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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.

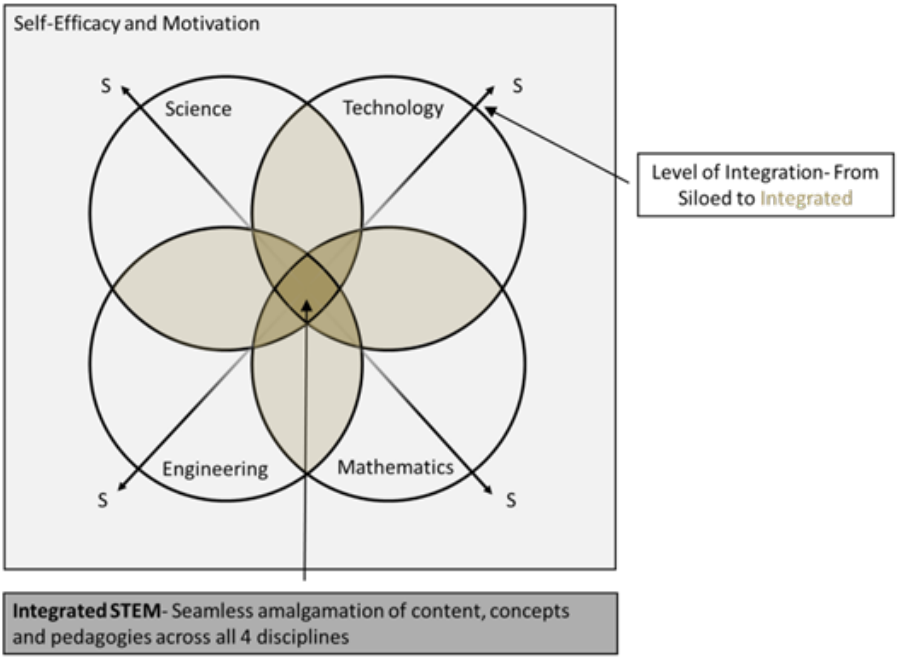
Previous works in this area highlight a number of key challenges for educators, inter alia the lack of clarity in definition, the challenges in effective integration, the low teacher confidence in providing effective iSTEM experiences (Stack Mulvihill, Reid, and Dunbar 2025), and existing frameworks, 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

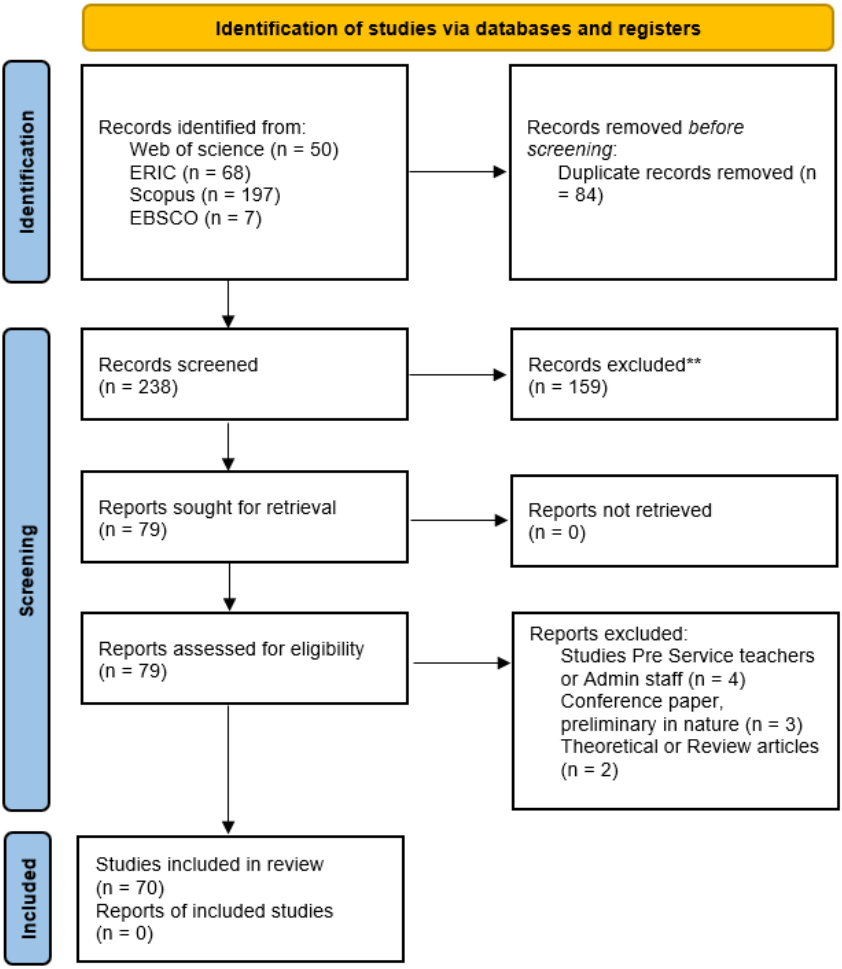
Following this search process, articles were screened for duplicates, leaving 238 articles remaining. Figure 3, below details the reviewing, screening and inclusion process which followed. A total of 70 articles were retained after title, abstract, keyword, and full text screening. The remaining articles 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).

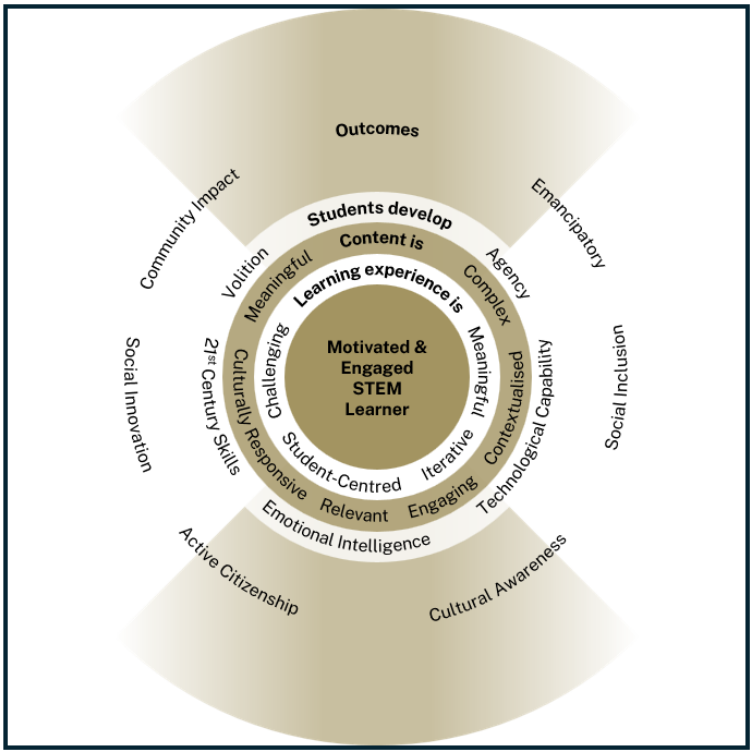
5 RECENTRING TECHNOLOGY EDUCATION, A COMBINED THEORETICAL FRAMEWORK

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

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