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

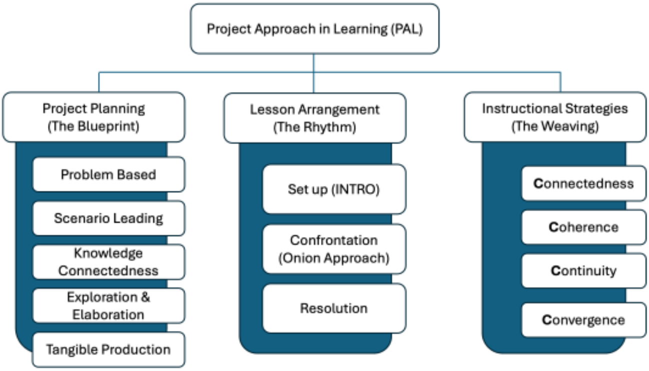
The core problem this paper seeks to address is the need for a pedagogical bridge that connects the activities of classroom instruction with the ultimate task of a STEM project: the cultivation of Engineering Thinking as a higher-order mindset. We posit that the Project Approach in Learning (PAL) model 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.

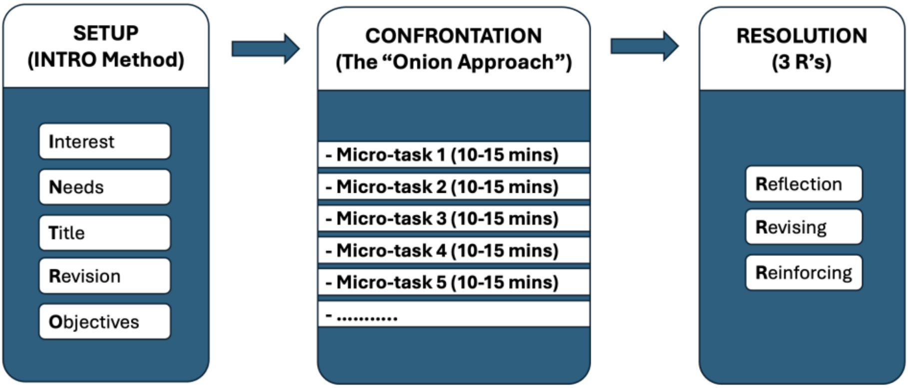
- Tangible Production: This has the most direct link to Materialization in ET. Tangible Production is a firm requirement of PAL, expecting students to solve real-world problems by creating functional, testable artifacts. While our primary context often emphasizes physical objects, "tangible" is not strictly 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

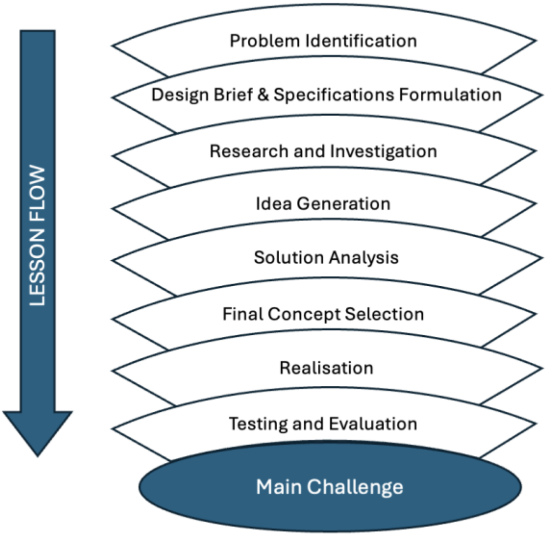


PAL's Lesson Arrangement adopts a three-act structure: Setup, Confrontation, and Resolution.

- **Setup (INTRO Method):** The INTRO method aligns perfectly with ET's **Visualization, Systemization,** and **Documentation**. The entire INTRO process—establishing **I**nterest, clarifying **N**eeds, giving a **T**itle, conducting **R**evision, and defining **O**bjectives—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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