the learning environments in which they participate. Within technology and STEM education, research has shown that students' attitudes, confidence, and sense of belonging are often shaped by stereotypes and everyday classroom interactions, rather than by innate ability (Wang *et al.*, 2023).

Gender-inclusive learning environments, particularly those supported through intentional use of digital tools, have the potential to challenge traditional norms and foster more equitable participation across genders. Casey *et al.* (2023) demonstrate that thoughtfully designed technology-enhanced contexts can positively influence students' motivation and engagement by

making learning spaces feel more inclusive. Recent studies highlight the importance of aligning classroom practices with societal commitments to gender equality in STEM, bridging educational experiences with real-world expectations (Parmaxi *et al.*, 2024). Grounded in this framework, the present study examines MUFY students' perceptions of gender inclusivity and engagement within a technology-enhanced learning context. Student attitudes are viewed as meaningful indicators of how inclusive educational practices are experienced in practice, offering insight into how technology integration may support or constrain equitable participation.

In the context of MUFY students, the adoption of digital learning accelerated significantly during the COVID-19 pandemic. Students entering MUFY today have experienced technology-mediated learning to different degrees, and many now expect educators to integrate digital tools meaningfully (Fischer *et al.*, 2020). There remains concern about gender representation in STEM, reinforcing the need to examine student perceptions in Pre-University settings (European Commission, 2020). This study focuses on MUFY Chemistry students as this subject is traditionally positioned within STEM, and utilises virtual labs, online assessment platforms, and collaborative digital tasks. These tools create an ecosystem to explore the interplay between gender perception, engagement, and confidence. By exploring students' views on gender inclusivity, educator encouragement and interest in technology-related futures, the study aims to further comprehend the data that often dominates discussions on STEM participation. The results of this inquiry offer practical relevance for curriculum leaders, educators and institutions designing technology-rich programmes. If students perceive these environments as inclusive and empowering, such insights can strengthen resolve toward equitable technological participation.

2 METHODOLOGY

2.1 *Research Approach*

This study employed a quantitative descriptive research design to explore students' perceptions of gender inclusivity and engagement within a technology-enhanced learning environment. A descriptive approach was selected, as the primary aim was to document patterns, tendencies and shared perceptions among students rather than to establish causal relationships or test predictive models. Furthermore, the gender of individual respondents was intentionally not collected or analysed. This choice was made to focus the inquiry on the collective student perception of the learning environment, rather than comparing attitudes between genders. By adopting this holistic approach, the study aims to document the prevailing classroom culture and the perceived effectiveness of inclusive instructional design for the entire cohort.

Descriptive designs are well suited to studies that seek to capture how learners interpret and experience their educational contexts, particularly in research examining inclusivity, attitudes, and perceptions in technology-mediated settings (Casey *et al.*, 2023). By focusing on students' self-reported views, this design allows insight into the lived classroom experience that often underpins decisions related to curriculum design, teaching practice, and institutional policy. In the context of gender inclusivity in STEM-related subjects, such perceptual data serve as meaningful indicators of how inclusive practices are experienced at the classroom level.

2.2 *Participants*

Participants were students enrolled in the Chemistry subject of the Monash University Foundation Year (MUFY) programme. MUFY is a Pre-University Programme equivalent to Year 12 in the Australian education system and prepares students for entry into Undergraduate Degree Programmes at Monash University and other institutions. Chemistry was selected as the focus of this study as it is traditionally situated within the STEM disciplines and incorporates multiple technology-enhanced learning components.

At the time of the study, there were 200 students enrolled in the Chemistry programme, taught by different Chemistry educators. Participation in the study was voluntary, and a total of 94 students completed the questionnaire. All responses were collected anonymously to minimise response bias and encourage honest reflection. No identifying information was gathered, and students were informed that participation or non-participation would not affect their academic standing.

2.3 *Instrumentation*

Data was collected using a structured questionnaire comprising closed-ended items measured on a Likert scale. The survey was designed to capture students' perceptions across several key dimensions, including gender inclusivity within the learning environment, educator encouragement, representation in learning materials and interest in technology-related subjects or future pathways.

Likert-scale items were selected due to their widespread use and effectiveness in capturing attitudinal and perceptual data in educational research. The survey items were informed by themes and constructs identified in prior studies on gender inclusivity, engagement and technology-enhanced learning (Wang *et al.*, 2023; Wong & Kemp, 2023). This alignment supported the content relevance of the instrument and ensured that the items reflected issues commonly discussed within the literature.

2.4 *Pedagogical Implementation of Gender Inclusivity*

To provide context for the student perceptions reported in this study, the instructional design followed two main pillars: i) *Representation in materials*: Educators curated digital resources, case studies and lab simulations that featured diverse contributors to the field of Chemistry. For example, when discussing molecular structures or atomic history, contributions from both male and female scientists were highlighted to counteract historical gender biases in STEM narratives. ii) *Instructional language and interaction*: Educators were trained to use gender-neutral language and to ensure equitable distribution of "airtime" during technology-mediated discussions. In digital breakout rooms and collaborative platforms (such as Padlet or Microsoft Teams), educators actively monitored participation to ensure that students of all genders were encouraged to lead technical tasks and present findings.

2.5 *Data Collection Procedure*

The questionnaire was administered online using a digital survey platform at the end of the academic term. The timing was such as students had already experienced sustained exposure to technology-enhanced learning activities by this stage of the course. These activities included the use of virtual laboratories, online assessment systems and collaborative digital tasks integrated into the Chemistry curriculum.

Administering the survey at the conclusion of the term allowed students to reflect on their experiences holistically, rather than responding based on isolated or initial impressions. Completion of the survey was self-paced, and students were given adequate time to respond.

2.6 *Data Analysis*

Survey responses were analysed using descriptive statistical techniques, specifically frequencies and percentages, to provide an objective overview of students' perceptions. This approach is consistent with prior research that positions student perception data as formative indicators for evaluating inclusivity and engagement within technology-enhanced learning environments (Casey *et al.*, 2023).

The results were presented visually using bar charts and pie diagrams to enhance clarity and support ease of interpretation. Inferential statistical analyses were not employed, as the purpose of the study was to describe observed trends, rather than to test hypotheses or infer population-level effects. This analytical approach aligns with the exploratory and descriptive nature of the research design.

3 RESULTS

The corresponding figures demonstrate students' responses on gender inclusivity and engagement in a technology-enhanced learning environment. Overall, the results show a strong belief among MUFY students that technology-based learning can be an inclusive and encouraging space for both male and female learners. The responses consistently leaned toward agreement across all indicators.

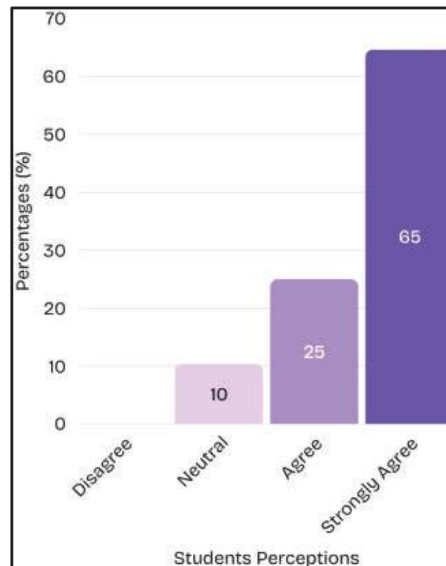
Theme 1: Perceptions of Gender Equality and Representation

i) *Gender capability*: 89.6% of students expressed the view that both male and female learners are equally capable of excelling with technology. ii) *Inclusive materials*: 91.7% of respondents felt that the examples and materials used in class represented both genders fairly.

3.1 *Gender capability in technology-enhanced learning.*

Figure 1

Student perceptions of gender equality in technology-enhanced learning capability.

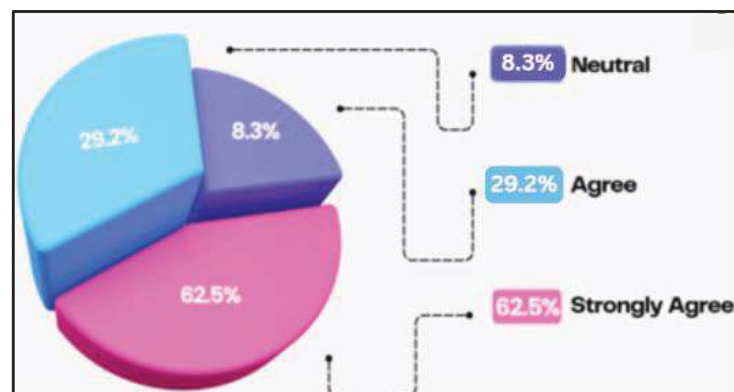


A large majority of students (89.6%) expressed the view that both male and female learners are equally capable of excelling when learning with technology (Figure 1). Only 10.4% of respondents indicated a neutral stance, with none expressing disagreement. This suggests that students largely rejected stereotypes regarding gender differences in technological ability.

3.2 *Gender-inclusive teaching materials.*

Figure 2

Student agreement levels of inclusivity and gender representation of class examples and materials.



Most respondents (91.7%) felt that the examples and materials used in class represented both genders fairly (Figure 2). None of the students disagreed, though 8.3% reported feeling neutral about the statement that class examples and materials were gender inclusive. This reflects positively on classroom resources used within the programme and indicates that students noticed inclusive content in the MUFY curriculum.

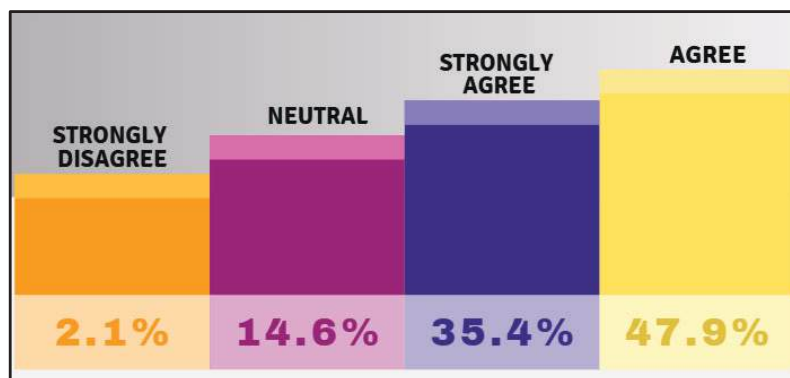
Theme 2: Technology as a Driver of Interest and Influence

i) *Academic and career motivation*: 83.3% of students reported that learning with technology increased their interest in technology-related subjects or future careers. ii) *Peer influence*: Analysis revealed that 44.7% of respondents agreed their friends' interest affected their career decisions, though most remained neutral or disagreed.

3.3 *Technology as a motivator for academic and career interest.*

Figure 3

Distribution of student responses on whether learning with technology increased their interest in technology-related subjects or future careers.

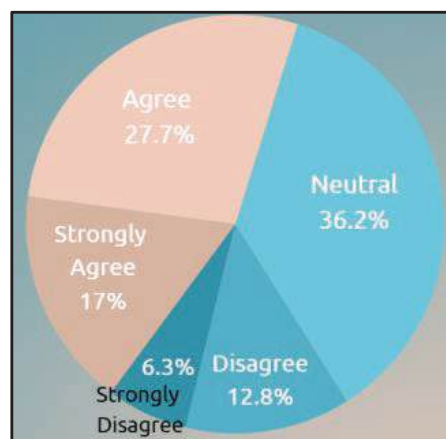


A significant majority of students (83.3%) reported that learning with technology increased their interest in technology-related subjects or future careers (Figure 3). Neutral responses accounted for 14.6% of the cohort, while only a small minority (2.1%) strongly disagreed. This finding demonstrated the positive influence of technology-enhanced lessons on fostering academic curiosity and shaping students' long-term aspirations.

3.4 *Peer influence on technology pathways.*

Figure 4

Student perceptions on the influence of friends' interest in technology subjects.



Analysis of peer influence revealed that 44.7% of respondents agreed their friends' interest (or lack thereof) in technology subjects affected their own career pursuit decisions (Figure 4). Most of the cohort, however, either remained neutral (36.2%) or disagreed (19.1%). This distribution suggests that personal motivation and direct classroom experiences may be stronger determinants in shaping students' long-term academic and professional choices, rather than peer group influence.

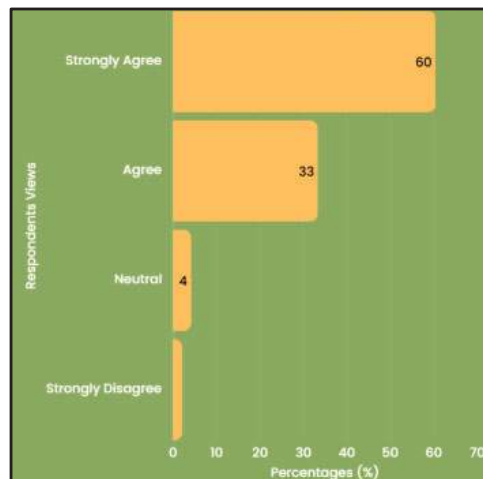
Theme 3: The Impact of Educator Support and Real-World Relevance

i) *Educator encouragement*: 93.7% of students agreed that educators encouraged them to use technology creatively and confidently, regardless of gender. ii) *Real-world context*: 89.4% of students agreed that coursework effectively demonstrated how technology solves diverse, real-world problems relevant to all genders. iii) *Societal importance*: 97.9% of respondents agreed that promoting gender equality in technology education is essential for building an inclusive future.

3.5 Perceptions of educator encouragement.

Figure 5

Respondent views on educators' encouragement of all students to use technology creatively and confidently.

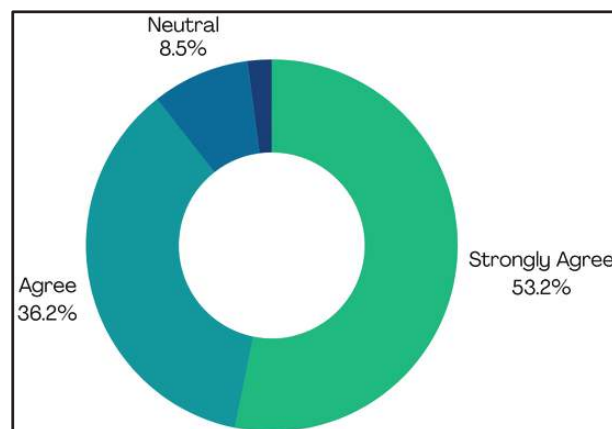


Students reported an overwhelming sense of educator support, with 93.7% agreeing that educators encouraged them to use technology creatively and confidently, regardless of gender (Figure 5). This result strongly highlights the perceived positive role of educators in fostering equal and confident participation in technology-enhanced learning. Only a small minority of students indicated neutrality (4.7%) or disagreement (2.1%) with the statement.

3.6 Technology connecting to real-world context.

Figure 6

Distribution of student agreement on whether MUFY coursework demonstrates technology's relevance to real-world problems for all genders.

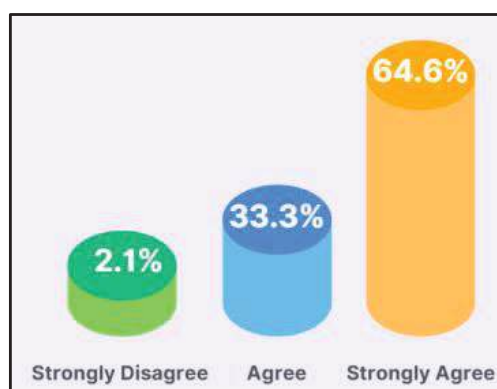


A similarly high percentage of students (89.4%) agreed that their coursework effectively demonstrated how technology can be used to solve diverse, real-world problems relevant to all genders (Figure 6). This strong consensus suggests that students perceive their learning as both relevant and socially meaningful. It was good that only a small minority of students expressed neutrality (8.5%) or disagreement (2.1%).

3.7 *Importance of gender equality in technology education.*

Figure 7

Student agreement on the importance of promoting gender equality in education for an inclusive future.



Student commitment to the principle of equality was robust as nearly all respondents (97.9%) agreed that promoting gender equality in technology education is essential for building an inclusive future (Figure 7). This is particularly notable as the findings indicated a point of near unanimity with no neutral responses recorded. The remaining 2.1% represented a minor fraction that indicated strong disagreement, consistent with expected variation across any attitudinal survey. This exceptional level of consensus reflects a powerful alignment between student beliefs and the broader goals of equity in modern technology education.

The results show a powerful consensus among MUFY students regarding gender equity and engagement in their technology-enhanced learning environment. Almost 90% of respondents consistently agreed that technology education is inclusive, relevant, and well-supported by educators, specifically confirming that both genders are equally capable (89.6%), teaching materials are inclusive (91.7%), and educators offer gender-neutral encouragement (93.7%). This positivity translated directly into high motivation, with 83.3% reporting an increased interest in technology-related careers. In addition, students strongly endorsed the value of equity, with a near-unanimous 97.9% agreeing on the importance of promoting gender equality for an inclusive future. The only area showing less consensus was peer influence, where only 44.7% agreed that their friends' interests affected their own career decisions, suggesting personal motivation may be the stronger factor.

4 DISCUSSION

The results of this study offer a notably positive picture of how MUFY Chemistry students perceive gender inclusivity and engagement in a technology-enhanced learning environment. Across nearly every indicator, students expressed strong confidence that their digital learning experiences were fair, supportive, and welcoming to all genders. However, this may not align with global literature, which often reports persistent gaps in confidence, representation, and interest in technology-related fields (UNESCO, 2017; Wang & Degol, 2017). The MUFY cohort's responses suggest that, within this educational context, several long-standing concerns may be less pronounced or mitigated by thoughtful instructional design and the broader learning culture.

One of the clearest findings was students' overwhelming rejection of gender stereotypes relating to technological ability (Master, Meltzoff, & Cheryan, 2021). Nearly 90% agreed that male and female learners are equally capable in technology-enhanced settings. This supports research that when learners gain sustained, meaningful exposure to digital tools, their perceptions of who "belongs" in technology often broaden (Bennett & Maton, 2010; Casey *et al.*, 2023). It may also reflect the normalisation of blended and online learning since the pandemic, which has made digital engagement part of everyday academic life rather than an optional skill (Fischer *et al.*, 2020; Zawacki-Richter *et al.*, 2020). The strong endorsement of gender-inclusive teaching materials further reinforce the idea that representation matters. Over 91.7% of students felt that class resources depicted both genders fairly. Previous studies debate that inclusive imagery, examples, and scenarios reduce the subtle cues that can discourage female participation in STEM (Peláez-Sánchez *et al.*, 2023; Perez-Felkner *et al.*, 2024). The MUFY students' responses indicate that these design principles are already reflected in their curriculum and are recognised by learners themselves. When students perceive that materials are fair, it creates the psychological safety necessary for creative and confident technological participation.

Technology's role in motivating interest in technology-related subjects and careers also emerged as a key theme. More than 83% of respondents reported that technology-enhanced learning increased their curiosity about technology fields. This aligns well with work by Casey *et al.* (2023), who discovered that engaging digital environments, particularly those framed with inclusivity can significantly strengthen learners' interest in STEM pathways. This outcome is highly desirable, especially given the global push to increase STEM interest among young people (European Commission, 2020). At the same time, this study highlights that this motivation may stem more from personal engagement and instructional quality than from social influence. Peer impact was the only area with limited consensus, with less than half agreeing that friends shaped their interest in technology careers. This trend differs from some broader studies that note strong peer effects in STEM aspirations (Wang & Degol, 2017; Wang *et al.*, 2023). This may suggest that the decision for MUFY students to pursue a technology-related career depends more on personal motivation and classroom experiences, rather than social pressure from peers.

Perhaps the strongest thread running through the results is the perceived role of educators. An overwhelming 93.7% of students felt that educators encouraged all students, regardless of gender to use technology confidently and creatively. Research has consistently shown that educators'

attitudes, expectations, and day-to-day interactions shape learner confidence far more than infrastructure alone (European Commission, 2020; Parmaxi *et al.*, 2024). The MUFY findings affirm that supportive teaching practices can help cultivate a learning environment whereby students feel equally valued and capable. The high agreement on technology's relevance to real-world problems (89.4%) further suggests that learners view their digital tasks as meaningful rather than procedural. UNESCO (2017) highlighted that when students see technology connected to diverse social issues, interest becomes more universal across genders. Likewise, nearly unanimous agreement (97.9%) on the importance of promoting gender equality in technology education reflects an awareness among students that inclusive participation is not merely a classroom issue, but a societal one.

The findings of this study offer a scalable model for other Chemistry and Engineering institutions. The high levels of student agreement regarding educator encouragement (93.7%) suggest that intentional pedagogical intervention such as the selection of diverse digital media and the management of digital collaboration can significantly mitigate the "chilly climate" often reported by underrepresented genders in STEM. By documenting these specific teaching strategies, this study provides a blueprint for creating inclusive technology-enhanced environments that can be adapted by other higher education providers.

Taken altogether, these results suggest that MUFY's technology-enhanced Chemistry learning environment supports both gender inclusivity and student engagement in ways that align strongly with recommendations in the literature. The current cohort is highly aware of the necessity of promoting gender equality for inclusive growth, which may, in turn, sustain and amplify the positive environment reported in the research. While broader inequities in STEM persist globally, this study shows that pedagogical choices, inclusive examples, supportive educators, and meaningful use of technology can create a learning space where students of all genders feel represented and motivated to engage with technology.

5 CONCLUSION

This study set out to explore MUFY students' perceptions of gender inclusivity and engagement in a technology-enhanced learning environment, and the findings paint a reassuring picture. Students consistently viewed their digital learning spaces as fair, welcoming, and supportive, with both male and female learners seen as equally capable of succeeding with technology. Such responses stand in contrast to many global concerns about gender gaps in STEM, suggesting that inclusive design and thoughtful teaching practice can meaningfully shift perceptions at the Pre-University level.

The strong emphasis students placed on educator encouragement and real-world relevance underscores a simple yet powerful point that technology alone does not create an inclusive environment, but educators do. When learning materials are balanced, tasks are meaningful, and students are invited to use technology creatively, confidence grows naturally across genders. At the same time, this study acknowledges that wider inequalities in STEM remain, and sustained effort is still needed to ensure that early positive experiences translate into long-term

participation. Nevertheless, the MUFY findings offer a hopeful reminder that progress is not only possible but already happening. When digital tools are integrated with care and supported by inclusive classroom culture, students of all genders can feel seen, capable, and motivated to engage with technology-rich futures.

6 DISCLOSURE STATEMENT

The author confirms that Generative AI tools were not utilized during the writing and planning process.

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Building Research Credibility in Technology Education: Lessons from the SCORE Project

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Abstract

The Systematizing Confidence in Open Research and Evidence (SCORE) project was a large-scale meta-scientific initiative organised by the Center for Open Science to examine credibility in quantitative research across the social and behavioural sciences. Involving 865 collaborators in the evaluation of 3,900 claims, the project has produced a series of journal articles and pre-prints addressing replicability, reproducibility, analytical robustness, and the prediction of replication outcomes.

Although technology education research was not examined as a distinct field within SCORE, its findings are highly relevant to the development of credible and cumulative research cultures. Key findings include that approximately half of examined claims replicated successfully, defined as a statistically significant result in the same direction as the original finding; that approximately half of analyses could be reproduced exactly and roughly three quarters could be reproduced approximately when data were available; and that about one third of independent analyses of the same data arrived at the same numerical result as the original paper within a tolerance region of ± 0.05 Cohen's d , rising to around three quarters when judged by the same general conclusion. SCORE also demonstrated that expert teams can provide informative predictions about which published claims are likely to replicate.

This presentation considers the implications of SCORE for technology education research, in dialogue with existing meta-research on transparency and replicability within the field. It develops the case for more open research practices and for verification studies in technology education, positioning both as practical routes to strengthening credibility and contextual transferability across quantitative, qualitative, and mixed methods traditions.

Key Words: Research credibility, Meta-science, Replicability, Robustness, Reproducibility.

Overcoming Rather than Adding: The Generation Mechanism and Bridging Path of the Gap Between STEM Teachers' TPACK Beliefs and Practices

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Abstract

The deep integration of digital technology and subject teaching is the core support for the high-quality development of STEM education. The TPACK framework provides a classic paradigm for teachers' technological integration, but existing research cannot fully explain the deep integration of the conceptually recognized technology and teaching in STEM education. Instead, it is limited to the common contradiction of the superficial application of technology as a tool in practice. This study defines and characterizes the gap between TPACK beliefs and practices, and constructs a multi-level generation mechanism model of the gap from three dimensions: institutional constraints, teaching design decision conflicts, and cognitive paradigm tensions. The study finds that this gap is not an accidental deviation caused by the individual teacher's lack of ability, but is the inevitable result of the systematic conflict between the additive technological application thinking and the deep integration requirements of TPACK. Furthermore, it constructs a belief and practice coupling model from cognition to design to practice, and proposes an operational path to bridge the gap, providing theoretical support for the practical transformation of the TPACK framework and the improvement of STEM teachers' technological integration capabilities.

Key Words: TPACK, STEM Teachers, The Gap Between Beliefs and Practices.

Opportunities, Challenges, and Pathways for Empowering Critical Thinking in Vocational College Students via Generative Artificial Intelligence

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Abstract

Generative artificial intelligence (GAI) is fundamentally reshaping teaching methods in vocational education. This study employs an explanatory mixed-methods research design, following a logical paradigm of quantitative analysis preceding qualitative analysis, to investigate trends in the impact of GAI on the cognitive development of vocational students and to examine the potential risks and challenges associated with integrating GAI into teaching. Centred on the fundamental purpose of education, this study draws upon Vygotsky's Sociocultural Theory (SCT) to construct an innovative, three-pronged pathway for the cognitive development of vocational students—comprising 'tools, interaction and development'—through the integration of GAI.

Key Words: Life course theory, Female scientific and technological talents, Competency elements, Growth path.

A Life Course Theory Perspective on the Developmental Pathways, Influencing Factors, and Cultivation Strategies of Female Scientific and Technological Talent

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Abstract

The persistent underrepresentation of women in science, technology, engineering, and mathematics (STEM) remains a major constraint on the development of inclusive and sustainable innovation systems. Drawing on life course theory, this study conducted in-depth life-history interviews with 12 women academicians from the Chinese Academy of Sciences and the Chinese Academy of Engineering. By reconstructing their longitudinal developmental trajectories, the study identifies three overarching dimensions of capability development—cognitive-innovative capability, resource-affective capability, and adversity-leadership capability—which together comprise eight empirically grounded competencies. The findings suggest a three-stage developmental model: enlightenment and foundation building, refinement and advancement, and accumulation and take-off. These stages are shaped by the dynamic interplay of four interrelated systems: family support, schooling experiences, individual agency, and sociocultural value orientations. Based on these findings, the study proposes a life-course-oriented framework for cultivating women's STEM talent. This framework emphasizes the identification of critical developmental turning points, the establishment of stage-specific and full-cycle support mechanisms, the coordination of family, school, and societal enabling environments, the sequential development of core competencies, the reconstruction of positive cultural representations of women in science, and the creation of a more inclusive scientific community. These strategies may enhance women's STEM expectations and self-efficacy, thereby strengthening their intrinsic motivation for scientific inquiry and further unleashing their innovative potential.

Key Words: Life course theory, Female scientific and technological talents, Competency elements, Growth path.

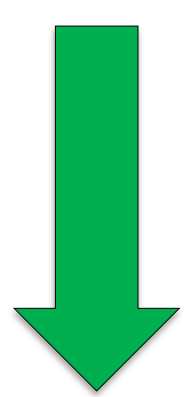


Complexity in textbooks in technology education from a gifted students' perspective

Helen Brink, Karlstad University, Sweden

Gifted students

- heterogenous group
- in every classroom
- high ability to reason
- rapid and deep learning
- creative
- high intrinsic motivation



Need for **complexity** (Brink, 2025b; Dai & Chen, 2013; Tirri & Laine, 2017)



Aim of the study

Investigate to what extent complexity is offered in activities in technology education textbooks for years 7–9.

Textbook analysis using AKTA Framework

3 textbooks for swedish technology education
12 chapters, 587 activities

Exemplar of coding

"Find out how far the development of self-driving cars has come." (*Analyze – Conceptual knowledge*)

Table 1. Coded activities (n= 587) using AKTA framework (Brink, 2025a).
Colored cells imply complexity.

		Abilities					
		Remember	Understand	Apply	Analyze	Evaluate	Create
Knowledge dimensions	Factual knowledge	204	173	0	0	0	0
	Conceptual knowledge	2	35	8	61	42	45
	Procedural knowledge	0	3	51	12	6	10
	Metacognitive knowledge	0	0	0	8	13	0

Results

- 2/3 of the activities non-complex.
- Most complex activities aim to develop students' conceptual knowledge and their ability to analyze technology.

Discussion

- Activities foster learning through information-seeking processes.
- Teachers play a pivotal role in designing technology education that incorporates complexity.
- Teaching based solely on textbooks is not sufficient to continuously meet the need for complexity.

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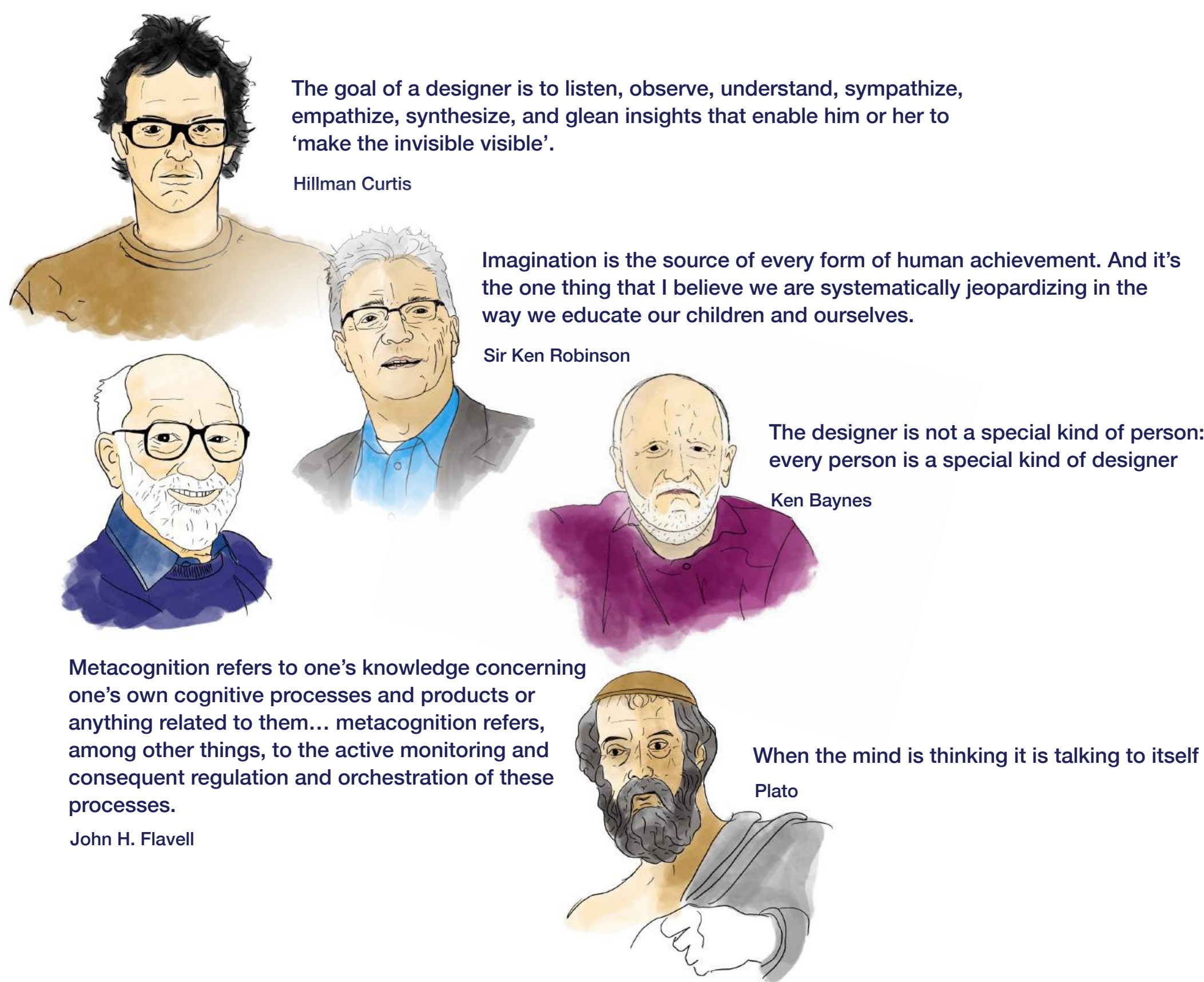


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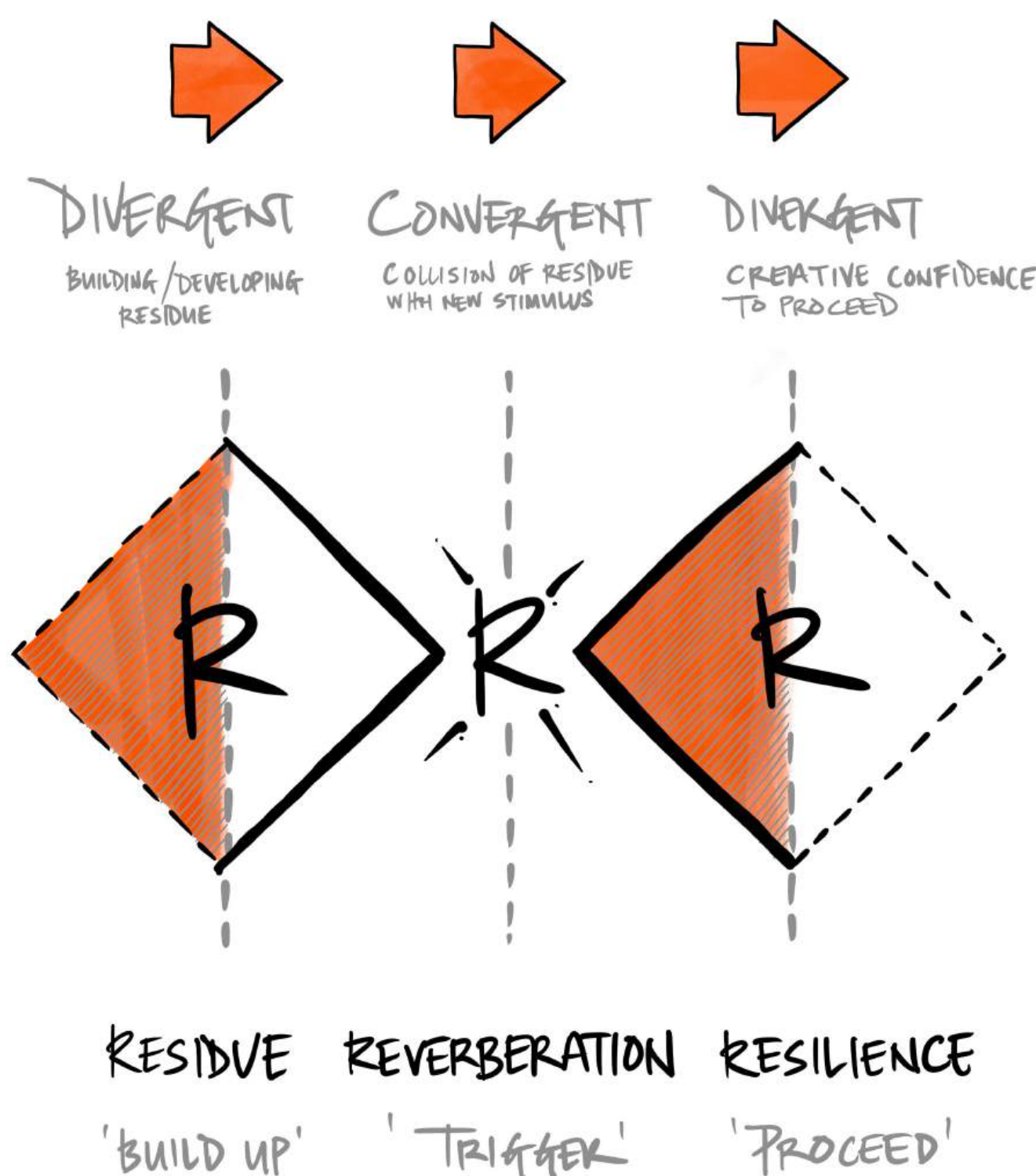
THE METACOGNATIVE TRIAD

Residue, Reverberation & Resilience

Deaglán Campbell, Niall Seery, 2026.



The Metacognitive Triad: Residue, Reverberation and Resilience, Deaglán Campbell, 2026. Adaptation of The Penrose Triangle 1958.

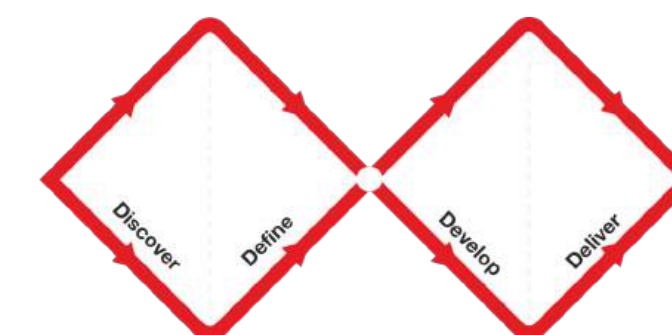


Residue, Reverberation and Resilience, Deaglán Campbell, 2026.

My conceptual framework of **Residue**: Left over thoughts and valuable knowledge, **Reverberation**: When it begins to 'feel' right and **Resilience**: When I have tried and failed (again and again) but I trust the process; so I proceed, as a pragmatic explanation and rationale for directing activity. Metacognitive reflection is not terminal; it cannot exclusively happen as a post-mortem at the conclusion of a project. Instead, it must be practiced continuously as a form of reflection-in-action. At the precise point of a failure - the metaphorical "smashed plate" - the student must engage in immediate cognitive reframing, actively asking: "**What did you learn here?**" and "**Even though it failed, what good stuff did you find?**"

By living with these new ideas in real-time, the learner is forced to evaluate their

progress and assign tangible value to the breakdown, determining whether the outcome helps them move forward. This immediate digestion of failure ensures that what was outwardly perceived as a setback is recontextualized as part of a learning continuum. Ultimately, this live reflection allows the intellectual **residue** of the mistake to be captured and stored as valuable knowledge for future breakthroughs.



The British Design Council - Double Diamond Model, 2003.

The British Design Council's Double Diamond Model was particularly helpful in illustrating the switching of thinking modes between different phases of the process. My intention for using this type of model allows me to create a framework for teaching design where we must be more explicit about the type of activities that occur at each of the phases.

NEXT STEPS

The next steps in my process are to conduct a series of studies using
1. In-Service Teachers
2. Professional Design Practitioners
3. Designers in Education

I aim to run these as workshops - allowing me to sense-check with as many variations of stakeholder as possible.

If you would like to participate in the study/workshops please contact me directly;
Deaglan.Campbell@tus.ie



The Educational Unicorn

How Relational Leadership Practices Shape Teacher Retention During Curriculum and Policy Reform: A Comparative Study of the UK and UAE.

STRAND :

‘technology education and social sciences’

Abstract

Teacher retention remains a persistent challenge within education systems undergoing sustained curriculum and policy reform. While existing literature has extensively documented structural factors such as workload, accountability mechanisms, and recruitment pressures, these explanations do not fully account for teachers’ decisions to remain in or leave the profession. Increasingly, research suggests that teachers’ lived experiences of leadership, emotional labour, and professional identity play a critical role in shaping professional sustainability.

This study responds to a notable gap in the literature by foregrounding the relational and emotional dimensions of leadership during reform, which remain under-represented in mainstream retention research. Drawing on comparative perspectives from the United Kingdom and the United Arab Emirates, the research explores how leadership is experienced across differing policy, cultural, and organisational contexts. The metaphor of *The Educational Unicorn* is used to capture teachers’ repeated search for environments in which accountability, reform, and professional care coexist without fracturing professional identity.

Key Words: *design and technology (D&T), Relational leadership; Teacher retention; Curriculum reform; Emotional labour; Professional identity; Comparative education.*

Conceptual Framework: Relational Leadership & Emotional Labour

This study is informed by relational leadership theory, which conceptualises leadership not as a positional role or technical function but as a relational way of being enacted through trust, recognition, dialogue, and ethical care (Giles, 2018; Smit & Mabusela, 2019). From this perspective, leadership is experienced through everyday interactions that shape meaning, belonging, and professional identity.

Closely aligned with this is the concept of emotional labour, which recognises the emotional regulation and identity work required of teachers, particularly during periods of reform-related uncertainty. When emotional labour is unsupported or rendered invisible, it is strongly associated with burnout, disengagement, and attrition. This study treats emotional labour not as an individual resilience deficit, but as a relational and leadership concern embedded within organisational cultures.

Methodology

This research adopts an interpretivist, phenomenological orientation, recognising that leadership and reform are experienced, interpreted, and given meaning through lived realities.

Design: Arts-informed narrative inquiry

Participants:

20 qualified secondary teachers

10 UK / 10 UAE

In-post practitioners and those who have recently left the profession

Data collection:

Semi-structured interviews (45–60 minutes)

An experience-based, anonymised vignette used as an elicitation device

Analysis:

Reflexive thematic analysis (Braun & Clarke, 2021)

Contextual lens:

Design and Technology education (used for access, not subject comparison)

The vignette is used to support phenomenological reflection rather than as a source of data, enabling participants to articulate relational and emotional experiences that are often tacit or silenced within performative cultures.

Research Questions

RQ1 – Experience and Mechanisms

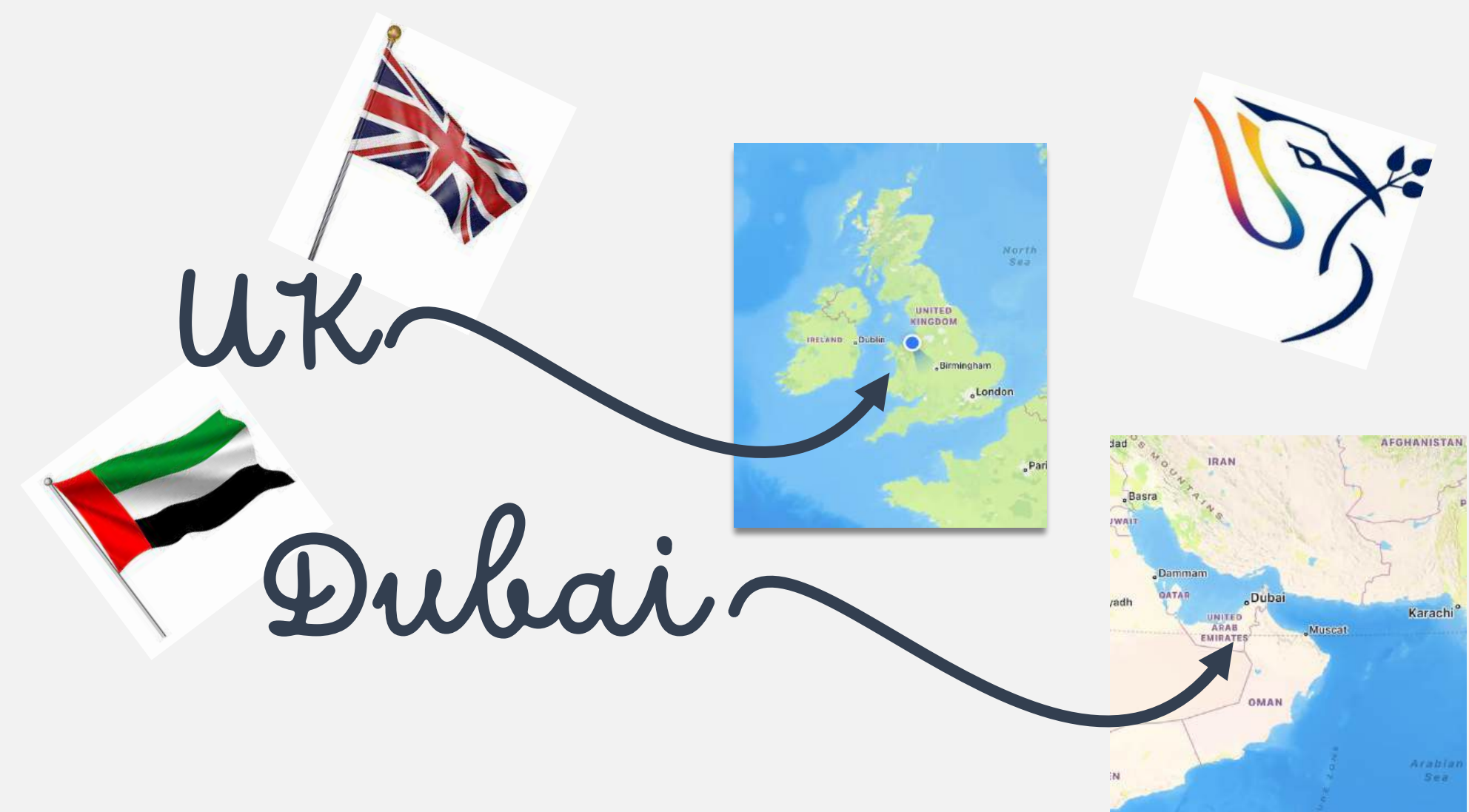
How do teachers experience relational leadership during curriculum and policy reform, and which relational practices (e.g. trust, care, communication, recognition) shape these experiences?

RQ2 – Impact on Identity and Retention

How does relational leadership during reform influence teachers’ emotional labour, professional identity, and intentions to remain in the profession?

RQ3 – Comparative Context

How does the influence and impact of relational leadership on teacher experience and retention differ between UK and UAE educational contexts?



Emerging / Anticipated Contributions

Leadership experienced as relational recognition or absence. Emotional labour as a mediator of reform sustainability

Retention as an ethical and relational outcome, not a workload variable

Contextual differences between national and international reform environments

The conditions under which *The Educational Unicorn* becomes myth or possibility

Implications for Leadership Practice

This study aims to contribute a practice-focused relational leadership framework that articulates conditions under which teachers are more likely to feel valued, supported, and professionally sustained during periods of change. Rather than offering prescriptive solutions, the framework foregrounds relational sensibilities, ethical care, and professional recognition as central to sustainable leadership. In alignment with the aims of a professional doctorate, the research also provides a foundation for practitioner-facing guidance to support school leaders navigating reform and retention challenges.

Conclusion

Retention is not solely a policy or workforce issue, but a relational and emotional one. Understanding how leadership is lived during reform is essential if schools are to move beyond deficit narratives and toward ethically sustainable professional cultures.

Future implications

As this research is currently at a pre-data stage, it is anticipated that the study will contribute to growing discussions around teacher retention, relational leadership, and professional sustainability within technology education contexts. By using technology education as a contextual lens, the findings are expected to inform future research, leadership development, and policy conversations about how reform is experienced at the relational and emotional level. The study may also provide a foundation for the development of practice-focused leadership frameworks that support ethically sustainable approaches to retention during periods of curriculum and policy change.



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Robotics as a Platform for Authentic Student STEM Achievement, Engagement, and Peer Learning

A Cross-National Study: Canada (Grades 7–9) & Ireland (Transition Year, 15–16)



Dr David Gill
(Canada)



Dr Clodagh Reid
(Ireland)



Dr Rónán Dunbar
(Ireland)

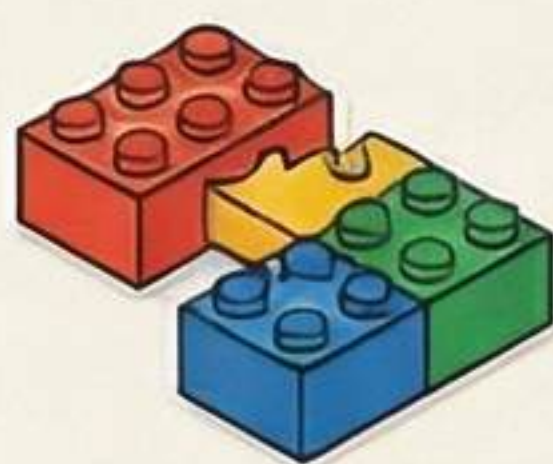


RESEARCH FRAMEWORK & METHODOLOGY



Investigating STEM Impact

The study investigates how integrating robotics programmes impacts student STEM achievement, engagement, and peer learning.



Qualitative/Constructivist Paradigm

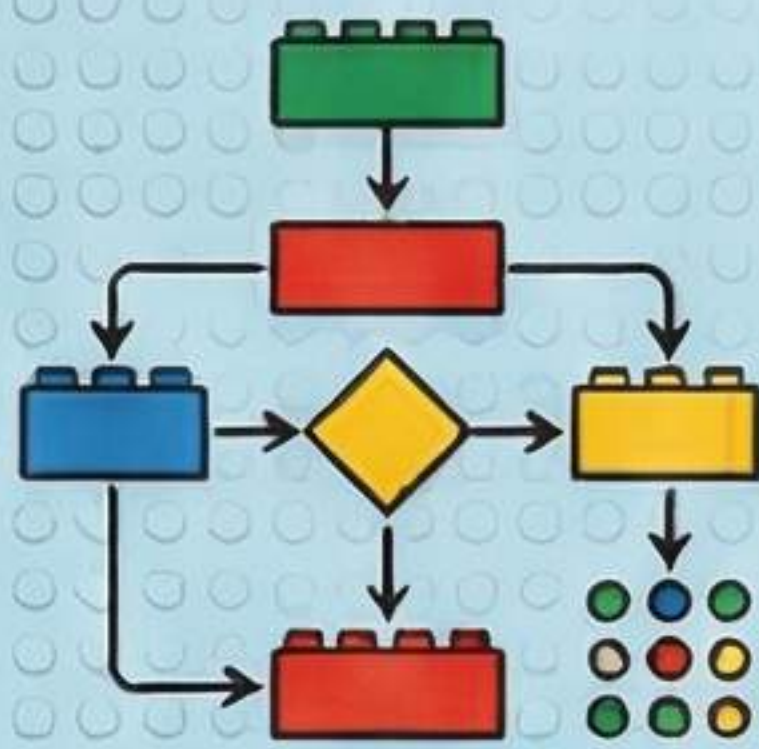
The study employs a case study methodology to explore the experiences of students and teachers within the FLL environment.

Data Collection Methods

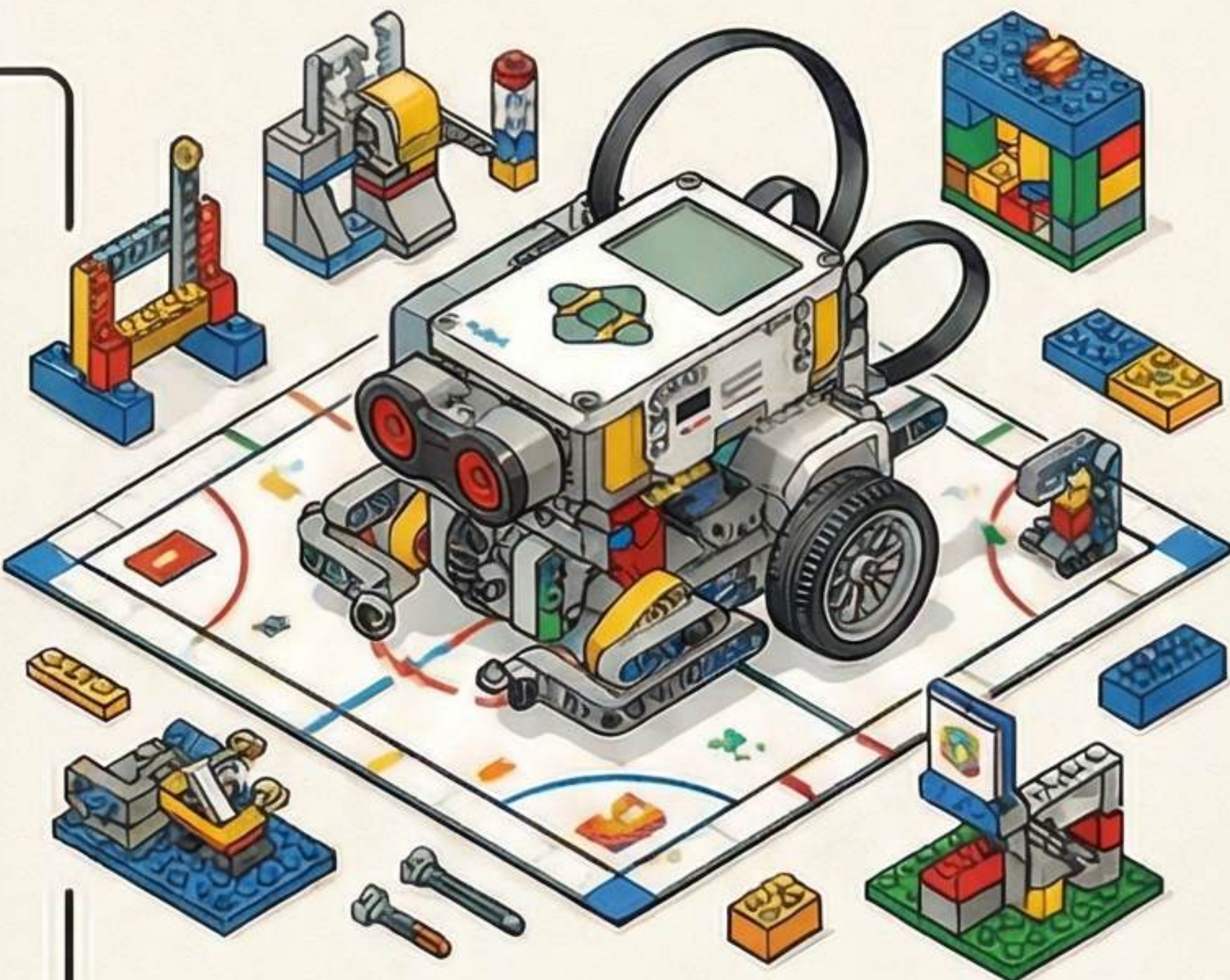


Evidence is gathered through researcher observations, teacher exit interviews, student focus groups, and the analysis of robotic artefacts and student planning documents.

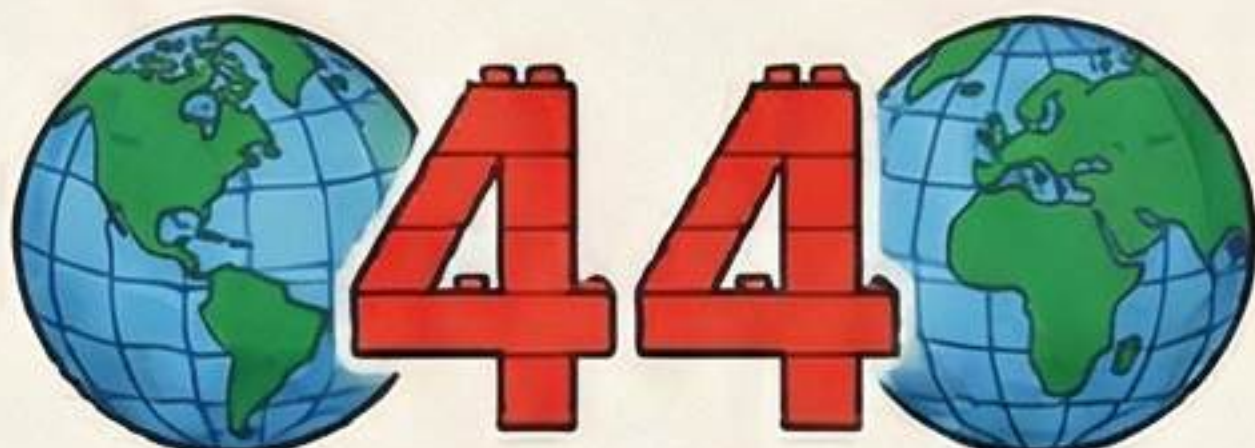
ANALYSIS METHODS: Thematic Analysis



Following the framework by Braun and Clarke (2006), the research identifies recurring patterns and themes across the multi-source dataset.



PARTICIPANT PROFILE: A Cross-National Study



Total Participants



- Canada (Grades 7–9)
- Amalgamated Academy & Pearce Junior High



- Ireland (Transition Year, ages 15–16)
- Mercy Secondary School Kilbeggan



Research Gap

To increase research on how authentic technical problem solving through Lego influence students' achievement and career awareness.

THREE MAIN FINDINGS

Redefined Achievement



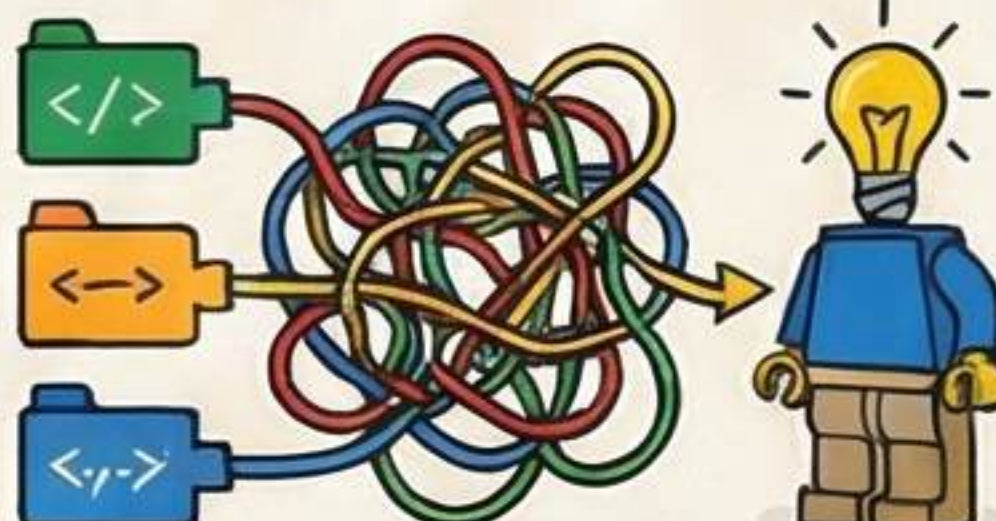
Students have shifted their view of success away from traditional high grades, instead valuing project completion and the ability to learn from failure.

Peer Mentorship & Social Learning



Technical understanding is enhanced when older students mentor newcomers, as explaining complex concepts to peers reinforces the mentor's own knowledge.

Resilience through 'Spaghetti Code'



Technical frustrations, such as complex coding errors, act as drivers for research and troubleshooting, resulting in deep pride and relief when solutions are found.



Out-of-school activities on adaptations to the local risk of flooding in urban planning

Jesper Haglund & Nina Christenson

Karlstad University, Sweden

Context of the study

There is a need for pupils to develop competence, in the form of knowledge, skills, and attitudes, in relation to environmental risks in society. Awareness of local vulnerable locations and how they can be protected in urban planning are relevant topics for integrative teaching in geography, science, and technology education.

In the present study, 150 grade 8 and 9 pupils participated during a day of out-of-school activities on the theme of climate-related risks with a focus on local risk of flooding.

The activities are designed to give pupils experience of and insight into technological solutions to pressing environmental challenges at the societal level.

Description of activities

During the Floodwalk, pupils walked along the riverside of Karlstad, their home city, and were made aware of locations that are particularly vulnerable to flooding, such as buildings close to the water and viaducts, and how the risk of flooding is addressed through adaptive measures in urban planning, such as building bicycle paths on banks along the river and canals.

In the game Riskville, a model of a city built with wooden blocks on a felt carpet, pupils were confronted with flooding scenarios, instructed to show on the carpet the consequences of such scenarios, and discuss how they could be addressed or prevented in urban planning.



Contact

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Data collection and analysis

Video data of pupils' interaction with Riskville have been collected and six pupils have been interviewed about their view on climate change and experiences of their participation in the out-of-school activities.

The data have been analysed from the perspective of pupils' expression of competence with regard to natural hazards and disaster risk reduction by means of adaptations in urban planning.

Results

The results show that the pupils appreciated the opportunity to learn about local risks of flooding, and were able to identify critical infrastructure that may be flooded or made inaccessible in flooding scenarios, and come up with suitable preventive measures.

Opportunities for technology education

The activities contribute to central learning goals in technology education, with a focus on local, authentic technological solutions to societal, environmental challenges.



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TEACHING AS A CONNECTED ENDEAVOUR

Katherine Larkin

Email: Katherine.larkin@tus.ie

Supervisors: Dr. Niall Seery and Dr. Rónán Dunbar

Relational



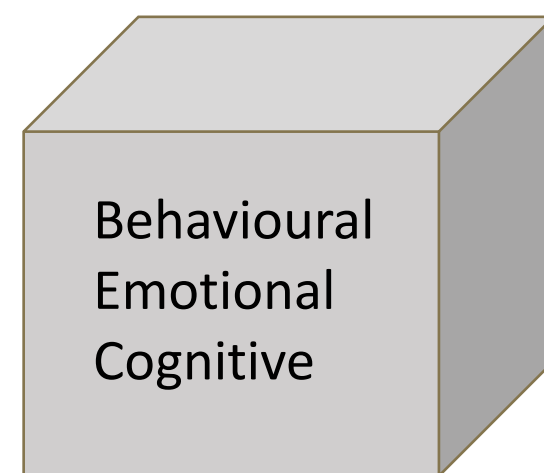
Students arrive with backpacks

Each student has a context and relationships that shape who they are and how they see and approach the world.
The backpack carried into school by each child



- Is the key to learning somewhere at the bottom of the bag?
- Is the bag bursting with enthusiasm and the joy of possibility?
- Is the bag too heavy to carry on their own?
- How many other questions are there that teachers need to ask...

3 Dimensional



Behavioural
Emotional
Cognitive

The Epic Teacher

Teachers bring what they have and ask students to do the same. Students need to **hear** and **see**, from our behaviours, that teachers are OPEN – they must not be afraid to address the backpack.

OPEN and HOPEful



Conditions Necessary

It must be safe to do so – **Trust**

There must be a higher purpose – **Hope**

High Standards – High Support

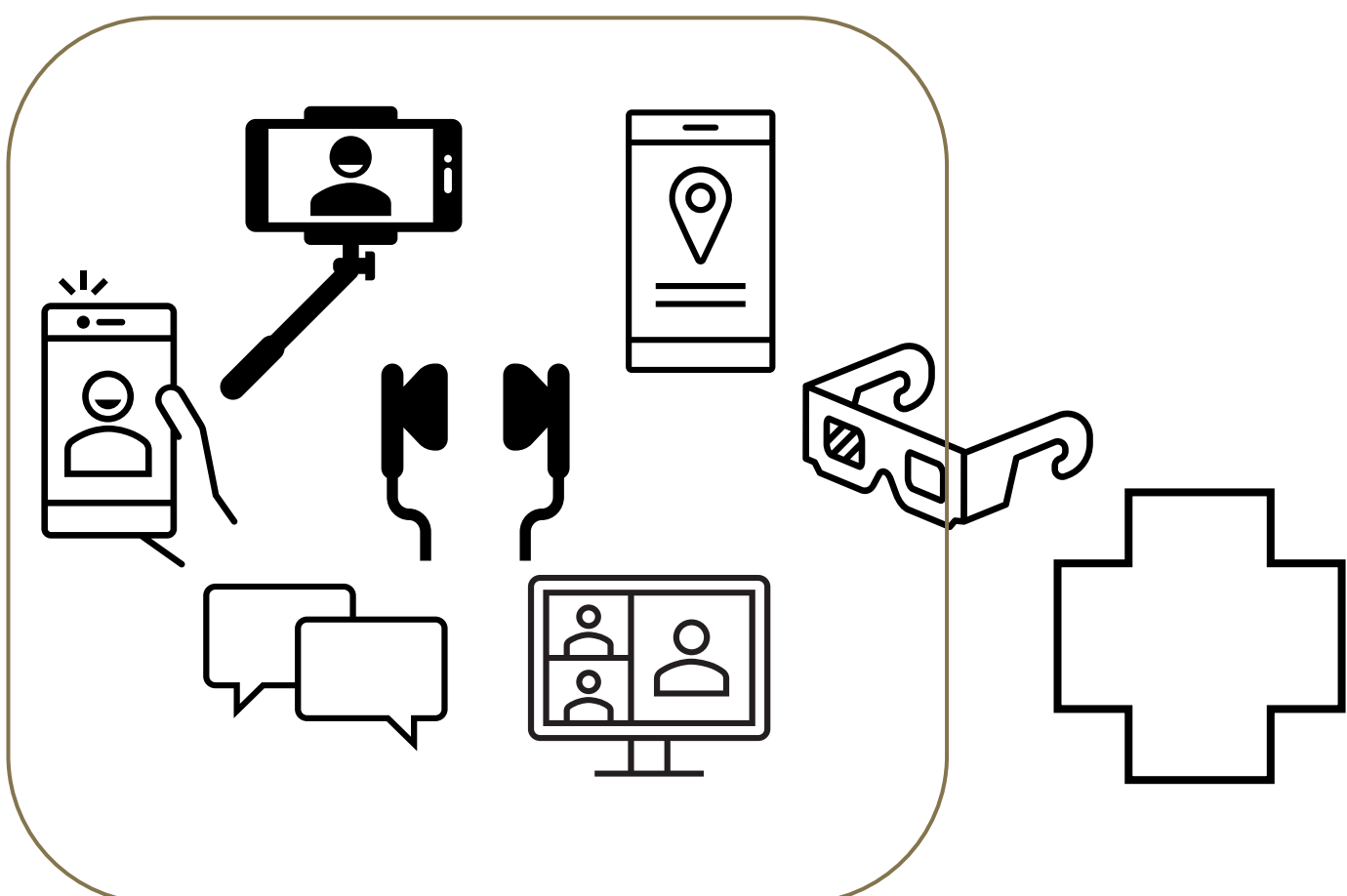
“I push because I know there’s more” but not so that you will break...

Open
Presence
Engaged
Nurturing

Honesty
Ownership
Perseverance
Empathy

Connected?

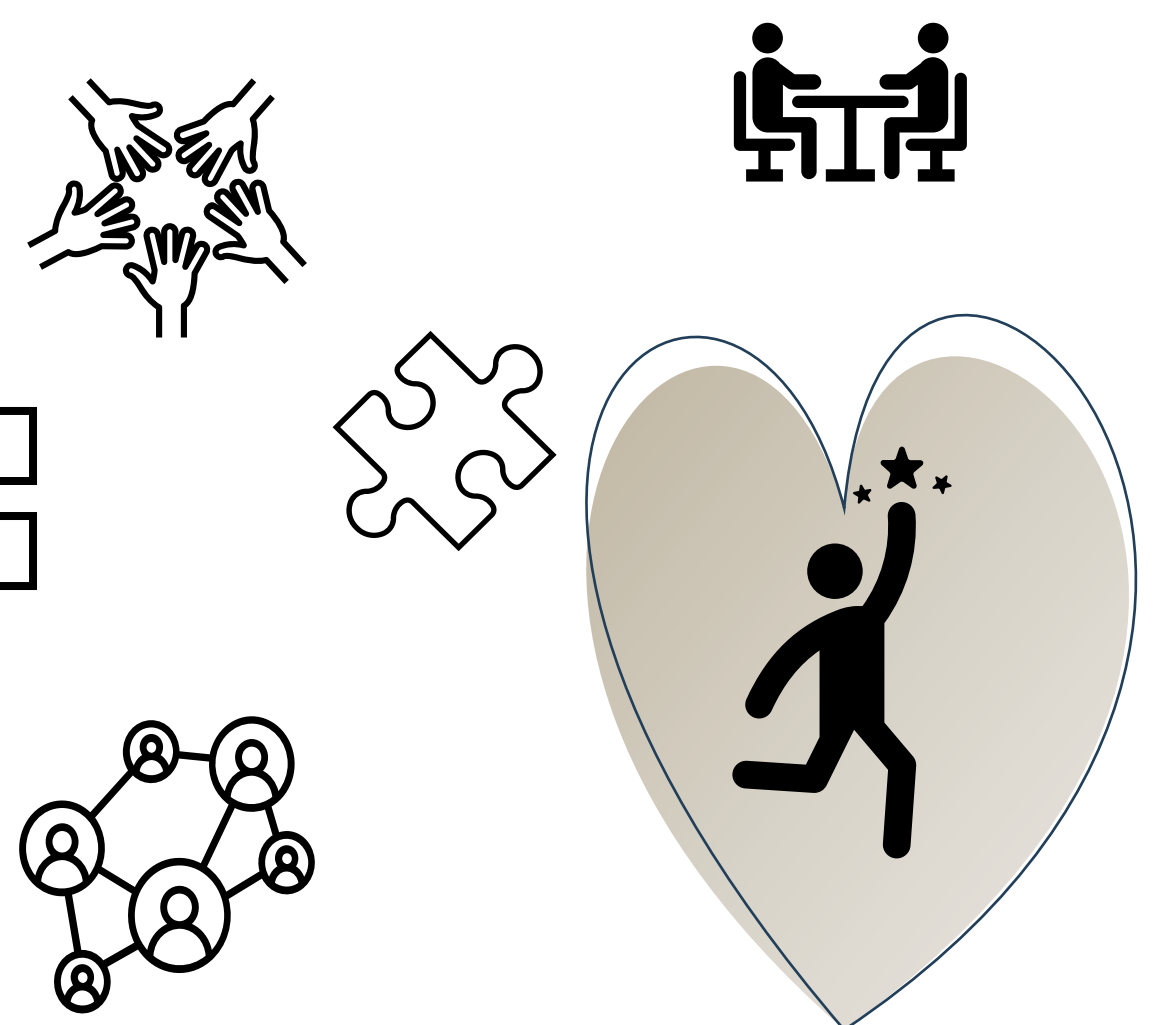
Technology - Human



Technology + Human



Humanity centric



Who are my learners?

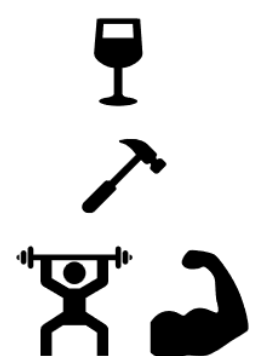


Nassim Taleb – Anti-fragile

Fragile

Resilient/Resistant

Antifragile



References:

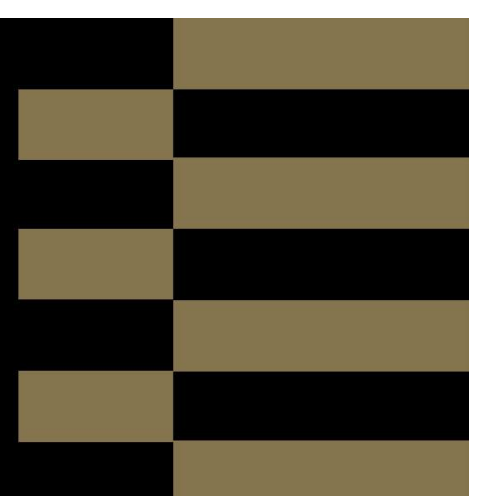
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Taleb, N. N. (2012). *Antifragile: Things That Gain from Disorder*. Random House.

Future Work:

- Investigate how to support self-efficacy while promoting anti-fragility
- How can graphicacy be developed to overcome frustrations of specific learning difficulties (SLD)/neurodiversity.





Technology Education as a Global Curriculum Phenomenon

A Theory-Led Definition and Typology

Matt McLain^{1*}, Peter Murphy², Brahim El Fadil³, Qiuyue Yang⁴, Mart Soobik⁵, Kaiju Kangas⁶, Émeline Roy⁷, Franz Schröer⁸, Wai Yip Antony Leung⁹, Jeffrey Buckley¹⁰, Keita Sera¹¹, Ruth Lemon¹², Soo Chin Chia¹³, Caroline McFarlane¹⁴, Adri du Toit¹⁵, Charlotta Nordlöf¹⁶, Szu-Chun Fan¹⁷, John G. Wells¹⁸

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The full article reporting on this study was submitted to an international journal on 29 March 2026 and has not yet been published at the time of creation of this poster on 15 April 2026.

INTRODUCTION

Despite four decades of scholarship and recurrent policy reform, technology education (TE) lacks international conceptual coherence. It is assembled from historically distinct craft, design, engineering, and socio-ethical traditions that are named, organised, and justified differently across jurisdictions.

This study provides the first theory-led, empirically grounded synthesis capable of defining TE internationally and capturing its patterned global variation.

Research Questions:

- **RQ1:** What features of TE are shared across international curricula?
- **RQ2:** What types of TE can be identified across international curricula?
- **RQ3:** What deeper structural dimensions explain variation across national approaches?

METHOD

Theory-led qualitative content analysis (QCA) of curriculum frameworks from 19 jurisdictions across five world regions, integrated with foundational and contemporary scholarship.

Data Sources: National curriculum documents from 19 jurisdictions; Pupils' Attitudes Towards Technology (PATT) Conference Series archive; articles from Design and Technology Education: An International Journal (DTEIJ), Journal of Technology Education (JTE) and International Journal of Technology and Design Education (IJTDE).

Three-Layer Analytical Framework:

- **Layer 1** – Descriptive coding: core features across curricula
- **Layer 2** – Axial coding: cross-national patterns and clusters
- **Layer 3** – Theoretical coding: meta-typological integration

Rigour secured through triangulation (Qualitative Content Analysis > Comparative Curriculum Analysis > Theoretical Framework Analysis), theoretical saturation, international expert cross-checking, and reflexive interpretation.

19 Jurisdictions Studied

Australia · British Columbia (Canada) · China · England · Estonia · Finland · France · Germany · Hong Kong · Ireland · Japan · New Zealand · Ontario (Canada) · Scotland · Singapore · South Africa · Sweden · Taiwan · United States of America

Purposively selected for geographical breadth, curriculum diversity, and epistemic traditions. All major world regions represented.

Pedagogical Universals

- Hands-on / minds-on exploration
- Making and prototyping
- Modelling and representation
- Collaborative design
- Problem-solving
- Reflection and evaluation
- Project-based learning

SHARED CORE (RQ1)

Common features of Technology Education:

- **Design & Designing:** Problem finding/solving, iterating, realising, critiquing
- **Systems & System Behaviours:** Structures, functions, interactions
- **Resources:** Materials, energy, information
- **Socio-Ethical Considerations:** Risk, impact, sustainability, values

GLOBAL TYPOLOGY (RQ2)

Five types of Technology Education:

- **Design-Led:** Iterative design–make–evaluate; user-centred; creativity, e.g. England, Singapore, Australia, Finland
- **Engineering-Oriented:** Engineering design; systems modelling; contextual problem solving, e.g. USA, China, France, Ontario
- **Craft-Based:** Embodied making; material intelligence; cultural heritage, e.g. Finland (Käsityö), German Werken
- **Everyday-Life-Centred:** Social contexts; technological citizenship; ethical relevance, e.g. Japan, German states, Taiwan
- **Integrated:** Cross-curricular STEM/STEAM; interdisciplinary; risk of dilution, e.g. Germany, BC (Canada), primary systems

META-TYOLOGY (RQ3)

Three axes of Technology Education:

- **Axis 1: Epistemic Orientation** – Design-led (England, Finland, Singapore) · Engineering-led (China, USA, France) · Craft-led (Finland)
- **Axis 2: Contextual Orientation** – Societal/Ethical (NZ, Japan) · Technical/Systems (China) · Everyday/Living (Taiwan)
- **Axis 3: Curriculum Structure** – Discrete subject (England, USA) · Integrated domain (Australia, Hong Kong) · Cross-curricular theme (Germany, primary systems)

KEY CONTRIBUTIONS

- First internationally intelligible, theory-led definition of technology education grounded in cross-national evidence.
- A global typology of five overlapping models capturing patterned curricular variation.
- A meta-typology (three axes) providing a transferable analytical framework for comparative research.

Reframes TE as a coherent global curriculum phenomenon rather than a cluster of disparate national traditions.

DEFINITION (RQ1)

The proposed international definition for Technology Education is:

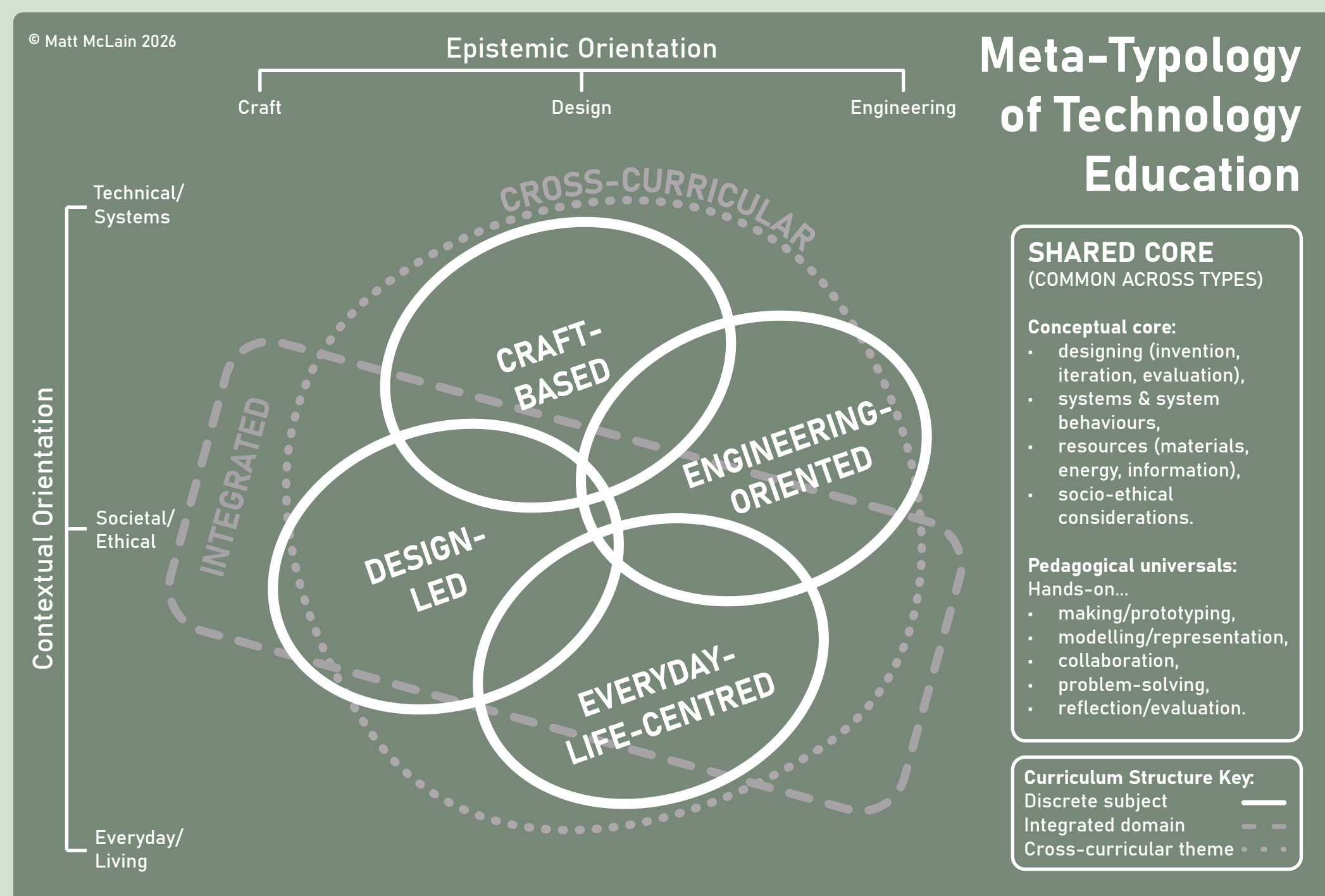
Technology education is a school subject and curriculum field concerned with how people design, make, understand, use, and evaluate technological products, systems, and environments. It develops learners' technological literacy and capability through engagement in design reasoning, material and digital practices, systems thinking, modelling, and socio-ethical reflection. Situated within cultural and ecological contexts, technology education empowers learners in primary and secondary schooling to intervene purposefully, creatively, critically, and responsibly in the human-made world.

IMPLICATIONS

- **For Research:** Enables cumulative, comparative studies using shared constructs; supports longitudinal tracking of reform trajectories.
- **For Policy & Curriculum Reform:** Provides tools to identify curricular orientation, compare with international patterns, and design resilient progression pathways.
- **For Teacher Education:** Offers a shared conceptual grammar for professional development structured around internationally validated constructs.

CONCLUSION

Despite significant cultural and structural variation, TE worldwide is consistently organised around a stable constellation of elements: design, making, systems, resources, values, and human technological capability. The definition, typology, and meta-typology together constitute the most comprehensive conceptual framework yet produced for understanding TE as a global curriculum field.



Examining Grade-Level Differences in Design Awareness through Learning Various Technological Contents in Japanese Junior High Schools

Hisashi Nakahara¹, Tetsuya Uenosono², Keita Sera³, Jun Moriyama⁴

¹ Oita University, ² Hirosaki University, ³ Nara University of Education, ⁴ Hyogo University of Teacher Education

1. Introduction

Background: Design is a core element of technology education, characterized by the co-evolution of problems and solutions through iterative processes (Cross, 2001; Dorst & Cross, 2001).

Research Gap: While design learning is emphasized, large-scale empirical evidence on how students’ design awareness develops across grades remains limited.

Objective: To examine grade-level differences and developmental tendencies in students’ design awareness across Grades 7–9 through accumulated learning in four technological domains.

2. Methodology

Participants

1,227 valid responses (Grades 7–9, Japan; response rate: 90.4%)

Survey (Nov 2025)

Likert scale items (5-point) and open-ended questions.

Categories

1. User perspective
2. Goals & constraints
3. Prototyping & improvement
4. Collaboration & subjects
5. ICT use
6. Metacognition

Analysis

- Kruskal–Wallis test (non-parametric)
- Qualitative coding ($\kappa = .80$)

4. Qualitative Results

Core Design Conception

- Most frequent: User perspective & needs (35.1%)

Developmental Change

- Increase in goal/problem setting (higher grades)
- Shift toward principle-based reasoning

Interdisciplinary Links

Mainly: Mathematics, Science, Art

Science references $\uparrow$ in Grade 9

⚠️ Limited Awareness

- Prototyping / collaboration / ICT rarely mentioned
- ~70% reported no explicit subject connection

5. Conclusion & Implications

Key Finding

Multi-year learning supports a shift from *Product-centered* $\rightarrow$ *Integrated problem-solving perspectives*

Educational Implications

Need to explicitly scaffold:

- Iteration (prototyping & improvement)
- Collaboration
- ICT as a cognitive tool

Limitation

Cross-sectional design $\rightarrow$ indicates tendencies, not causal development

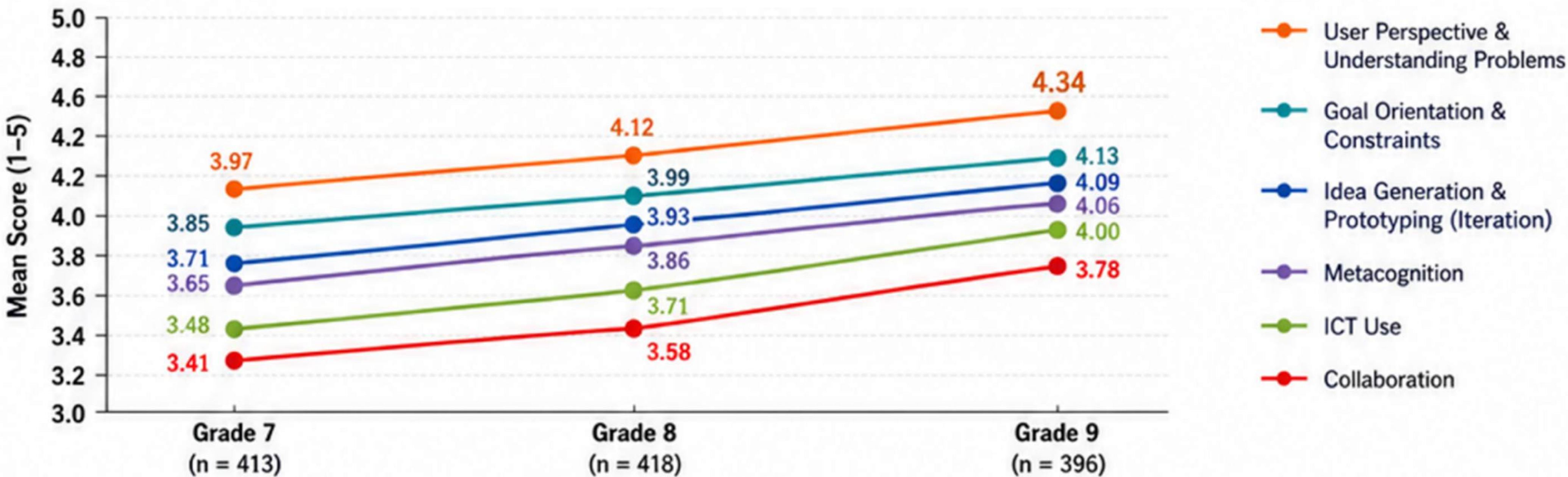
Future Work

Longitudinal studies & analysis of instructional practices

3. Quantitative Results

Development of Design Awareness Across Grades

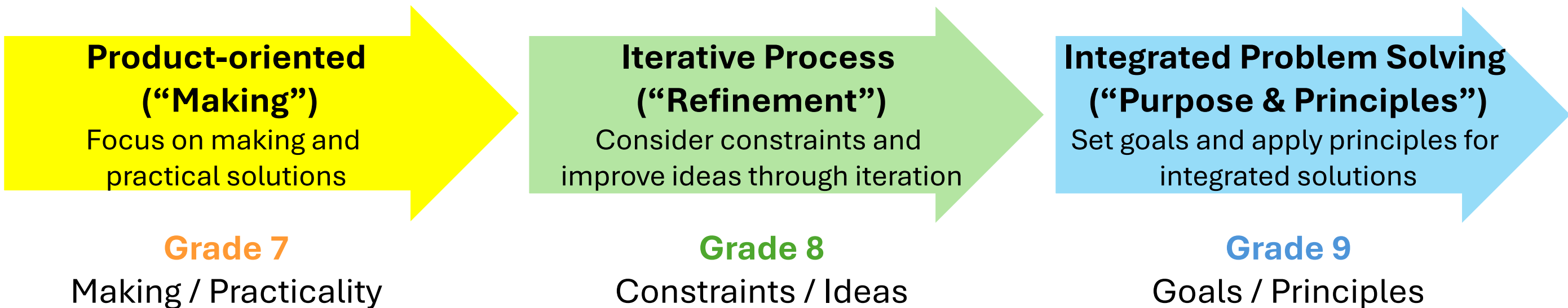
All categories show significant grade-level differences ($p < .001$)



Significant increases were observed across all categories, indicating the development of students’ design awareness.

These findings suggest a shift from product-centered making to iterative and integrated problem solving.

Shift in Design Conceptions Across Grades



INTRODUCTION

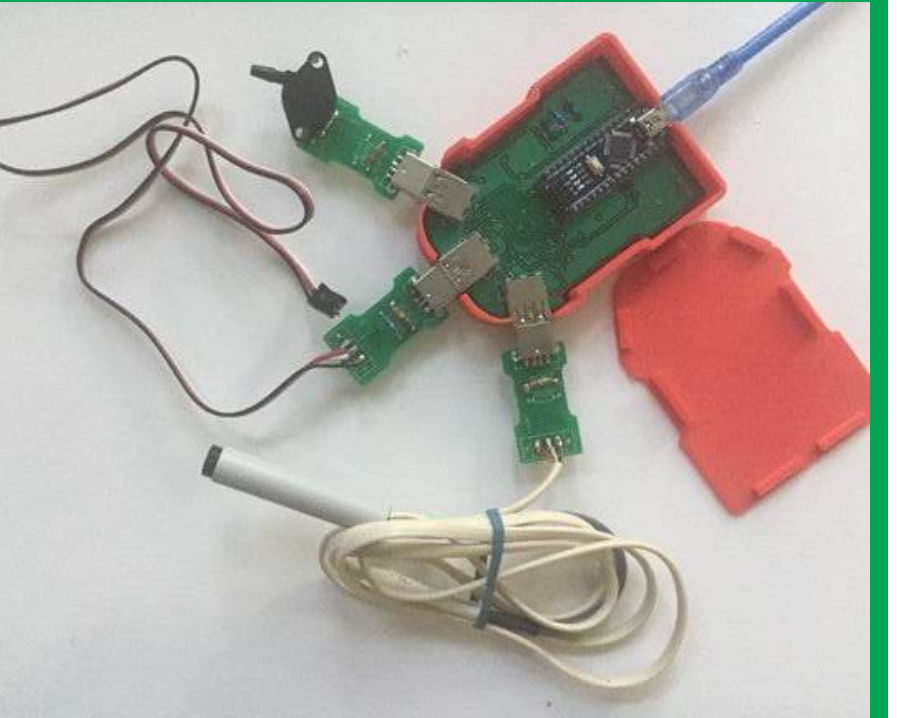
Technologies that rely on sensors and converters to transform physical quantities into digital signals are ubiquitous in contemporary technological systems, from everyday devices to industrial applications. Yet these systems often operate as “black boxes” for learners. Whereas it was once possible for a secondary school student to understand how an alcohol thermometer works, understanding an electronic thermometer—or more broadly a sensor-based system—may appear abstract and inaccessible (Sorey, Willard & Kim, 2010). This opacity is problematic because technology education should enable students to understand how devices function, rather than interact with them without conceptual insight. In science and technology learning, understanding how a measuring instrument works is essential to grasp measurement error and assess the validity of experimental data (Fournier, 2001). The aim of this study is to develop and evaluate a STEM intervention to support students' understanding of how electronic measuring devices function.

THEORETICAL FRAMEWORK

This study revisits findings from a broader research project (Pellerin, 2016) through the lens of Raymond Duval's theory of semiotic representation registers (Duval, 1995). This framework supports the interpretation of how students develop technological understanding of electronic measuring systems by coordinating symbols (voltage, current, temperature, etc.) across discursive (linguistic and symbolic) and non-discursive (figurative and graphic) registers within STEM contexts (science, technology, engineering, and mathematics).

PREVIOUS RESEARCH

Microcomputer-based laboratory systems have been used to support students' understanding of physical phenomena through sensor-based measurements and modeling. Among these systems, the MicrolabExAO was initially developed in Québec (Nonnon, 2002) and its development has also been extended to Moroccan universities (Margoum, 2022).



METHOD

Objective 1: To develop a STEM educational intervention

Using a research-development methodology (Harvey & Loisel, 2009), the intervention consisted of a construction-based STEM activity in which students built electronic measuring instruments using sensors. It was designed following a didactic engineering approach and refined through a functional trial with an expert in technology education.

Objective 2: To test the intervention with secondary school students

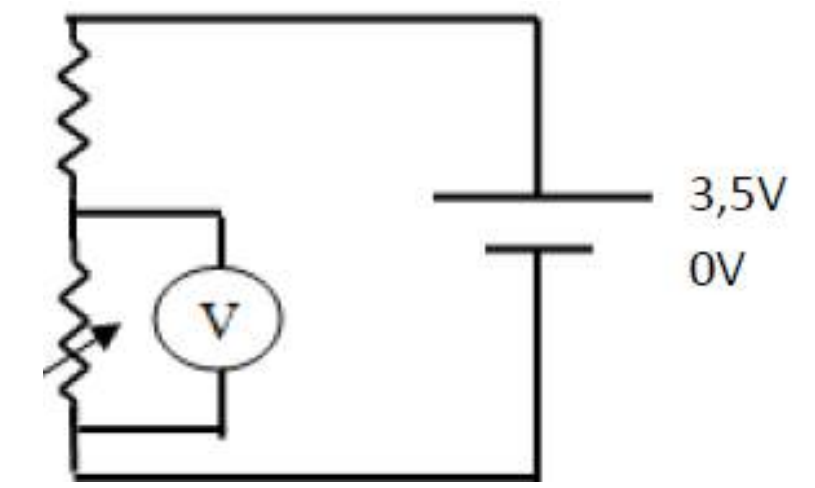
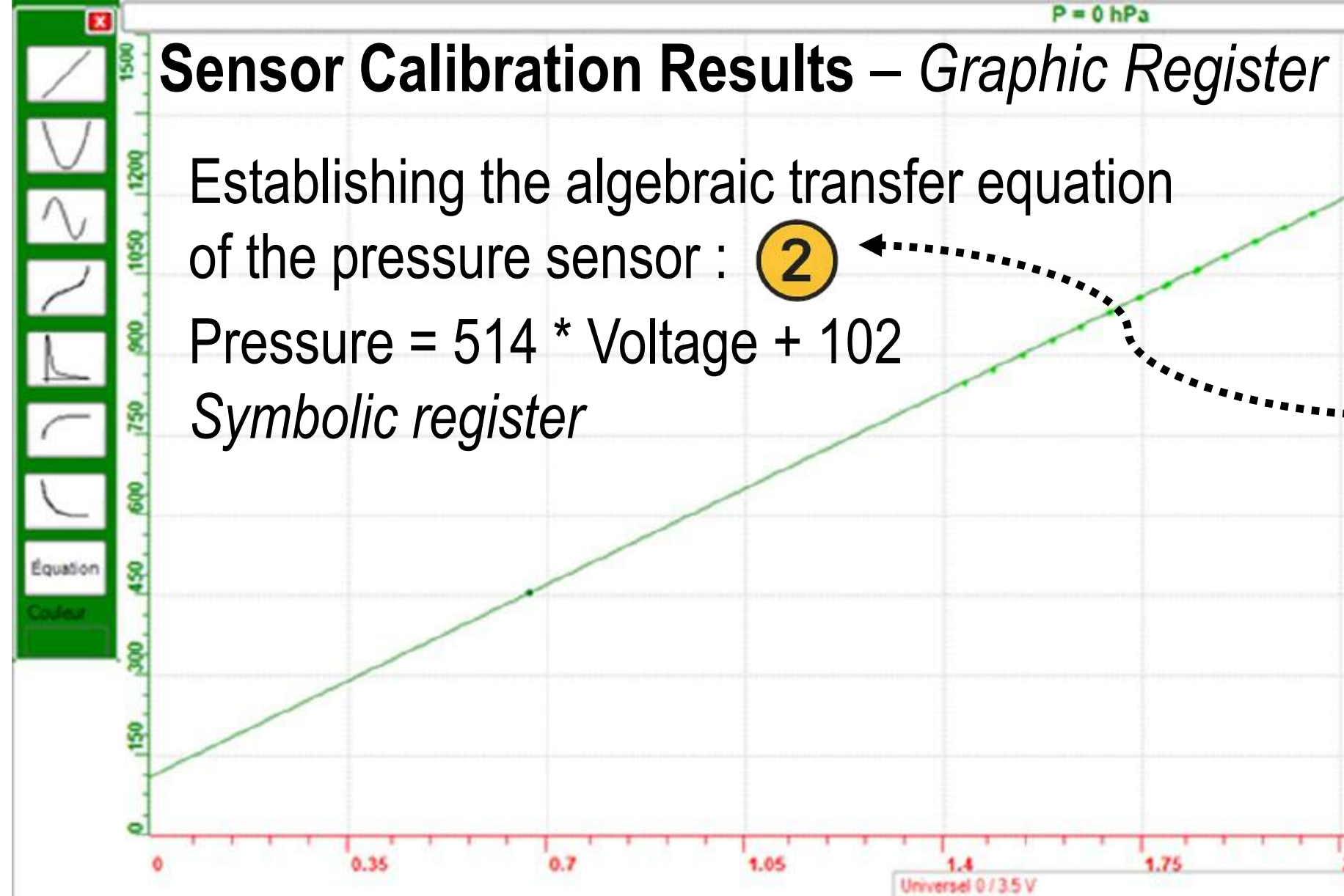
Empirical trial: Six 10th- and 11th-grade students received basic training on transducers and built four measuring instruments (thermometer, luxmeter, position detector, manometer) across four 2-hour sessions. Each session focused on one instrument, with progressively reduced guidance to foster STEM integration through practical interdisciplinary activity (Boix-Mansilla, 2010).

Objective 3: To evaluate understanding of electronic instruments

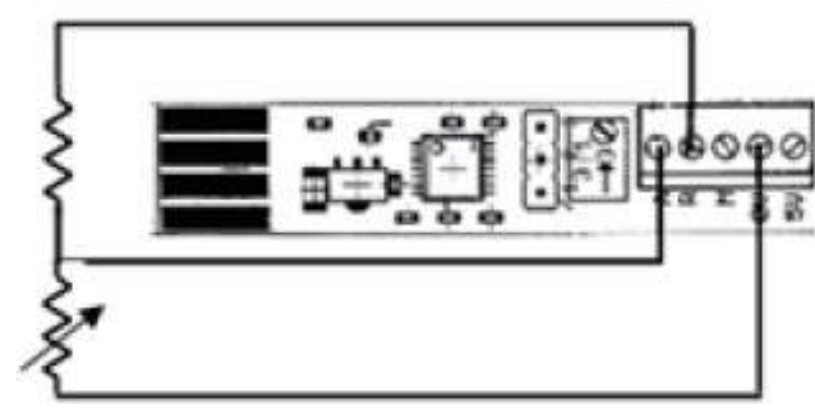
Students' autonomous manometer construction was observed, filmed, and followed by a questionnaire on understanding. A mixed thematic content analysis with emergent coding was conducted on transcripts of students' actions (Paillé et Mucchielli, 2021).

RESULTS

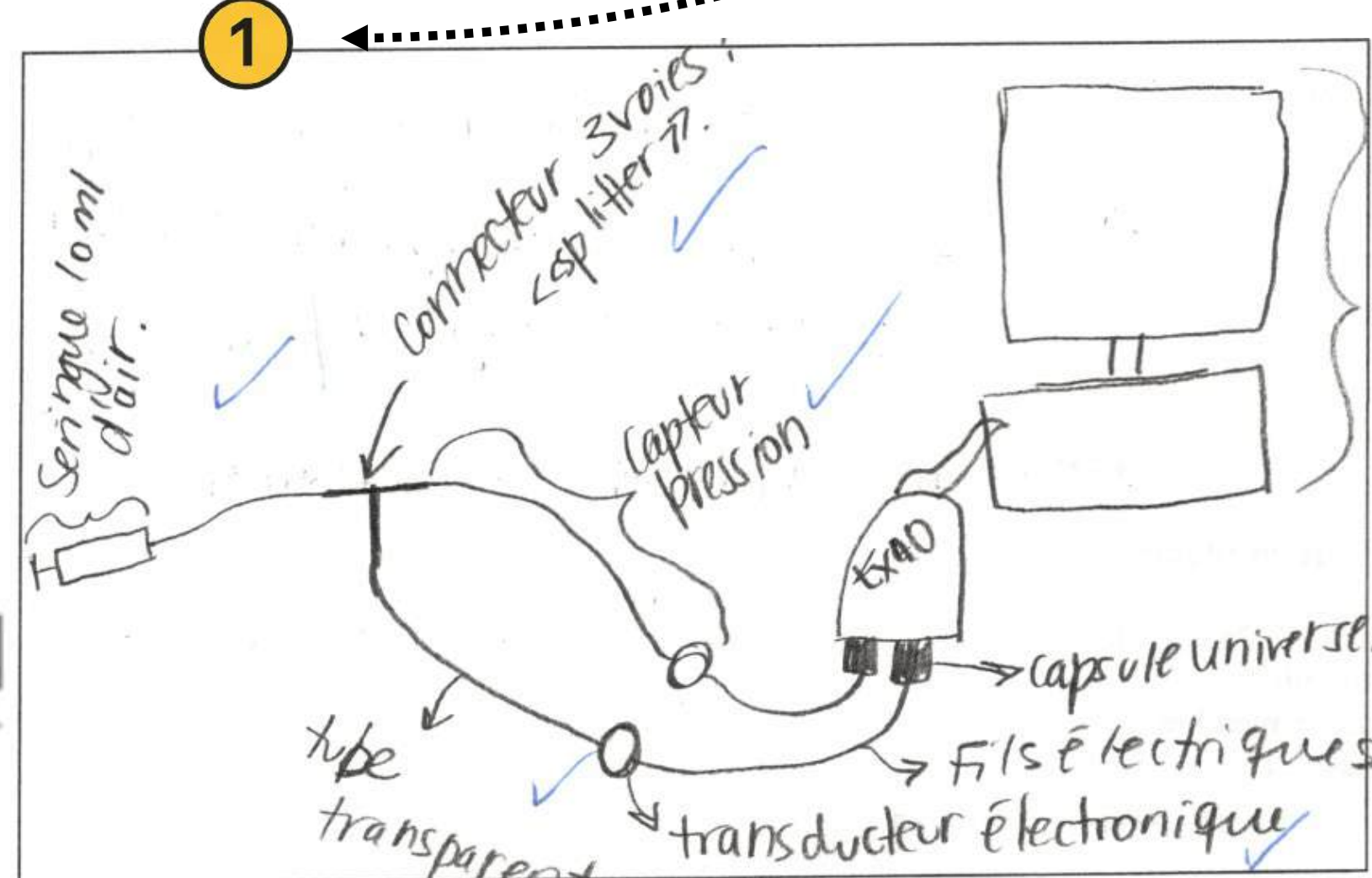
Y-axis : Reference manometer pressure (hPa)



Circuit Diagram – Graphic register



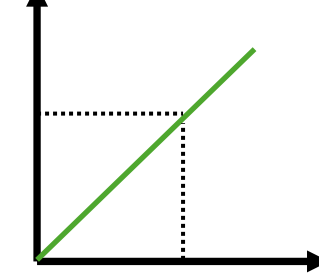
Wiring Diagram (universal capsule) – Figurative register



Assembly Diagram – Figurative register

MODEL – Symbolic semiotic register :

Algebraic transfer equation
Pressure = a * Voltage + b



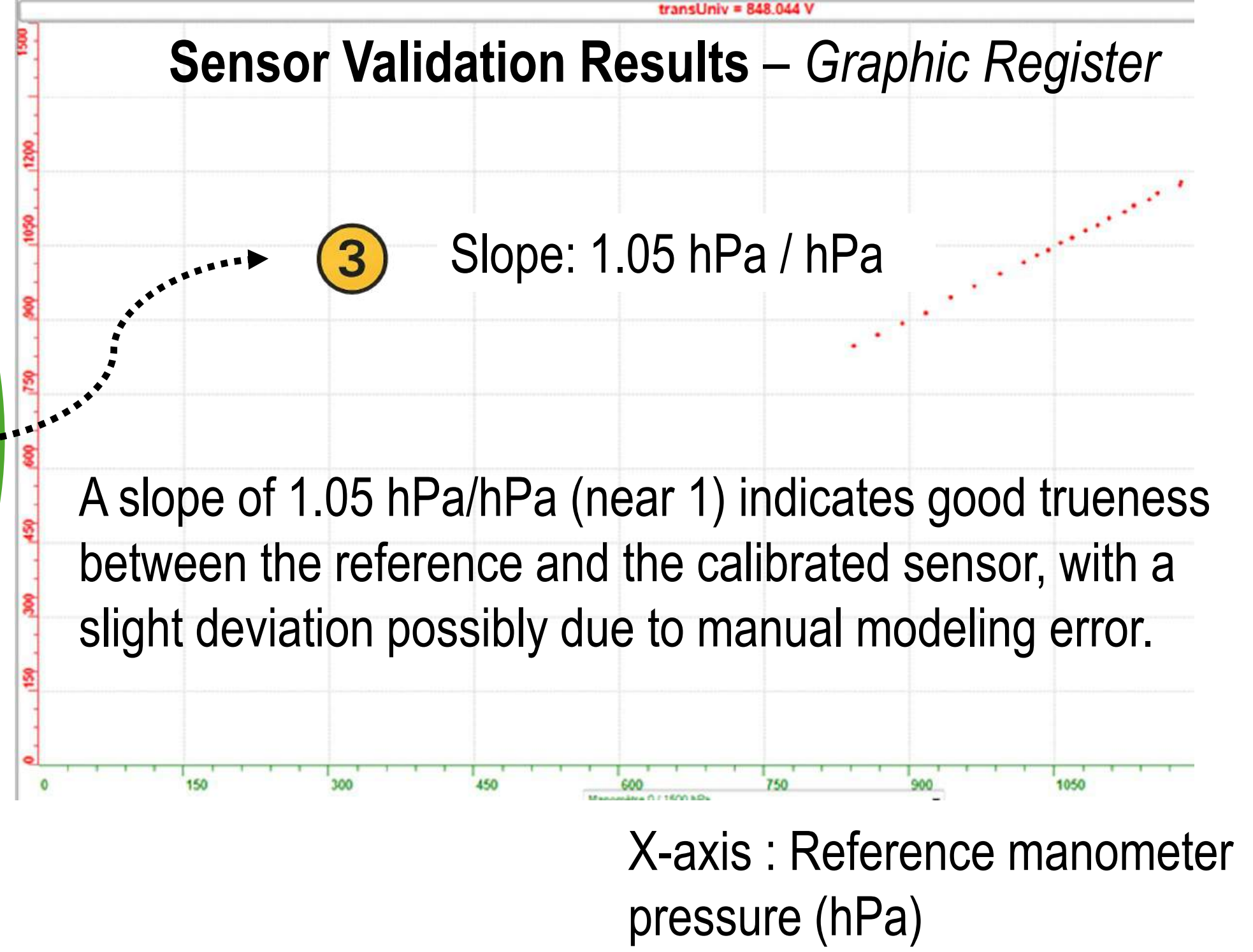
Model construction through induction

Model validation through deduction

REALITY – Non semiotic register :

Interaction of variables (pressure and voltage) during experimental action

Y-axis : Calibrated sensor pressure – new manometer (hPa)



Student Performance on Tasks Involving Sensor Construction and Conceptual Understanding

Students	A1	A2	A3	A4	A5	A6
Autonomous construction of the manometer	Yes	Yes	No	Yes	Yes	No
Efficiency coefficient - effective actions vs action model	74%	91%	69%	100%	87%	50%
Understanding of sensor functioning – qualitative questions*	67%	93%	47%	80%	60%	40%
Interdisciplinary learning via semiotic register coordination	Yes	Yes	No	Yes	Yes	No

*Example of A2's answer to the post-test question: "Explain how a thermistor works" :
"The temperature sensor consists of two resistors mounted on a universal capsule. One of the resistors is fixed, while the other is variable; the sensor measures the voltage across the variable resistor. By varying the temperature, the voltage measured by the interface also changes. A graphical modeling of this variation allows the derivation of a mathematical equation linking temperature to the voltage measured by the sensor. The electronic thermometer thus operationalizes voltage into temperature."

DISCUSSION

The construction of an electronic manometer engages students in understanding a sensor-based technological system that converts pressure into voltage, making explicit the internal functioning of a device that might otherwise remain a “black box.” Through calibration and validation, students establish an algebraic transfer equation linking pressure and voltage, combining inductive model-building with deductive validation. Results show that 4 out of 6 students constructed their manometer autonomously by developing their own experimental protocol, with efficiency rates ranging from 50% to 100% — 100% meaning each action matched the expected action model. We cross-referenced this practical indicator with a qualitative questionnaire on understanding how the instrument works. Student A2's response illustrates a coherent understanding of how a thermistor-based measuring device operates. These results suggest that constructing sensor-based instruments can support students' technological understanding by helping them grasp how devices convert, model, and validate data. Rather than interacting with the instrument as an opaque artifact, students engaged with its internal logic and system structure. Some methodological limitations must be noted. The sample includes only six students, and the experiment relies on specific hardware and software — the MicrolabExAO system developed at Université de Montréal — which may limit transferability to other contexts.

CONCLUSION

This study shows how high school students can develop technological understanding by constructing electronic measuring systems. By engaging with sensor-based devices, students move beyond using instruments as opaque tools and begin to understand their internal functioning and data conversion. As digital technologies increasingly mediate everyday life, technology education should strengthen students' capacity to critically engage with such systems, rather than interact with them as black boxes. These findings invite further exploration of how this construction-based approach could extend to other technologies, including smartphone-integrated sensors, whose operations may appear even more inaccessible.

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Primary school preservice teachers' design of food trucks in technology education

Anna Perez¹, Björn Citrohn¹, Johan Boström¹, & Jesper Haglund^{1,2}

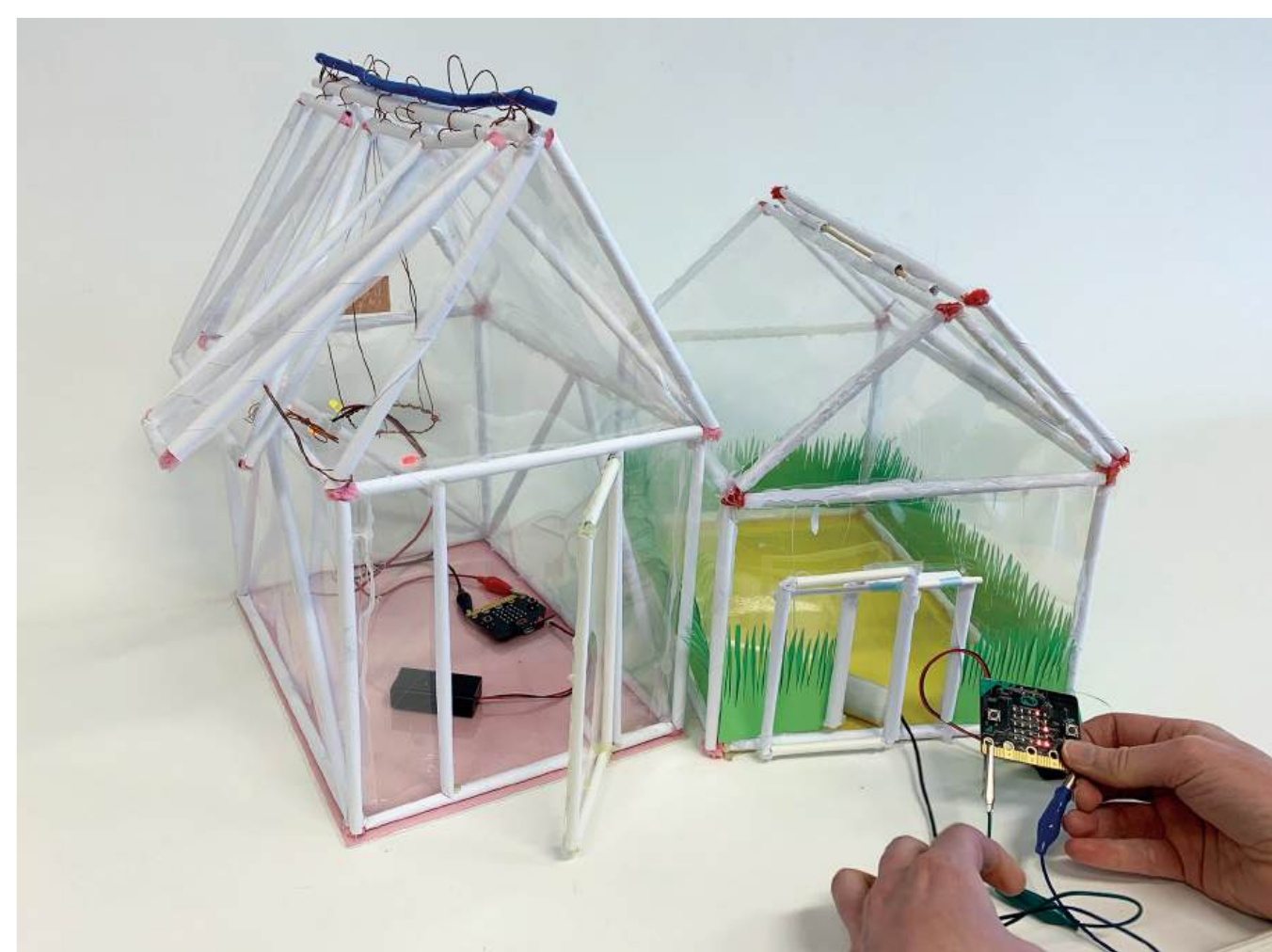
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BACKGROUND

In a technology course at the primary school teacher programme at Linnaeus University, preservice primary school teachers take part of a group project where they design a technical system.

One ambition with the project is for students to work hands on with the design process. Another ambition is to introduce programming in the context of technical solutions to challenges in society, in line with the technology syllabus for compulsory school in Sweden.

Different cohorts of preservice teachers have had different assignments, such as the design of a greenhouse, where the temperature is measured and regulated with a thermostat and the opening and closing of a window.



CONTEXT OF THE STUDY

The present study focuses on preservice teachers' assignment to design a model of a food truck. Originally, the task was based on the absence of food trucks on the university campus, which adds authenticity to the task, called for in technology education. Students were asked to conduct a market analysis to explore what a hypothetical food truck could offer and where it should be placed.

The food truck assignment included drawing in Tinkercad, programming of functions using microbit, e.g. a queue system, construction of a physical model of the food truck, and peer presentations.



AIM OF THE STUDY

The aim of the study is to develop empirically grounded knowledge about preservice teachers' experiences of carrying out a task in technology education in which they design a technical system, and how well prepared they feel to teach the subject of technology with a focus on the design process and programming.

METHOD

Semi-structured interviews were conducted with seven (N = 7) primary school preservice teachers, after their participation in the project with the food truck.

Themes for the interviews included:

- the role they took as individual students in their project groups
- what they have learnt about the design process and programming in the context of technology education
- how well prepared they feel for teaching technology in primary school

The interviews undergo thematic analysis, with a focus on the participants' experiences of taking part in the food truck project, and of teaching technology in their future role as teachers in primary school.



PRELIMINARY FINDINGS

Early analysis reveals that the interviewed preservice teachers took different roles in their study groups. Roles included responsibility for overall design of the food trucks, the digital tools, and aesthetic appearance of the food trucks.

The rationale to take on responsibility for the digital tools varies. Some preservice teachers express a particular interest in the digital tools, while others had identified this as an area where they needed to develop their competence.

The preservice teachers differ in their views of the role of programming in the food truck assignment. While some of them reflect on how programming can be a part of technical solutions to challenges in society, others regard it as an isolated task in the assignment.

They express confidence in their role of teaching technology in primary school, albeit with differences across topics, such as the design process and programming.



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From Using to Learning: Educational Possibilities of 3D Printing in Technology Education through Design-Based Research

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01 INTRODUCTION

3D printing activities in schools often remain superficial (“**keychain syndrome**”) and lack meaningful design decisions.

This study explores how students position 3D printing when they freely select and combine woodworking and 3D printing in an open-ended design task.

Research Questions

- RQ1: What aspects of 3D printing do students identify as advantageous when engaged in a problem-solving task that incorporates both woodworking and 3D printing?
- RQ2: Compared with students who use 3D printing primarily for decorative purposes, what kinds of design-related considerations characterize students who use 3D printing in a functional manner?

02 RESEARCH METHOD

Research Design (DBR)

Participants

- 177 first-year lower secondary students (Japan)
- No prior formal experience with 3D printing

Learning Design

1. Preparation tasks (restricted materials)
2. Open-ended problem-solving task
3. Reflection

Task

Students identified real-life problems and designed and fabricated products by selecting:

- Woodworking • 3D printing • Combination of both

Data Collection

- Student products (N = 120 analyzed)
- Questionnaire (7 items ; 4-point scale: enjoyment, difficulty, etc.)
- Open-ended responses → quantitative text analysis (KH Coder)

03 RESULT



Functional group showed **significantly higher awareness** of 3D printing characteristics than the decorative group.
($M = 3.01$ vs. 2.53 , $p = .014$, $d = 0.58$)

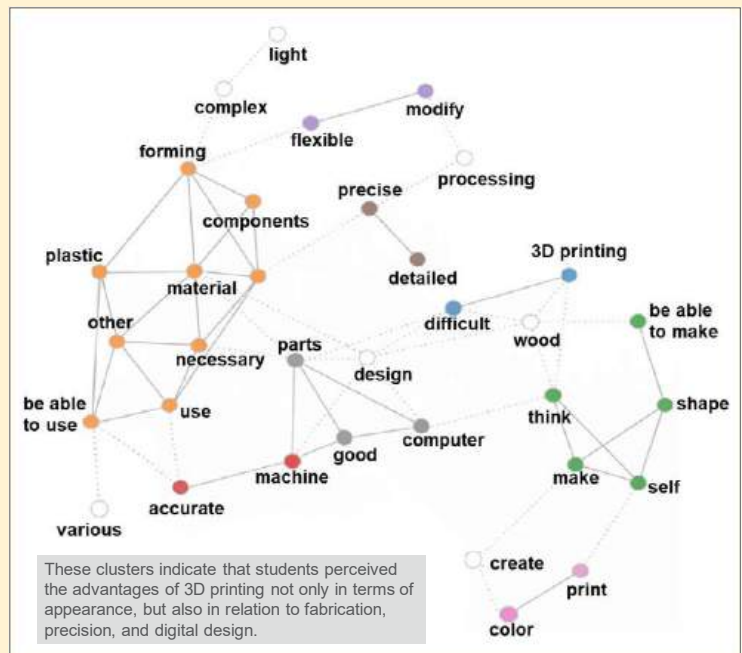
04 CONCLUSION & IMPLICATIONS

- Students used 3D printing as either a functional design resource or a decorative addition.
- Using 3D printing alone did not necessarily lead to an understanding of its technological characteristics.
- Its educational value emerged when students compared it with other materials and fabrication methods.
- Technology education should help students understand 3D printing as a design option, not merely as a tool to experience. This perspective may extend to other emerging technologies.

03 RESULT

Multiple perspectives on 3D printing advantages
Clusters represent different perspectives on 3D printing:

- **Expression** (make, shape, color, self, create)
- **Fabrication** (plastic, material, components, parts)
- **Precision** (precise, detailed, accurate, machine)
- **Digital design** (computer, design, 3D printing, difficult)



These clusters indicate that students perceived the advantages of 3D printing not only in terms of appearance, but also in relation to fabrication, precision, and digital design.

Characteristic words differed between groups:

- **Decorative group** → Usability and appearance (easy, color, self)
- **Functional group** → Materials and design (shape, wood, design, complex)

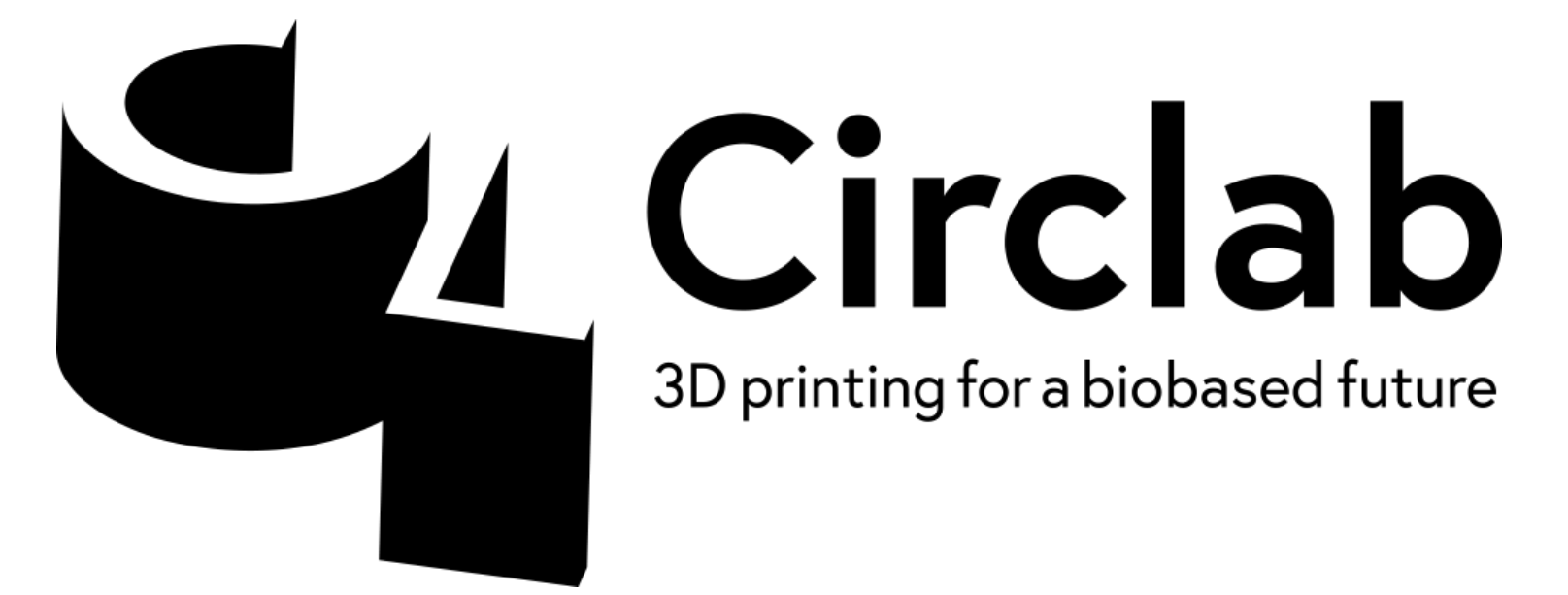
Functional group	Score	Decorative group	Score
shape	0.297	make	0.209
make	0.257	self	0.133
wood	0.143	be able to	0.133
think	0.130	easy	0.098
computer	0.071	color	0.083
flexible	0.062	3D printing	0.079
design	0.062	design	0.061
complex	0.062	decide	0.061

Note. Scores indicate how characteristic each word is for each group based on association measures (e.g., Jaccard coefficient).

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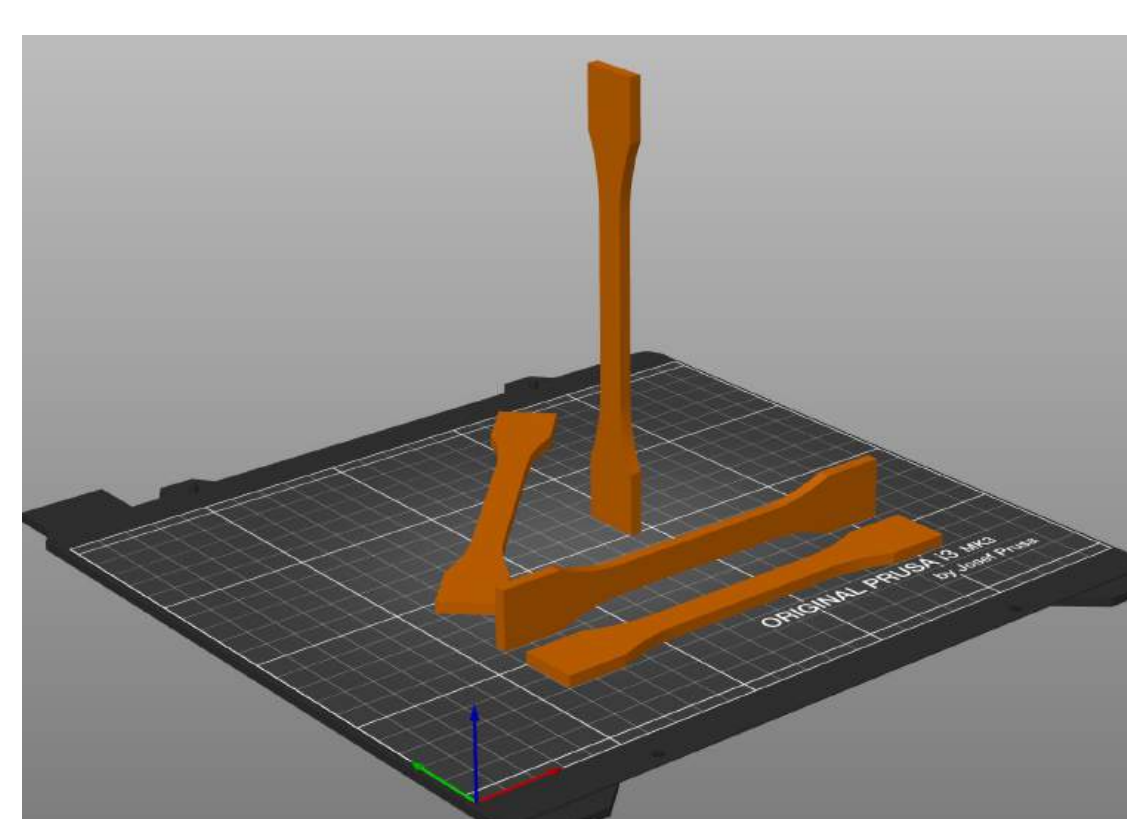
3D printing with thermoplastic and biobased composites at an industrial testbed as an authentic resource in teaching of the design process

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Context of the study

In our research project, a collaboration has been formed between upper-secondary school teachers in the chemistry and technology subjects at Stjerneskolan, researchers in science and technology education at Karlstad University, and Circlab, an industrial testbed for sustainable additive manufacturing, by 3D printing of composites from thermoplastics, bio-based and recycled materials.



Resources at the 3D printing testbed

The facilities at Circlab are available on a continuous basis for participating teachers and pupils. This includes access to up-to-date equipment for CAD modelling, 3D printing, 3D printable materials (composites) and mechanical testing of artefacts.

In this way, the testbed provides opportunities for increased authenticity in the teaching of the design process, with connections to the demands of present customers, and involvement in construction of prototypes and finished products.

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Study design

The present study is conducted as a design research study in teaching of technology at the upper-secondary technology programme, in which teaching sequences are developed, tested, and evaluated through rounds of iterations.

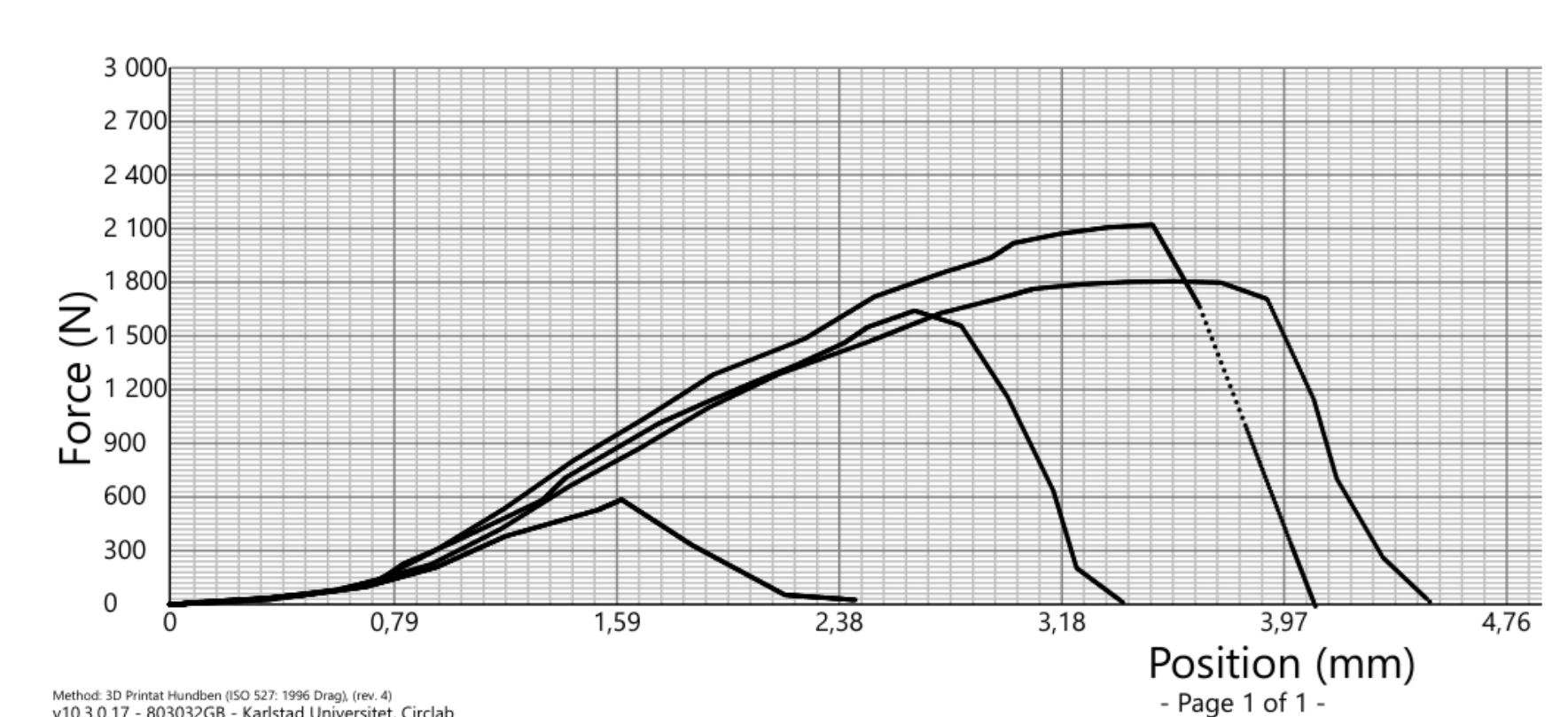
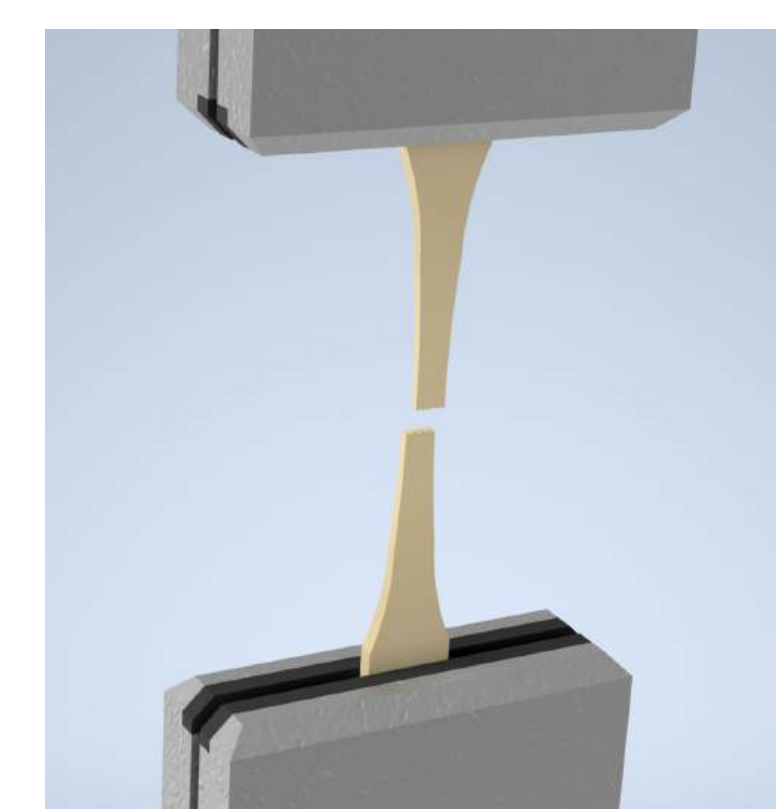
Video observation of pupils' interaction with the resources at the testbed and amongst themselves, and group interviews with pupils about their experiences will be conducted.

Teaching design

The action research will be conducted as two modules.

In the first module, pupils will be introduced to 3D scanning of objects and 3D printing of models of the objects in different materials.

In the second, more advanced module, pupils will draw a standard object in CAD, a "dogbone", 3D print it in different materials and along different printing directions, and make a tensile test of its material properties.



Expected outcomes and implications

As a planned outcome of the study, teaching sequences will be developed and tested, in which pupils gain insight into the design process, composite material properties, and some considerations of sustainability, by access to up-to-date equipment at an industrial testbed.

At the organisational level, implications will be drawn with regard to experiences of a collaboration between a school, an industry, and academia.

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