Article

Journal of Educational Computing Research
2024, Vol. 62(2) 431–467

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/07356331231211916
journals.sagepub.com/home/jec
Sage

Integrating Computational Thinking Into Scaffolding Learning: An Innovative Approach to Enhance Science, Technology, Engineering, and Mathematics Hands-On Learning

Hsin-Yu Lee[1], Ting-Ting Wu[2], Chia-Ju Lin[1], Wei-Sheng Wang[1], and Yueh-Min Huang[1]

Abstract

Science, Technology, Engineering, and Mathematics (STEM) education is essential for developing future-ready learners in both secondary and higher education levels. However, as students transition to higher education, many encounter challenges with independent learning and research. This can negatively impact their Higher-Order Thinking Skills (HOTS), engagement, and practical expertise. This study introduces a solution: Computational Thinking Scaffolding (CTS) in the Jupyter Notebook environment, designed to enhance STEM education at the tertiary level. CTS incorporates five phases: Decomposition, Pattern Recognition, Abstraction, Algorithm Design, and Evaluation. Utilizing a quasi-experimental method, we assessed the impact of CTS on the HOTS, engagement, and practical skills of undergraduate and postgraduate students. Our findings hold substantial relevance for university educators, academic advisors, and curriculum designers aiming to enhance students' HOTS and hands-on

[1]Department of Engineering Science, National Cheng Kung University, Tainan, Taiwan
[2]Graduate School of Technological and Vocational Education, National Yunlin University of Science and Technology, Douliou, Taiwan

Corresponding Author:
Yueh-Min Huang, Chair Professor, Department of Engineering Science, National Cheng-Kung University, No. 1, University road, Tainan 701, Taiwan, R.O.C.
Email: huang@mail.ncku.edu.tw

capabilities in STEM disciplines. The results validate the effectiveness of CTS in elevating tertiary STEM learning outcomes, and they spotlight the adaptability of the Jupyter Notebook as a valuable tool in higher education. In conclusion, our research underscores the merits of CTS for improving outcomes in higher STEM education and sets a benchmark for future endeavors in this domain.

Keywords

science, technology, engineering, and mathematics hands-on learning, scaffolding learning, computational thinking, higher-order thinking skills, hands-on abilities, engagement, higher education

Introduction

The importance of Science, Technology, Engineering, and Mathematics (STEM) education in preparing students with necessary knowledge and skills for future challenges has been well-acknowledged not only in K-12 settings but also in higher education institutions (Wang & Degol, 2017). As universities and colleges aim to produce graduates ready to tackle global problems, higher-order thinking skills (HOTS) and student engagement have been recognized as pivotal success metrics in STEM curricula at tertiary levels (Baharin et al., 2018). In the higher education context, traditional teaching methods such as lectures, dominated by a teacher-centered approach (Czajka & McConnell, 2016), have been criticized for their inability to sufficiently engage students and foster HOTS, especially for adult learners who crave deeper, more contextual learning experiences (Good & Lavigne, 2017). As a response, educational researchers, especially those in universities and colleges, have shifted their focus towards more active learning strategies, specifically, hands-on learning (Chang & Chen, 2022), which encourages active engagement and the development of HOTS in students. Nevertheless, in higher education settings where autonomy is emphasized, without sufficient guidance, students can easily feel overwhelmed, which can hinder their engagement and obstruct the cultivation of HOTS (Idris et al., 2023; Lee et al., 2023b; Wu et al., 2023a).

To counteract these potential difficulties, an instructional approach known as scaffolded learning has emerged as a viable solution. Originating from Proximal Development theory proposed by Vygotsky and Cole (1978), scaffolded learning emphasizes the role of teacher guidance in the learning process. Educators offer crucial guidance and support to students, assisting them in accomplishing tasks they would find too challenging to tackle independently. The scaffold, akin to a construction frame supporting a building, is gradually removed as the learner gains competence and independence, fostering self-regulated learning (Berk & Winsler, 1995).

However, applying this teaching approach to the complex realm of STEM education poses certain challenges. It requires well-articulated guiding principles to provide a structured learning process, making intricate STEM concepts accessible to learners (Schaper et al., 2022; Wang et al., 2022a). In this context, computational thinking, a process that systematically integrates computer science principles and procedural problem-solving methods, seems an ideal guiding principle for scaffolding in STEM education (Mumcu et al., 2023; Wing, 2006). By incorporating CT within the scaffolding process, problem-solving can be effectively broken down into more manageable steps, thereby enhancing students' comprehension and mastery of the subject (Mumcu et al., 2023). This integration of CT within scaffolding learning can clarify complex concepts and methodologies, offering a more effective and engaging learning experience (Srisangngam & Dechsura, 2020; Wang et al., 2022b).

In view of these considerations, we propose a Computational Thinking Scaffolding (CTS) approach for STEM hands-on activities, built on the five steps of computational thinking proposed by Wing (2006) and Anderson (2016). Using a quasi-experimental design, the study seeks to examine the impacts of the CTS approach on learners' HOTS, engagement, and hands-on abilities. The research questions driving this study are as follows:

1. How significantly does the implementation of CTS in higher education influence the development of students' HOTS in STEM hands-on activities?
2. How significantly does the application of CTS in collegiate settings affect student engagement in STEM hands-on activities?
3. To what extent does the introduction of CTS in university-level courses enhance students' hands-on abilities in STEM activities?

By answering these questions, this study aims to enrich the current understanding in the STEM education literature, proposing CTS as a potential means to enhance students' engagement, hands-on abilities, and HOTS. Furthermore, it underscores the importance of conceptual frameworks like CT in determining the methodologies and directions of STEM education, thus providing empirical support for its theoretical foundations.

Related Work

Engagement in Science, Technology, Engineering, and Mathematics Hands-On Learning

Stemming from early American garage culture, Hands-on Learning encourages inventive outcomes via learners' active experimentation (Dewey, 1986; Thuneberg et al., 2018). It facilitates learners to scrutinize and redefine their experiences, facilitating knowledge construction (Ting & Tai, 2019). This learner-centric method underscores student engagement's vital role in STEM education (Lee et al., 2023b; Wong, 2021; Wu et al., 2023b). In light of the complexities inherent in STEM education, student's active involvement is necessary for comprehensive understanding, thereby boosting STEM education's effectiveness (Gamse et al., 2017; Murphy et al., 2019).

Hands-on learning is known for significantly enhancing learning engagement (Lee et al., 2023a; May et al., 2023). It spurs interest and motivation, providing richer learning experiences than conventional teaching methods and improving outcomes (Chen et al., 2020a). Sakamoto et al. (2017) demonstration of how hands-on learning incorporated into microscopic surgery training enhanced surgical proficiency. Slayter and Higgins (2018) combined problem-oriented and hands-on learning to cultivate Microsoft Excel expertise. Research indicates hands-on learning eases learning difficulties (Brigham et al., 2011; Salmi et al., 2017) and augments learning effectiveness (Ballantyne & Packer, 2009).

However, hands-on learning's integration into STEM education poses challenges. Traditional lectures have struggled to deliver dynamic STEM or STEAM subjects (Chen et al., 2019), attributed to these subjects' inherent diversity and complexity (Brown et al., 2011). Researchers are thus seeking to effectively integrate hands-on learning into STEM education as a potential strategy to augment learning engagement and effectiveness (Christensen et al., 2015; Ziaeefard et al., 2017). For instance, Glaroudis et al. (2019) successfully incorporated hands-on learning into an Internet of Thing (IoT)-based STEM program, resulting in positive learner feedback. Similarly, Chen et al. (2020a) used immersive VR technology in a STEM program, which improved student grades and facilitated knowledge internalization.

In conclusion, hands-on learning increases student engagement and learning outcomes, particularly in STEM education, by facilitating understanding and application of knowledge. Therefore, the focus should be on reinforcing its application in STEM education to maximize its effectiveness.

Computational Thinking

In recent years, computational thinking has been globally recognized for its significance within the realms of education and academia (Saad & Zainudin, 2022; Zhou et al., 2023a). This perspective posits CT not as a specialized skill exclusively for computer scientists, but a fundamental literacy necessary for navigating the digital age of the 21st century (Wing, 2006). In the realm of STEM education, CT plays a pivotal role. It provides a method of problem-solving and innovation, capabilities deemed essential for all students in our future society (Kennedy & Sundberg, 2020). The strength of CT lies in its ability to encourage students to understand and utilize scientific patterns, engineering designs, mathematical modeling, and technological practices to solve problems and promote innovation (Lee et al., 2020). According to Wing (2006), CT is defined as a process encompassing four main steps: decomposition, pattern recognition, abstraction, and algorithmic design. However, this definition was later expanded upon by Anderson (2016), who proposed five core competencies of CT as follows:

- Decomposition: Systematically breaking down an overarching problem into smaller sub-problems.
- Pattern Recognition: Identifying repeated patterns within sub-problems and uncovering rules that can be efficiently used to resolve these sub-problems.
- Abstraction: Conceptualizing corresponding patterns according to the rules of several sub-problems, thereby representing the iterative model of the problem.
- Algorithm Design: Designing an algorithm in a systematic way to generate iterative solutions to a problem.
- Evaluation: Ensuring that the designed algorithm comprises all necessary steps to resolve the problem through comprehensive evaluation.

Despite evidence suggesting that CT significantly enhances students' HOTS such as creativity, and critical thinking within STEM activities (Gadot & Tsybulsky, 2023; Ha et al., 2023), challenges persist in effectively guiding students through these five steps and integrating them successfully into learning activities. To address this issue, this research introduces an innovative strategy—CTS. CTS incorporates the core competencies of CT proposed by Wing (2006) and Anderson (2016) into STEM hands-on learning activities, thus more effectively guiding students in using CT to solve problems within hands-on learning. The potential effects of CTS on enhancing students' hands-on abilities, HOTS, and engagement in STEM activities will be further explored through a quasi-experimental design.

Scaffolding Learning

Scaffolding learning, derived from Vygotsky's concept of the Zone of Proximal Development (ZPD), is an approach aimed at facilitating students' progressive acquisition of skills (Berk & Winsler, 1995; Vygotsky & Cole, 1978). ZPD refers to the range between what learners can do independently and what they can do with guidance. It's the space where instruction is most beneficial, enabling learners to accomplish tasks they wouldn't be capable of alone (Vygotsky & Cole, 1978). This pedagogical method is often compared to the scaffolding at a construction site: the scaffold supports the structure as it's being built and is gradually removed as the building becomes capable of standing independently. Similarly, as learners' abilities improve, the instructional support, or 'scaffolding,' is gradually reduced. This promotes autonomy in learners and helps them progress towards achieving tasks independently (Puntambekar & Hubscher, 2005). This method is recognized for its ability to boost learning efficiency, augment students' self-regulation skills, and cultivate HOTS (Alrawili et al., 2020; Thoutenhoofd & Pirrie, 2015).

The role of scaffolding is pivotal in STEM education, which emphasizes hands-on learning in science, technology, engineering, and mathematics (Falloon, 2017; Kim et al., 2020). Without suitable scaffolding, students may disengage due to confusion or struggle to develop HOTS (Kennedy et al., 2021). For instance, Wu et al. (2019) demonstrated how different scaffolding models could enhance STEM teachers' design thinking skills. Similarly, Kim et al. (2020) confirmed the utility of Computer-based Scaffolding (CBS) in problem-centered STEM education.

Science, Technology, Engineering, and Mathematics education is not merely about understanding science, technology, engineering, and mathematics, but more importantly, applying this knowledge to solve cross-disciplinary problems (Wang & Degol, 2017). This objective aligns with the principles of computational thinking, which focus on problem-solving processes (Wing, 2006). Thus, integrating computational thinking, particularly in hands-on learning environments, can boost learners' engagement and HOTS. However, the integration of computational thinking (Gadot & Tsybulsky, 2023; Ha et al., 2023) and scaffolding learning (Kim et al., 2020; Wu et al., 2019) into STEM education has been studied separately, but rarely in conjunction. The potential benefits of using computational thinking as the scaffolding principle remain largely unexplored.

Therefore, we propose the CTS, providing scaffolding support in STEM education using computational thinking principles. This novel integration could potentially enhance learners' hands-on abilities and engagement, but empirical studies are required to validate this hypothesis and understand its impact on students' HOTS.

Higher-Order Thinking Skills

In recent years, researchers have consistently emphasized the importance of higher-order thinking skills (HOTS) (Di et al., 2019; Zhou et al., 2023b). The emergence of HOTS is not a coincidence, but a necessary educational demand to cope with today's diverse and complex social environment (Huang et al., 2022, 2023). HOTS refers to thinking skills beyond the basic levels of memory and understanding. They encompass critical thinking, problem-solving, and creativity (Hwang et al., 2018; Lu et al., 2021). Furthermore, when delineating HOTS, it's noteworthy that critical thinking, problem-solving, and creativity align respectively with the cognitive domain of analyzing, evaluating, and creating within Bloom's taxonomy (Bloom et al., 1956; Krathwohl, 2002). Specifically, analyzing refers to students' abilities to deconstruct information and engage in critical thinking, clearly scrutinizing information and making rational judgments (Hwang et al., 2018; Lu et al., 2021). Evaluating denotes the ability of students to assess the information collected and analyzed when facing problems, propose potential solutions, and select the most appropriate strategy to solve the problem (Hwang et al., 2018; Lu et al., 2021). Creating, meanwhile, suggests students' abilities to produce new ideas or objects, or to clarify, analyze, and evaluate existing concepts and methods, thereby developing innovative ideas and methods (Hwang et al., 2018; Lu et al., 2021).

In this context, STEM education gains prominence, particularly in fostering students' HOTS (Zhong et al., 2022). In all STEM fields, HOTS are integral for effective critical thinking, problem-solving, and creativity (Wahono et al., 2020). Analysis is vital in STEM, as students must decipher complex data and concepts to think critically (Wang et al., 2020). STEM education also stresses the importance of evaluation, wherein students must gather, assess, and apply relevant information to solve various problems (Leung, 2020). This ability is essential across engineering, coding, and mathematical logic (Su et al., 2022). Creativity in STEM education is indispensable, fostering the ability to innovate and generate new solutions (Gao et al., 2020; Nguyen et al., 2020). Whether through experimental design in science, new program creation in technology and engineering, or the development of novel solution strategies in mathematics, creativity is paramount. In summary, HOTS' significance in STEM education lies in fostering deep understanding, critical thinking, problem-solving, and creativity, equipping students with the skills needed to face the challenges of the 21st century.

Methodology

Participants

In this research, we engaged 86 students from the Department of Engineering Science aged 19–23 at a Southern Taiwanese university over two semesters. All participants, enrolled in the Networks Embedded System and Application course, were strategically divided into a Control Group (CG) and an Experimental Group (EG) to facilitate a balanced comparison.

The CG, comprising 42 students from the initial semester, followed the traditional STEM pedagogical methodology. This approach emphasizes hands-on activities as the primary learning vehicle and relies on the instructor's guidance for completing tasks and troubleshooting issues. By engaging in direct, experiential learning, students in this group were able to interact with core concepts in a tangible way. Conversely, the EG, which consisted of 44 students from the following semester, were introduced to an innovative CTS strategy. CTS, a cutting-edge teaching methodology, is designed to cultivate computational thinking skills in students, equipping them with the capability to break down complex problems and develop logical, solution-oriented thinking.

Group assignments were based on semester of enrollment, which eliminated the influence of inherent characteristics and potential bias. All participants, unaware of their specific group designation, gave informed consent to participate in the experiment and for data collection, understanding the study's overall objectives and nature. To ensure experiment reliability and validity, we maintained consistent teaching standards across both groups by employing the same instructor, an identical syllabus, and uniform instructional materials and environments. In accordance with the Helsinki Declaration, we upheld the highest ethical standards, ensuring participant confidentiality and data anonymization throughout the study. The university's institutional review board approved the research protocol.

Experimental Procedure

To examine the effects of implementing CTS on HOTS, engagement, and hands-on abilities, a quasi-experimental design was utilized in this study. The research focused specifically on the "Networks Embedded System and Application" course, which spanned across two semesters. The control group participated in the previous semester, while the experimental group took part in the subsequent semester. The course was carefully crafted to facilitate individual learning while also promoting peer interactions and discussions during project implementation. It placed significant emphasis on applying both software and hardware knowledge to tackle real-world problems, particularly within the context of IoT and Artificial Intelligence (AI). This pedagogical approach aligns with the fundamental principles of STEM education, as depicted in Figure 1.

In STEM-based pedagogy, hands-on learning activities are traditionally structured in two phases: the delivery of foundational knowledge, and the implementation of projects. This format aligns with the model of cognitive construction posited by Bloom's taxonomy (Krathwohl, 2002).

During the foundational knowledge instruction phase, educators play a pivotal role in assisting students in developing lower-order thinking skills. They elucidate the requisite concepts for the week's lessons, thereby aiding students in remembering (Remember) and understanding (Understand) the fundamental principles. Further, by providing illustrative examples, they encourage students to deepen their comprehension and apply (Apply) these concepts. The project implementation phase follows, wherein teachers articulate the objectives and requirements of the project. Students are then required to apply the knowledge and skills they have amassed to fulfill these objectives. This phase not only encourages students to cultivate their analytical abilities (Analyze), but also reinforces their problem-solving skills (Evaluate). Ultimately, it enables students to utilize their theoretical knowledge across various contexts and fields (Create).

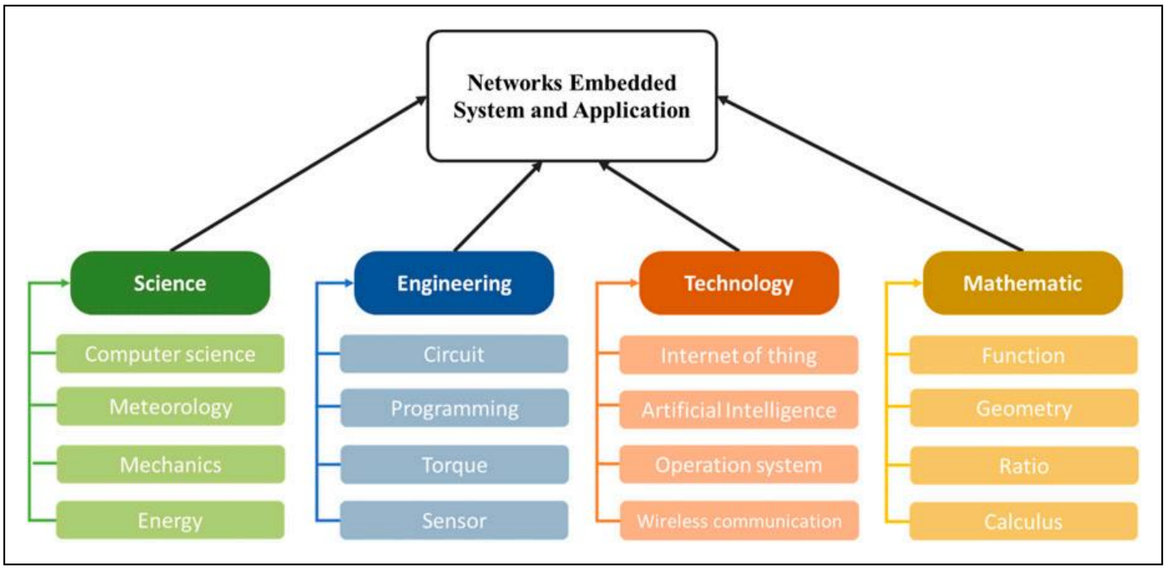

Figure 1. STEM concepts in Networks Embedded System and Application.

This instructional model was applied to the "Networks Embedded System and Application" course and carried out over a span of six weeks. The first hour of each session was devoted to providing foundational knowledge, with the aim of cultivating lower-order thinking skills in the learners. The following 2 hours were geared towards project work, promoting higher-order thinking through hands-on project implementation. During the seventh week, learners were required to implement a final project, crafting an AIoT artifact by leveraging what they had learned over the previous six weeks. The completed projects were then displayed during the eighth week. Instructor invited experts from related fields to grade these projects according to the Creative Product Analysis Matrix (CPAM) model (Besemer & O'Quin, 1999). Both the Control Group (CG) and Experimental Group (EG) underwent pre- and posttests designed to gauge changes in their engagement and HOTS. It's important to note that the instruments used for quantifying engagement and HOTS have been previously validated (Hwang et al., 2018; Reeve & Tseng, 2011). These evaluations were conducted at two pivotal junctures: firstly, at the start of the experimental activities in the first week, and then, after the conclusion of these activities in the eighth week, as illustrated in Figure 2. The assessment data provided valuable insights into the effectiveness of this instructional model.

The primary distinguishing characteristic between the EG and CG lies in the phase of project implementation. Regardless of whether it is the EG or CG, the activities conducted during the foundational knowledge instructing phase are identical. Teachers provide the same materials and teach the same concepts to both groups. However, during the project implementation stage, the difference emerges. Participants in the EG receive a Jupyter Notebook file based on the CTS model, where they are expected to follow the guidelines therein to complete the weekly project. In contrast, participants in the CG receive a PowerPoint file that outlines the task description and provides step-by-step instructions. After reading through, these students are also expected to complete their projects on Jupyter Notebook.

Computational Thinking Scaffolding

Jupyter Notebook. Jupyter Notebook, an open-source web application, amalgamates code, text, equations, and visualizations into an all-encompassing learning platform (Jupyter, n.d.). With multi-language support like Python, Julia, and R, it excels in scientific computing compared to other Python environments. Jupyter's Markdown features, which enable integration of explanations and additional information with code, enhance its educational utility. This facilitates scaffolded learning, allowing gradual introduction of concepts and reduction of supports as learners gain proficiency. The Markdown feature also allows creation of rich textual narratives, incorporating links, images, and videos. This facilitates multilevel concept engagement, enhances understanding, and provides clear learning objectives and tasks. Jupyter Notebook's interactivity stands out. Learners can run, modify code, and instantaneously view

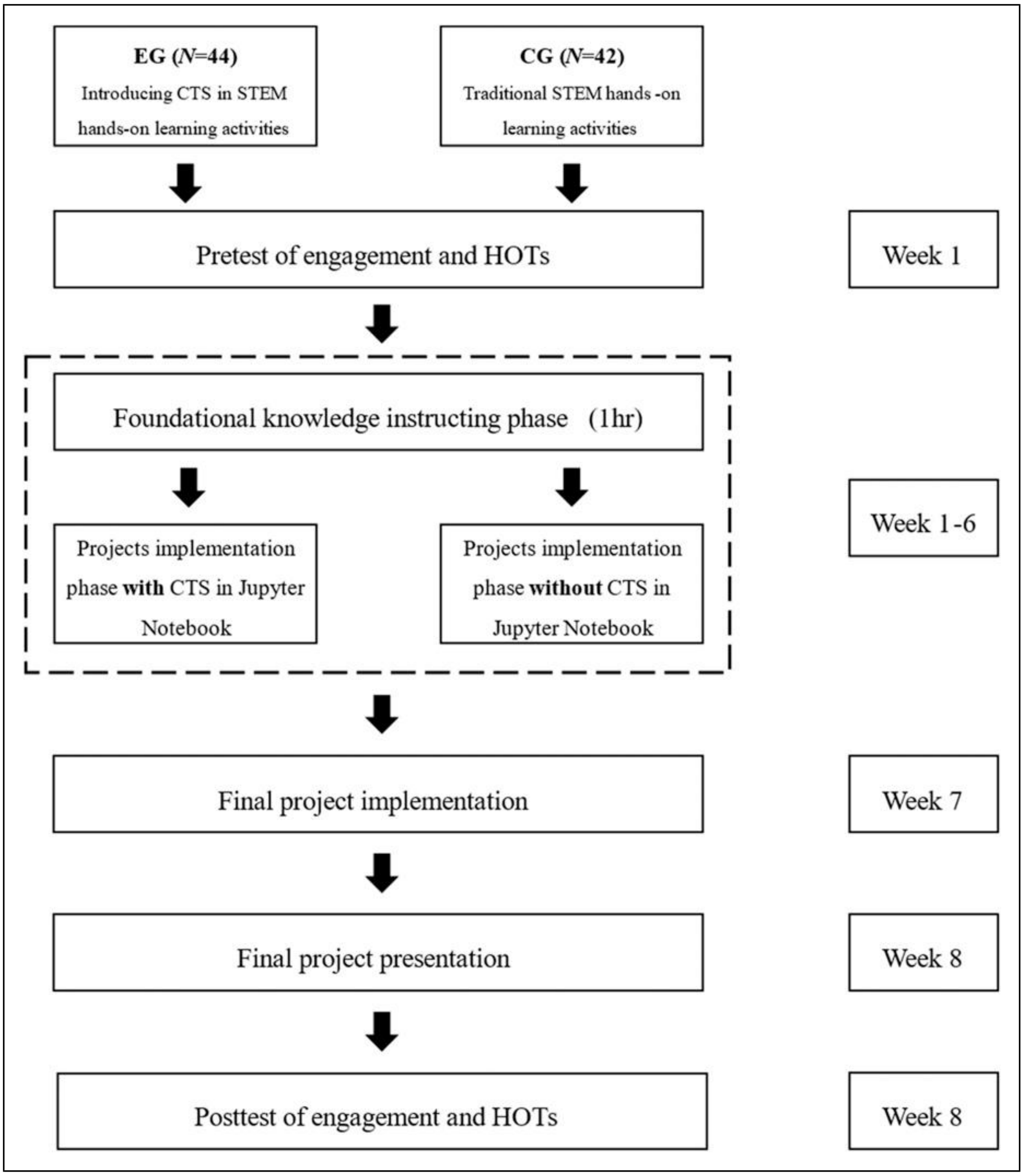

Figure 2. Experimental procedure.

results, enhancing comprehension. The built-in data visualization tools solidify learners' understanding of data analysis concepts.

Figure 3 demonstrates Jupyter's user-friendly interface. The left panel displays the program's structure, promoting comprehension of code organization—a crucial aspect of scaffolded coding learning. The top toolbar controls the Code and Markdown sections, the latter facilitating the creation of layered, instructional guides. This permits gradual introduction of concepts, providing support at each stage—a key scaffolding principle. The Code section allows for writing programs with variable sharing across

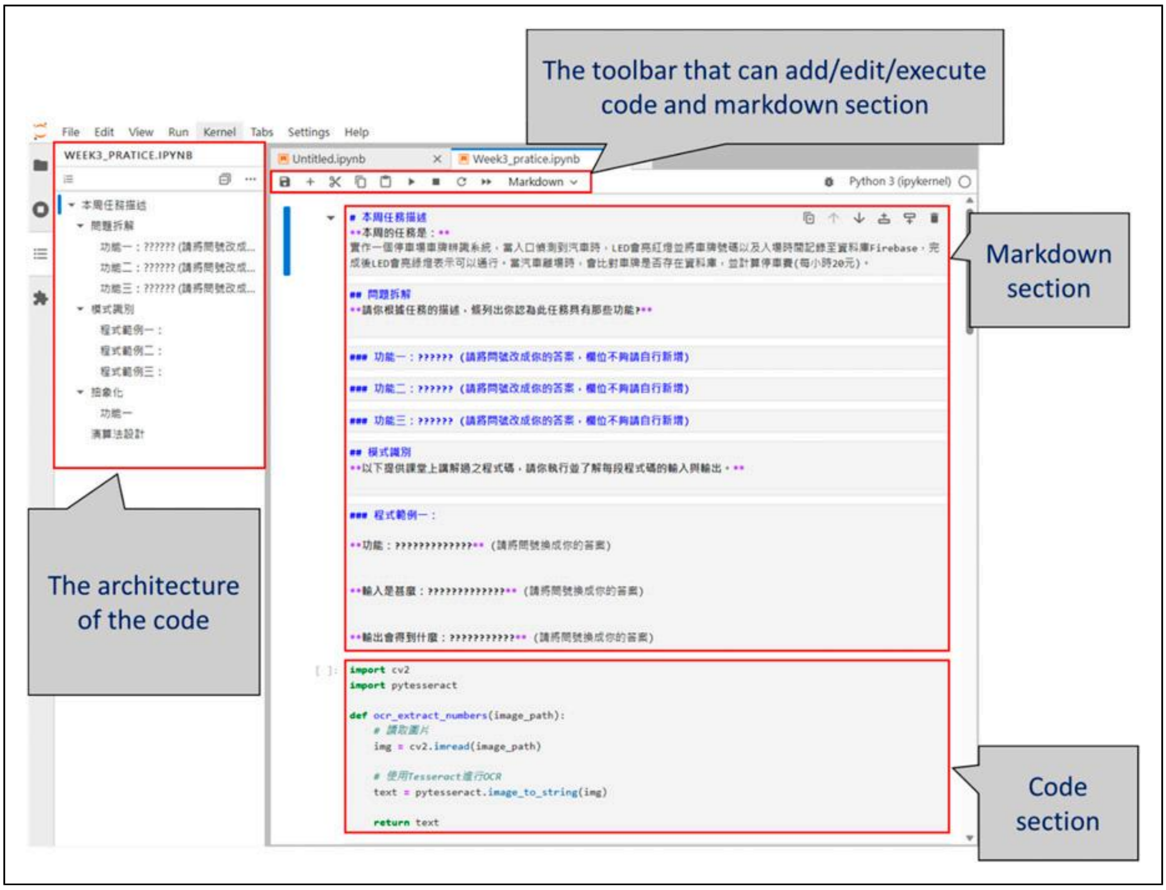

Figure 3. The development interface in Jupyter Notebook.

sections, improving code readability, debugging, and demonstrating good programming habits—a subtle scaffold for professional programming acquisition.

In conclusion, Jupyter Notebook, with its interactive, rich Markdown features, visualization, sharing functions, and embedded systems compatibility, provides an optimal tool for scaffolded learning. It facilitates interactive learning experiences that transcend mere understanding, deeply engaging students and enhancing their STEM skills.

The Concepts of Computational Thinking Scaffolding. In pursuit of encouraging the tangible application of computational thinking in STEM hands-on learning, we developed an educational scaffolding. This structure is predicated on the five stages of computational thinking: problem decomposition, pattern recognition, abstraction, algorithm development, and evaluation. Consequently, we realized this scaffold in the Jupyter Notebook environment, creating the CTS. We mapped this model with concepts of HOTS to determine the effectiveness of CTS in cultivating these skills among learners. A detailed exposition is presented in Table 1.

Table 1. The Descriptions of CTS.

CT Competencies	Definition	Descriptions of CTS in STEM Hands-On Learning	HOTS Integrative CT Competencies
Decomposition	Systematically breaking down an overarching problem into smaller sub-problems. (Anderson, 2016; Wing, 2006)	1. The learner understands the task to be completed for the week 2. The task's code is broken down into multiple sub-tasks, which are listed under the sub-tasks section of the Decomposition field in markdown	Critical thinking • Analyze the task of the week and decompose it
Pattern recognition	Conceptualizing corresponding patterns according to the rules of several sub-problems, thereby representing the iterative model of the problem. (Anderson, 2016; Wing, 2006)	1. The instructor will provide the subroutine necessary for connecting to the hardware required to complete this course 2. Students need to sequentially test the inputs and outputs of the subroutines provided by the instructor in the code section of the pattern recognition field, to understand all subroutines' operation and function	Critical thinking • Analyze the subroutine provided by the instructor to understand its function

(continued)

Table 1. (continued)

CT Competencies	Definition	Descriptions of CTS in STEM Hands-On Learning	HOTS Integrative CT Competencies
Abstraction	Conceptualizing corresponding patterns according to the rules of several sub-problems, thereby representing the iterative model of the problem (Anderson, 2016; Wing, 2006)	1. Based on each subtask listed in the markdown section of the Decomposition field, students create a subroutine in the abstraction field 2. Learners need to first define the inputs and outputs of each subtask 3. Then, using the concept of conditional judgments and loops, they connect the code section in the pattern recognition field logically and rule-wise to complete the writing of each subtask's program	Problem-solving • Evaluate the analyzed results and provide possible solutions
Algorithm design	Designing an algorithm in a systematic way to generate iterative solutions to a problem (Anderson, 2016; Wing, 2006)	1. Learners, using the concept of conditional judgments and loops, link the inputs and outputs of each subtask in the algorithm design field to ultimately complete the overall task	Problem-solving • Evaluate the inputs and outputs of each subtask to establish a solution for the task

(continued)

Table 1. (continued)

CT Competencies	Definition	Descriptions of CTS in STEM Hands-On Learning	HOTS Integrative CT Competencies
Evaluation	Ensuring that the designed algorithm comprises all necessary steps to resolve the problem through comprehensive evaluation (Anderson, 2016)	1. Appropriately verify whether the code in the algorithm design field meets the task's requirements 2. In the evaluation section, provide a comprehensive account of the challenges and intricacies faced during the developmental phase 3. Based on this introspection, refine the programming approach and endeavor to elucidate a more streamlined resolution	Critical thinking • Appropriately verify whether the code in the algorithm design field meets the task's requirements Problem-solving • Evaluate the efficiency and functionality of the code to determine if it meets the requirements Creativity • Propose a more efficient solution

Implementing Computational Thinking Scaffolding in Jupyter Notebook. To provide a comprehensive understanding, this segment utilizes the CTS resources from the experiment's third week as a representative case. The CTS for every week is architected using an identical structure and template, with deviations only in the 'Pattern Recognition' phase where corresponding code examples are offered per the weekly tasks, and in the 'Evaluation' phase, where assessment criteria are altered in accordance with the task requirements. Figure 4 delineates the CTS architecture which employs a hierarchical layout within the Jupyter Notebook and integrates the five competencies of computational thinking as its foundational framework. Consequently, learners can precisely identify their process within the facets of computational thinking as they navigate through the material.

Every instructional material of CTS initially provides a lucid description of the task learners are expected to undertake for the current week, demonstrated in Figure 5. Subsequently, learners need to engage in a process of task deconstruction, predicated on the task's description, replacing the question marks with respective responses for each identified sub-task (as depicted in Figure 5). This pedagogical approach enables students to dissect tasks into several sub-tasks analytically, cultivating critical thinking in HOTS.

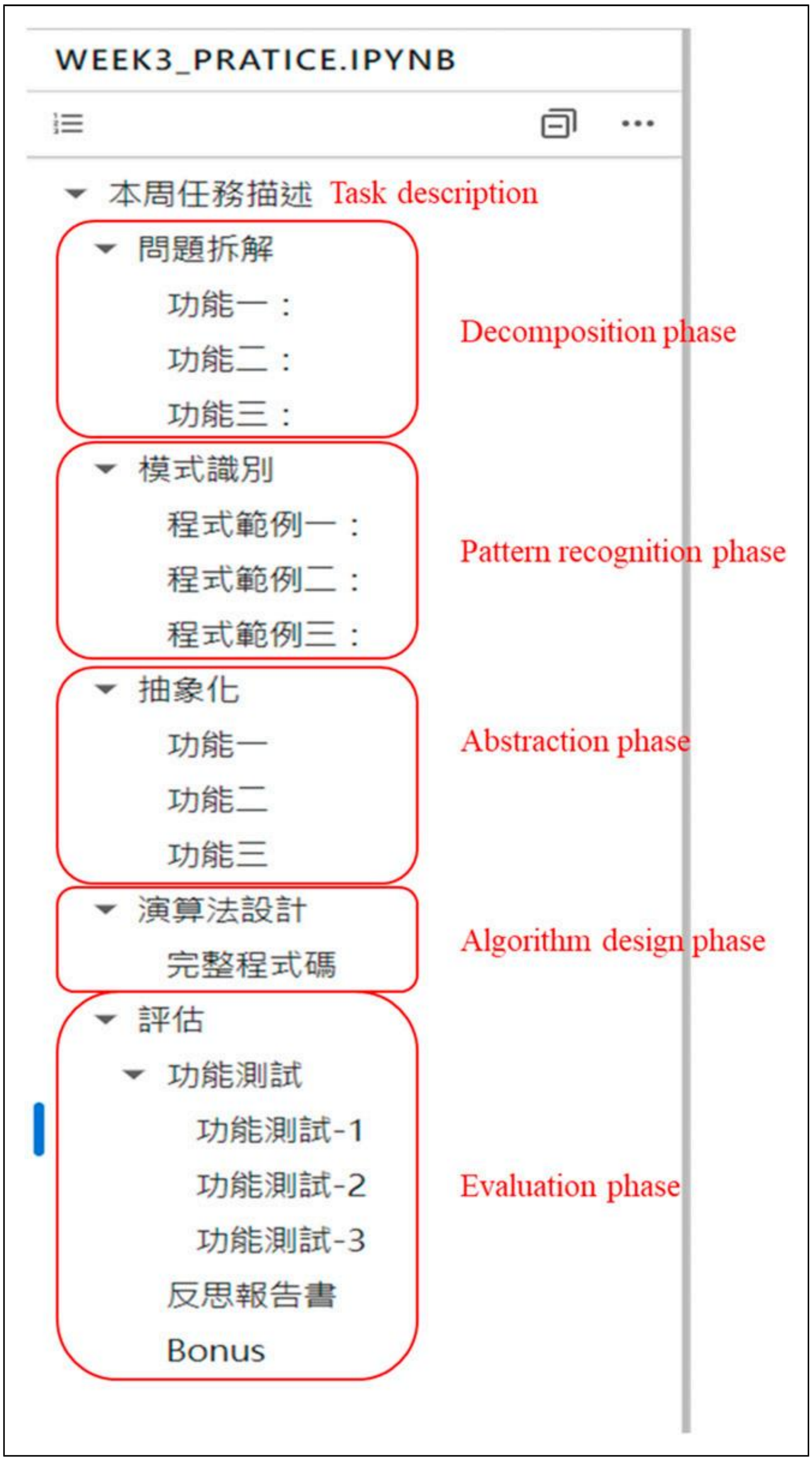

Figure 4. CTS's architecture in Jupyter Notebook.

Figure 5. The task description in CTS and the Decomposition phase of CTS implemented in Jupyter Notebook.

During the Pattern Recognition phase, instructors present learners with code snippets, previously introduced in preceding sessions, potentially beneficial for the current assignment (refer to Figure 6). This strategy empowers learners to concentrate on the development and ideation of their programs, eschewing the need to retrieve or research foundational code elements. In this phase, learners' responsibilities encompass testing each code segment and comprehending its structure, purpose, input, and output. Subsequently, they substitute question marks with suitable responses (as indicated in Figure 6). Through this process, learners can scrutinize the instructor-provided sub-routine to decipher its function, seeking inherent patterns and relationships, thereby fostering their critical thinking in HOTS.

In the Abstract phase, learners are required to explain in detail the roles of the subtasks they decomposed in the Decomposition phase and replace the question marks with their answers, as illustrated in Figure 7. Subsequently, they need to establish functions for each of the decomposed subtasks, clearly defining the input and output of these functions. Ultimately, through logical reasoning and programming techniques such as loops, learners can adapt and connect the code examples provided in the Pattern Recognition phase, completing the programming for each subtask. This process allows students to evaluate the results analyzed in the previous phase, list possible solutions, and ultimately foster problem-solving skills in HOTS.

During the Algorithm Design phase, learners need to connect the subtasks completed in the Abstract phase through logical judgment and programming techniques

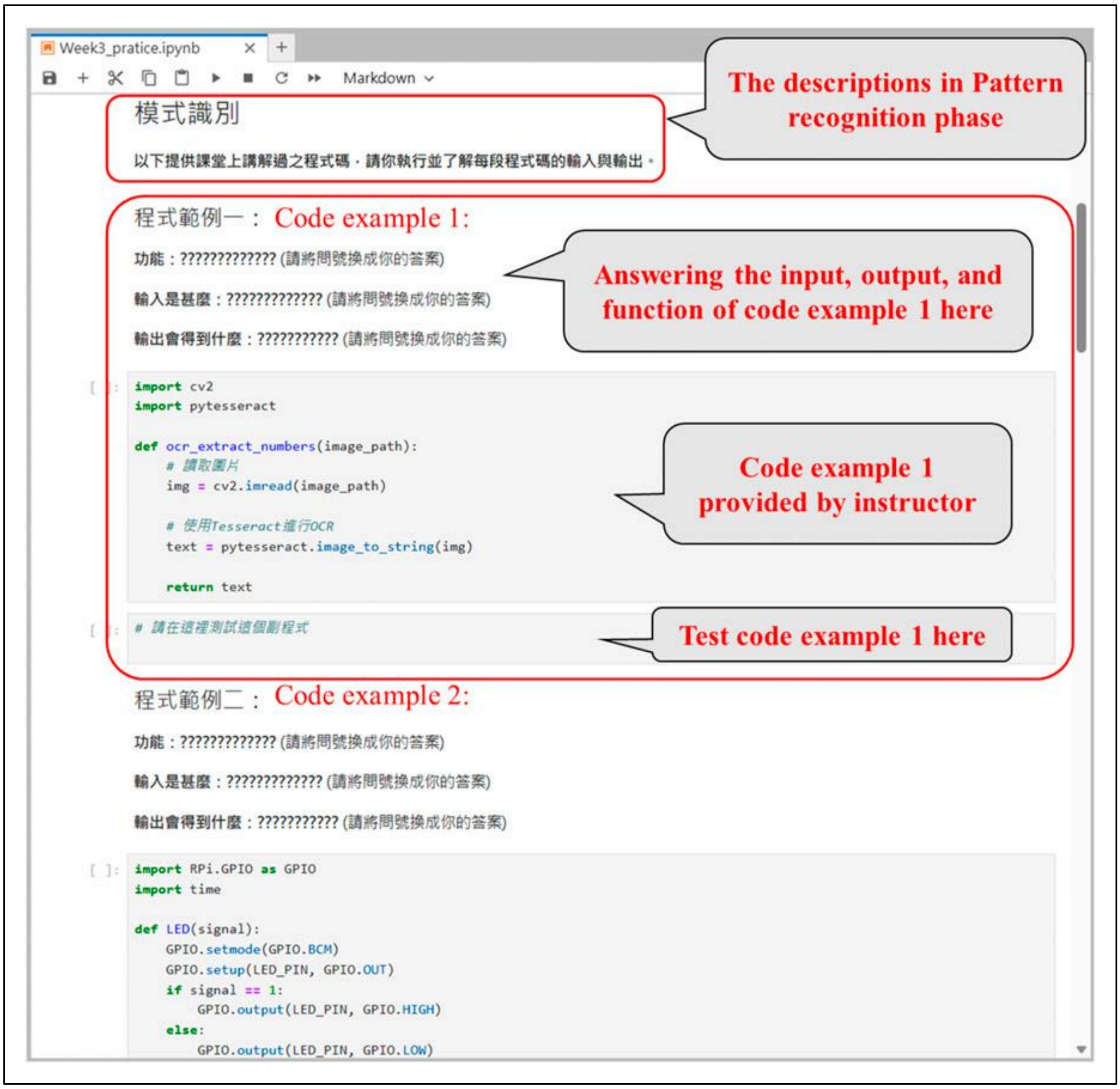

Figure 6. The Pattern recognition phase of CTS implemented in Jupyter Notebook.

such as loops to complete the task, as shown in Figure 8. After completing the program, learners can appropriately verify whether the code meets the requirements of the task, and better understand data flow or optimize the code by adjusting inputs and outputs or parameters. This process allows students to evaluate the inputs and outputs of each subtask, develop feasible solutions for the task, and ultimately enhance students' problem-solving skills in HOTS. (Figure 9).

In the Evaluation phase, learners first need to write programs according to the functions that teachers need to verify, confirming that the learner's implemented projects have achieved their goals. Then, learners need to write reflection reports based on their learning process and problems encountered during this process, helping them to review the learning process and deepen their impressions. Ultimately, learners can undertake bonus additional challenges, optimizing and transforming their original

Figure 7. The Abstract phase of CTS implemented in Jupyter Notebook.

Figure 8. The Algorithm design phase of CTS implemented in Jupyter Notebook.

programs to enhance performance and readability. Through this process, students can first analyze whether the written code meets the task requirements, thereby enhancing critical thinking in HOTS. In addition, when students write reflection reports, they will evaluate the current stage of the program and solutions, thereby enhancing problem-

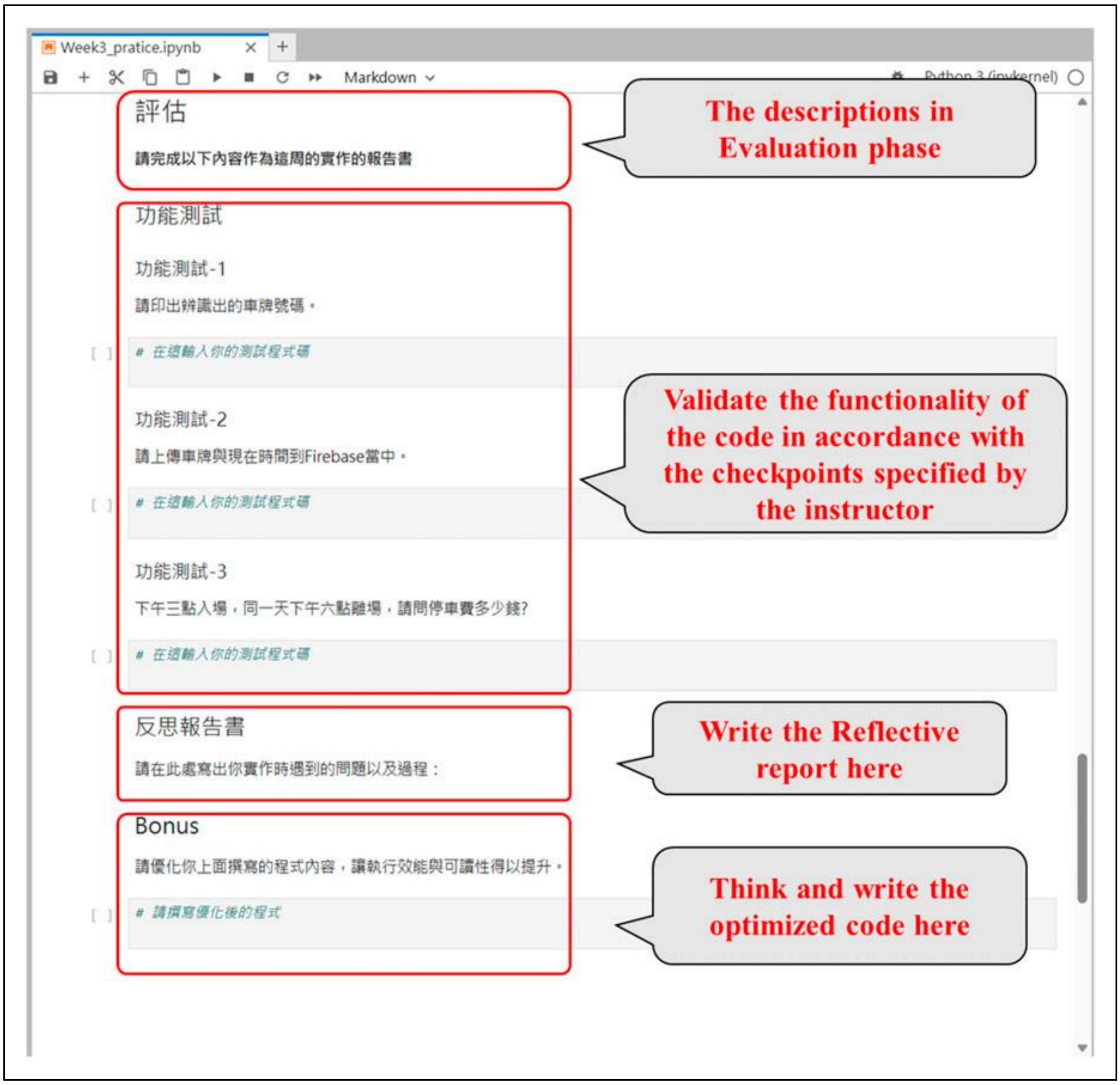

Figure 9. The Evaluation phase of CTS implemented in Jupyter Notebook.

solving skills in HOTS. In the end, students can identify shortcomings in the existing code, construct solutions with better performance and readability, and achieve creativity in HOTS.

Research Tools

Higher-Order Thinking Skills. Higher-order thinking encompasses three essential dimensions: critical thinking, problem-solving, and creativity. As revealed in their insightful study, Hwang et al. (2018) developed a measurement tool to assess these dimensions. This tool, a questionnaire, was carefully tailored to meet the specific needs of their study, offering eleven carefully modified items to measure the three dimensions. The first dimension, critical thinking, refers to a cognitive ability enabling individuals to engage in thoughtful analysis and reasoned judgments. The second dimension, problem-solving primarily pertains to the ability to recognize and address problems effectively, which is gauged by gathering and evaluating relevant information. The third dimension, creativity, focuses on the capacity to generate and cultivate innovative ideas. By employing this comprehensive framework and utilizing the measurement tool developed by Hwang et al. (2018), researchers and educators can gain valuable insights into individuals' abilities in critical thinking, problem-solving, and creativity, thereby facilitating their growth and development in these vital areas. It is worth mentioning that the Cronbach's alpha coefficients for the critical thinking, problem-solving, and creativity dimensions were calculated as .79, .81, and .74, respectively (depicted in Table 2), suggesting an acceptable degree of reliability for each dimension.

Engagement. In this study, a questionnaire originally developed by Reeve and Tseng (2011) was employed to assess student engagement across three dimensions. The questionnaire consisted of 17 items, which were adapted to suit the specific objectives of this research and administered as both a pretest and a posttest. The first dimension, known as behavioral engagement, encompassed behaviors indicative of on-task attention, active participation, and effort invested in the learning process. The second dimension, labeled emotional engagement, aimed to capture the emotional state of students in the classroom. Items in this section measured the degree of curiosity and interest experienced by students during their learning activities. The third dimension, cognitive engagement, assessed the development and application of learning strategies. This dimension focused on participants' abilities to connect new information with their personal experiences, as well as their utilization of metacognitive strategies. Validity and reliability analyses were conducted to evaluate the questionnaire's effectiveness in measuring student engagement across these three dimensions. The obtained results indicated satisfactory validity and reliability for all dimensions. Specifically, the Cronbach's α coefficients for behavioral, emotional, and cognitive engagement were .80, .85, and .78, respectively (depicted in Table 3).

These values demonstrate the questionnaire's ability to measure student engagement consistently and accurately in the context of this study. The utilization of this modified questionnaire, based on the work of Reeve and Tseng (2011), represents a robust and reliable approach to assess student engagement. By encompassing behavioral, emotional, and cognitive aspects of engagement, the questionnaire provides a comprehensive tool for educators and researchers to gauge students' involvement and interest

Table 2. Reliability Analysis of Higher-Order Thinking Scale.

	Critical Thinking	Problem-Solving	Creativity
Original reliability	.84	.85	.80
Revised reliability	.79	.81	.74

in the learning process. Moreover, the high reliability coefficients affirm the questionnaire's credibility and its suitability for evaluating student engagement.

Creative Product Analysis Matrix Model. Utilizing the Creative Product Analysis Matrix (CPAM) as our evaluation tool, this study aimed to assess students' hands-on abilities. Conceived by Besemer and O'Quin (1999), CPAM provides a structured approach to examining creative output. It includes three primary dimensions: Novelty, Resolution, and Elaboration and Synthesis.

The Novelty subscale gauges the degree of originality or innovation in the creative product. It is specifically designed to assess the extent to which a product deviates from existing norms, concepts, or products. Resolution, the second subscale, focuses on the utility, functionality, and validity of the creative product. This subscale ascertains whether the product achieves its intended purpose or successfully addresses the identified problem. Lastly, the Elaboration and Synthesis, or Style, subscale evaluates the intricacy of the design, detailing, elegance, and harmony of the creative product. It takes into account craftsmanship, aesthetic appeal, and the overall quality of the product.

Within the context of our study, we measured each of the nine indicators on a 5-point Likert scale. The output from each student was scored by two independent evaluators, with the final score being the mean of the two. We assessed the reliability of our scoring method by calculating the correlation coefficient between the scores, which ranged from .71 to .86 (Table 4). This suggests substantial inter-rater reliability, and its statistical significance (p < .001) lends further robustness to our evaluation

Table 3. Reliability Analysis of Engagement Scale.

	Cognitive Engagement	Behavioral Engagement	Emotional Engagement
Original reliability	.88	.94	.78
Revised reliability	.80	.85	.78

Table 4. Scorer Reliability of the CPAM (Besemer & O'Quin, 1999).

Subscales	Indicators	Scorer Reliability
1. Novelty	1.1 Original	.82***
	1.2 Surprising	.81***
2. Resolution	2.1 Valuable	.83***
	2.2 Logical	.78***
	2.3 Useful	.71***
	2.4 Understandable	.73***
3. Elaboration & Synthesis	3.1 Organic	.74***
	3.2 Elegant	.82***
	3.3 Well-crafted	.86***

Note. *p < .05, **p < .01, ***p < .001.

methodology. Given its comprehensive nature, the CPAM model's use in this study aligns with its proven applicability for evaluating students' hands-on abilities (Horikami & Takahashi, 2022; Hsiao et al., 2022; Huang & Chang, 2023).

Data Analysis

To systematically address the first research question, an Analysis of Covariance (ANCOVA) was conducted to discern any significant differences in the posttest scores of Higher-Order Thinking Skills (HOTS) between the EG and CG. In this analysis, the pretest HOTS scores were employed as covariates, and the posttest HOTS scores served as dependent variables. In addressing the second research question, ANCOVA was similarly utilized to determine any substantial differences in posttest engagement scores between the EG and CG. Here, the pretest engagement scores were integrated as covariates, with the posttest engagement scores functioning as dependent variables. For the third research question, a one-way Analysis of Variance (ANOVA) was undertaken to ascertain differences between the EG and CG in terms of the final project scores. Notably, a pair of experts assessed each student's final project, adopting the CPAM as the evaluation criterion. All statistical procedures were executed using Jamovi, version 2.4 (Jamovi, 2023).

Results

The Impact of Computational Thinking Scaffolding on Higher-Order Thinking Skills

Levene's test was conducted to verify the homogeneity of variances. The outcomes of the test confirmed homogeneity for critical thinking ($F = .318$, $p = .574 > .05$), problem-solving ($F = .141$, $p = .708 > .05$), and creativity ($F = .982$, $p = .325 > .05$). The findings thus substantiated the robustness of the variance equality and the suitability of ANCOVA for this analysis.

The descriptive statistics relating to HOTS and the results from the ANCOVA analysis are presented in Tables 5 and 6, respectively. Table 6 reveals significant

Table 5. Descriptive Results for HOTS.

	EG (*N* = 44)				CG (*N* = 42)			
	Pretest		Posttest		Pretest		Posttest	
	M	SD	M	SD	M	SD	M	SD
Critical thinking	12.8	2.08	16.2	2.17	12.7	2.18	13.9	2.39
Problem-solving	12.4	1.69	15.1	2.50	12.1	1.91	13.0	2.13
Creativity	9.70	1.52	10.3	1.37	9.43	1.11	9.90	1.19

disparities in critical thinking ($F = 22.31$, $p < .001$) and problem-solving ($F = 18.99$, $p < .001$) between the EG and the CG. Moreover, as shown in Table 5, the posttest scores for critical thinking ($M_{EG} = 16.2 > M_{CG} = 13.9$) and problem-solving ($M_{EG} = 15.1 > M_{CG} = 13.0$) were notably higher in the EG as compared to the CG. The insights gleaned from these analyses suggest that the introduction of CTS in STEM hands-on activities can lead to a significant enhancement in HOTS across critical thinking and problem-solving aspects. It's noteworthy that even though there was no statistically significant difference in creativity between the EG and the CG ($F = 1.01$, $p = .317 > .05$), the scores for the EG were still marginally higher than the CG ($M_{EG} = 10.3 > M_{CG} = 9.90$).

The Impact of Computational Thinking Scaffolding on Engagement

Levene's test was conducted to verify the homogeneity of variances. The outcomes of the test confirmed homogeneity for cognitive engagement ($F = 2.87$, $p = .094 > .05$), behavioral engagement ($F = 2.52$, $p = .116 > .05$), and emotional engagement ($F = .537$, $p = .466 > .05$). The findings thus substantiated the robustness of the variance equality and the suitability of ANCOVA for this analysis.

The descriptive statistics relating to engagement and the results from the ANCOVA analysis are presented in Tables 7 and 8, respectively. Table 8 reveals significant disparities in cognitive ($F = 48.60$, $p < .001$), behavioral ($F = 41.4$, $p < .001$), and emotional ($F = 24.48$, $p < .001$) engagement between the EG and the CG. Moreover, as shown in Table 7, the posttest scores for cognitive ($M_{EG} = 33.2 > M_{CG} = 27.2$),

Table 6. ANCOVA Results for HOTS.

Variable	SS	df	Mean Square	F	*p*	Partial η^2
Critical thinking	111.8	1	111.84	22.31	**<.001*** **	.212
Problem-solving	97.6	1	97.59	18.99	**<.001*** **	.186
Creativity	1.54	1	1.54	1.01	.317	.012

Note. *p < .05, **p < .01, ***p < .001. Bold values represent significant difference.

Table 7. Descriptive Results for Engagement.

	EG (*N* = 44)				CG (*N* = 42)			
	Pretest		Posttest		Pretest		Posttest	
	M	SD	M	SD	M	SD	M	SD
Cognitive engagement	25.3	4.26	33.2	3.36	25.4	4.18	27.2	4.72
Behavioral engagement	16.6	1.91	19.8	2.12	16.7	1.30	17.3	1.33
Emotional engagement	12.8	1.92	15.0	2.39	12.5	2.13	12.5	2.46

behavioral ($M_{EG} = 19.8 > M_{CG} = 17.3$), and emotional engagement ($M_{EG} = 15.0 > M_{CG} = 12.5$) were notably higher in the EG as compared to the CG. The insights gleaned from these analyses suggest that the introduction of CTS in STEM hands-on activities can lead to a significant enhancement in learner engagement across cognitive, behavioral, and emotional aspects.

The Impact of Computational Thinking Scaffolding on Hands-On Abilities

The descriptive statistics relating to hands-on abilities and the results from the ANOVA analysis are presented in Table 9. This table reveals significant disparities in Logical ($F = 5.157$, $p = .026$), Useful ($F = 5.209$, $p = .025$), Understandable ($F = 4.429$, $p = .038$), and Well-Crafted ($F = 15.045$, $p < .001$) indicators between the EG and the CG. However, for the remaining indicators, the ANOVA results revealed no significant

Table 8. ANCOVA Results for Engagement.

Variable	SS	df	Mean Square	F	*p*	Partial η^2
Cognitive engagement	778.4	1	778.4	48.60	**<.001*** **	.369
Behavioral engagement	133	1	132.88	41.4	**<.001*** **	.333
Emotional engagement	136.4	1	136.42	24.48	**<.001*** **	.228

Note. *p < .05, **p < .01, ***p < .001. Bold values represent significant difference.

Table 9. ANOVA Results for Hands-On Abilities.

Subscales	Indicators	Group	M	SD	F	*p*
1. Novelty	1.1 Original	EG	2.68	.96	.694	.407
		CG	2.88	1.23		
	1.2 Surprising	EG	3.30	1.00	.708	.402
		CG	3.12	.94		
2. Resolution	2.1 Valuable	EG	4.05	.81	2.714	.103
		CG	3.76	.79		
	2.2 Logical	EG	3.70	.90	5.157	**.026***
		CG	3.29	.81		
	2.3 Useful	EG	3.75	.97	5.209	**.025***
		CG	3.26	1.01		
	2.4 Understandable	EG	3.80	1.09	4.429	**.038***
		CG	3.26	1.25		
3. Elaboration & Synthesis	3.1 Organic	EG	4.07	.82	2.032	.158
		CG	3.81	.86		
	3.2 Elegant	EG	3.61	1.10	.627	.431
		CG	3.43	1.06		
	3.3 Well-crafted	EG	4.32	.77	15.045	**<.001*** **
		CG	3.67	.79		

Note. *p < .05, **p < .01, ***p < .001. Bold values represent significant difference.

difference. The insights gleaned from these analyses suggest that the introduction of CTS in STEM hands-on activities can lead to a significant enhancement in hands-on abilities.

Discussion

Impact on Higher-Order Thinking Skills

The growing emphasis on HOTS in educational research, particularly within the STEM disciplines, is shifting the focus from traditional lecture-based teaching to the application of practical, interdisciplinary knowledge to solve real-world problems (Baharin et al., 2018; Sun et al., 2022). Our research reveals that incorporating CTS within STEM hands-on learning environments can significantly enhance HOTS, specifically in the domains of critical thinking and problem-solving.

In developing critical thinking, CTS integrates fundamental principles of computational thinking during various stages of problem-solving. During the Decomposition stage, students are guided to break down complex problems into simpler sub-problems, fostering their analytical capabilities. In the Pattern Recognition stage, students are facilitated to analyze, understand, and apply programming segments, thus nurturing their critical thinking skills (Krathwohl, 2002). The Evaluation stage involves learners assessing whether their compiled code meets the functional requirements, a process which further refines their analytical and critical thinking skills (Bloom et al., 1956; Krathwohl, 2002). Our findings support the argument that explicit and appropriate guidance is essential for the development of effective critical thinking skills (Huang et al., 2022; Wong & Kowitlawakul, 2020).

When it comes to problem-solving, the introduction of CTS has a dual impact. Firstly, it stimulates students' logical skills during the Abstract and Algorithm Design stages, guided by the scaffold, to piece together the sub-problems into a coherent code or problem-solving process. This improves their logical reasoning and organizational skills (Chevalier et al., 2020; Lai & Wong, 2022). Secondly, during the Evaluation stage, students are guided to assess and refine their executed code or problem-solving process, thus reinforcing their problem-solving abilities (Alterman & Harsch, 2017).

Despite these findings, it's worth noting that while the incorporation of CTS into STEM hands-on learning improves students' critical thinking and problem-solving skills, its effect on creativity is less significant. Creativity, a complex construct including aspects of originality, adaptability, and practicality, may be restrained by the structured approach of CTS. This framework, while aiding in problem decomposition, pattern recognition, and solution formulation, might limit students' creative thinking and independent exploration (Bledow et al., 2012). Future research should consider incorporating more flexibility into the CTS framework, aiming to stimulate student creativity and further enhance their HOTS.

Impact on Engagement

Student engagement is pivotal in the realm of STEM education. Contemporary STEM pedagogies emphasize not merely the acquisition of knowledge but also the honing of problem-solving competencies. Consequently, the degree of a student's engagement becomes a salient determinant of their academic achievements (Bathgate et al., 2019; Struyf et al., 2019). In a bid to amplify such engagement, we incorporated a CTS into hands-on STEM activities. This integration seeks to scaffold learners' problem-solving endeavors, rendering their approaches more methodical.

Cognitive engagement is characterized by the depth of a learner's involvement in thinking, understanding, and problem-solving tasks (Fredricks et al., 2004). We found that the CTS strategy effectively helped learners follow a logical trajectory from problem identification, through the planning of a solution, to ultimately evaluating their plan. This approach enhanced learners' engagement in the learning process and fostered a deeper understanding and absorption of knowledge. Our results resonate with prior research that highlighted the role of effective scaffolding and proper guidance in promoting cognitive engagement (Hou & Keng, 2020; Lee & Hannafin, 2016; Mamun et al., 2020).

Behavioral engagement refers to the level at which learners actively participate in learning activities and tasks (Fredricks et al., 2004). With the application of CTS, learners were observed to construct solutions more systematically. The CTS provided a useful framework for learners when difficulties arose, guiding them to analyze the problem and construct solutions effectively. In STEM hands-on activities, the CTS served as a useful tool in promoting active participation and exploration, consequently boosting their behavioral engagement. This outcome is consistent with previous studies advocating for the benefits of effective scaffolding and apt guidance on enhancing behavioral engagement (Delen et al., 2014; Lee & Hannafin, 2016).

Emotional engagement addresses the learners' emotional investment in the learning process, such as their level of interest, motivation, and satisfaction (Fredricks et al., 2004). Our research found that implementing CTS potentially made the learning process more captivating, offering an innovative and enjoyable way of learning. This helped to raise the learners' interest levels and overall satisfaction with the learning process. CTS, with its step-by-step guidance and clear explanations, potentially lowered the occurrences of difficulties, preventing learners from feeling overwhelmed or lost when encountering problems, which in turn, bolstered their emotional engagement. These findings align with previous research highlighting that effective scaffolding and suitable guidance can enhance learners' emotional engagement (Chen et al., 2020b; Han, 2021; Lee & Hannafin, 2016).

Impact on Hands-On Abilities

Constructivist theory emphasizes that hands-on learning fosters a deeper understanding of concepts, which is particularly relevant in STEM education (Dewey, 1986; Thuneberg et al., 2018). In this study, we utilized the CPAM model, finding considerable improvements in students' hands-on abilities when CTS were introduced. The enhancements were notably present in Logical, Useful, Understandable, and Well-crafted dimensions.

In the Logical domain, CTS aids students in systematically analyzing and constructing problem-solving plans. It guides learners in decomposing complex problems into manageable sub-problems during the Decomposition phase, subsequently helping them comprehend the logical connections between these sub-problems during the Pattern Recognition phase. In the final Abstract and Algorithm Design phases, CTS fosters logical reasoning, which substantially boosts learners' logical thinking and problem-solving.

In the Useful dimension, CTS's focus on practicality proves instrumental. During the Pattern Recognition and Abstract phases, students are encouraged to propose practical, valuable solutions, while the Evaluation phase prompts them to consider the feasibility of their solutions in the real world. This alignment with real-world applicability enhances their practical skills and, to an extent, their critical thinking abilities, bolstering the Useful aspect of hands-on abilities.

From an Understandable perspective, the step-by-step structure of CTS provides learners with a clear pathway, assisting them in comprehending and mastering learning content. During hands-on practices, students need to understand and apply diverse knowledge and skills. Here, the structure of CTS, from decomposition to algorithm design, provides critical guidance, helping learners establish logical connections and deepen their understanding of problems and solutions.

In terms of the Well-crafted aspect, CTS emphasizes meticulousness in problem-solving, encouraging learners to attend to details and strive for quality. During the Decomposition and Pattern Recognition phases, students are urged to depict every problem aspect thoroughly. Moreover, in the Algorithm Design and Evaluation phases, CTS establishes clear norms and standards, driving students to meet these quality requirements.

Moreover, the results in Table 9 also indicate that the introduction of CTS does not have any significant impact on the Novelty dimension in CPAM for learners. This result resonates with the non-significance of Creativity in HOTS in this study. Future research could explore infusing greater flexibility into the CTS framework, thus stimulating student creativity, and further augmenting their HOTS.

Conclusion

This study aimed to develop a Computational Thinking Scaffolding (CTS) for hands-on learning in STEM education, based on the five stages of computational thinking as proposed by Wing (2006) and Anderson (2016): Decomposition, Pattern Recognition, Abstraction, Algorithm Design, and Evaluation. Utilizing a quasi-experimental design, this study explored the impact of integrating CTS on HOTS, engagement, and hands-on abilities.

The implications of this study are twofold. Firstly, it adds to the growing body of literature concerning the integration of scaffolding learning and computational thinking in STEM education. The research showcases how computational thinking can be woven into scaffolding learning as a guiding principle for hands-on activities, thus enhancing students' problem-solving capabilities and the application of interdisciplinary knowledge. Furthermore, the study introduces a novel teaching framework, CTS, which can be implemented in Jupyter Notebook, a versatile and interactive web application that promotes STEM hands-on learning. Secondly, the research provides pragmatic implications for educators and curriculum designers aiming to enhance students' HOTS, engagement, and hands-on abilities in STEM education. It advocates for the adoption of CTS as an instructional tool that can aid students' learning processes and outcomes in STEM hands-on learning. It also offers insights on how Jupyter Notebook can be employed as a learning environment that seamlessly integrates code, explanatory text, mathematical equations, and visualization.

However, this study acknowledges several limitations that suggest avenues for future research. First, the introduction of CTS had a marginal impact on nurturing creativity, a pivotal component of HOTS. Subsequent versions of the CTS might benefit from incorporating a broader array of flexible elements to augment student creativity. Second, the research context was confined to a single course, namely the Networks Embedded System and Application, within the discipline of Engineering Science. Moreover, given that CTS was anchored in the Jupyter Notebook platform, there may be potential constraints in its generalizability. Future inquiries should consider exploring the effectiveness and adaptability of CTS across diverse courses and disciplines within the STEM educational framework. Additionally, it would be beneficial to broaden CTS to more interactive development ecosystems, predominantly those rooted in iPython, to boost its portability and outreach.

Acknowledgements

We are extremely grateful to the research assistants and students who participated in this study.

Author Contributions

Hsin-Yu Lee is responsible for assisting in the conduct of experiments and surveying related literature, writing the manuscript, and proofreading the manuscript. Ting-Ting Wu is the leader of this research, he is in charge of the research design, conducting teaching and learning experiment, data analysis. Chia-Ju Lin is responsible for assisting in the conduct of experiments and surveying related literature. Wei-Sheng Wang is responsible for assisting in the conduct of experiments. Yueh-Min Huang is responsible for designing research experiments, providing fundamental education theories and comments to this research, and he is also responsible for revising the manuscript. All authors spent more than 2 months to discuss and analyze the data. The author(s) read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project was funded by the National Science and Technology Council (NSTC), of the Republic of China under Contract numbers NSTC 109-2511-H-006-011-MY3, NSTC 110-2511-H-006-012-MY3.

ORCID iDs

Hsin-Yu Lee https://orcid.org/0000-0003-3257-305X
Chia-Ju Lin https://orcid.org/0000-0002-2321-1834
Yueh-Min Huang https://orcid.org/0000-0001-7052-1272

Data Availability Statement

The data presented in this study are available upon reasonable request from the corresponding author, except Experimental Research Participation Consent Form.

References

Alrawili, K. S., Osman, K., & Almuntasheri, S. (2020). Effect of scaffolding strategies on higher-order thinking skills in science classroom. *Journal of Baltic Science Education*, *19*(5), 718–729. https://doi.org/10.33225/jbse/20.19.718

Alterman, R., & Harsch, K. (2017). A more reflective form of joint problem solving. *International Journal of Computer-Supported Collaborative Learning*, *12*(1), 9–33. https://doi.org/10.1007/s11412-017-9250-1

Anderson, N. D. (2016). A call for computational thinking in undergraduate psychology. *Psychology Learning and Teaching*, *15*(3), 226–234. https://doi.org/10.1177/1475725716659252

Baharin, N., Kamarudin, N., & Manaf, U. K. A. (2018). Integrating STEM education approach in enhancing higher order thinking skills. *International Journal of Academic Research in Business and Social Sciences*, *8*(7), 810–821. https://doi.org/10.6007/IJARBSS/v8-i7/4421

Ballantyne, R., & Packer, J. (2009). Introducing a fifth pedagogy: Experience-based strategies for facilitating learning in natural environments. *Environmental Education Research*, *15*(2), 243–262. https://doi.org/10.1080/13504620802711282

Bathgate, M. E., Aragón, O. R., Cavanagh, A. J., Waterhouse, J. K., Frederick, J., & Graham, M. J. (2019). Perceived supports and evidence-based teaching in college STEM. *International Journal of STEM Education*, *6*(1), 11. https://doi.org/10.1186/s40594-019-0166-3

Berk, L. E., & Winsler, A. (1995). Scaffolding children's learning: Vygotsky and early childhood education. In: *NAEYC Research into Practice Series* (vol. 7). ERIC.

Besemer, S. P., & O'Quin, K. (1999). Confirming the three-factor creative product analysis Matrix model in an American sample. *Creativity Research Journal*, *12*(4), 287–296. https://doi.org/10.1207/s15326934crj1204_6

Bledow, R., Rosing, K., & Frese, M. (2012). A dynamic perspective on affect and creativity. *Academy of Management Journal*, *56*(2), 432–450. https://doi.org/10.5465/amj.2010.0894

Bloom, B. S., Engelhart, M. D., Furst, E., Hill, W. H., & Krathwohl, D. R. (1956). *Handbook I: Cognitive domain*. David McKay.

Brigham, F. J., Scruggs, T. E., & Mastropieri, M. A. (2011). Science education and students with learning disabilities. *Learning Disabilities Research & Practice*, *26*(4), 223–232. https://doi.org/10.1111/j.1540-5826.2011.00343.x

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current perceptions. *Technology and Engineering Teacher*, *70*(6), 5.

Chang, C.-C., & Chen, Y. (2022). Using mastery learning theory to develop task-centered hands-on STEM learning of Arduino-based educational robotics: Psychomotor performance and perception by a convergent parallel mixed method. *Interactive Learning Environments*, *30*(9), 1677–1692. https://doi.org/10.1080/10494820.2020.1741400

Chen, H., Park, H. W., & Breazeal, C. (2020b). Teaching and learning with children: Impact of reciprocal peer learning with a social robot on children's learning and emotive engagement. *Computers & Education*, *150*(5), 103836. https://doi.org/10.1016/j.compedu.2020.103836

Chen, J.-C., Huang, Y., Lin, K. Y., Chang, Y. S., Lin, H. C., Lin, C. Y., & Hsiao, H. S. (2020a). Developing a hands-on activity using virtual reality to help students learn by doing. *Journal of Computer Assisted Learning*, *36*(1), 46–60. https://doi.org/10.1111/jcal.12389

Chen, W., Shah, U. V., & Brechtelsbauer, C. (2019). A framework for hands-on learning in chemical engineering education—training students with the end goal in mind. *Education for Chemical Engineers*, *28*, 25–29. https://doi.org/10.1016/j.ece.2019.03.002

Chevalier, M., Giang, C., Piatti, A., & Mondada, F. (2020). Fostering computational thinking through educational robotics: A model for creative computational problem solving. *International Journal of STEM Education*, *7*(1), 39. https://doi.org/10.1186/s40594-020-00238-z

Christensen, R., Knezek, G., & Tyler-Wood, T. (2015). Alignment of hands-on STEM engagement activities with positive STEM dispositions in secondary school students. *Journal of Science Education and Technology*, *24*(6), 898–909. https://doi.org/10.1007/s10956-015-9572-6

Czajka, C. D., & McConnell, D. (2016). Situated instructional coaching: A case study of faculty professional development. *International Journal of STEM Education*, *3*(1), 10. https://doi.org/10.1186/s40594-016-0044-1

Delen, E., Liew, J., & Willson, V. (2014). Effects of interactivity and instructional scaffolding on learning: Self-regulation in online video-based environments. *Computers & Education*, *78*(3), 312–320. https://doi.org/10.1016/j.compedu.2014.06.018

Dewey, J. (1986). Experience and education. *The Educational Forum*, *50*(3), 241–252. https://doi.org/10.1080/00131728609335764

Di, W., Danxia, X., & Chun, L. (2019). The effects of learner factors on higher-order thinking in the smart classroom environment. *Journal of Computers in Education*, *6*(4), 483–498. https://doi.org/10.1007/s40692-019-00146-4

Falloon, G. (2017). Mobile devices and Apps as scaffolds to science learning in the primary classroom. *Journal of Science Education and Technology*, *26*(6), 613–628. https://doi.org/10.1007/s10956-017-9702-4

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*(1), 59–109. https://doi.org/10.3102/00346543074001059

Gadot, R., & Tsybulsky, D. (2023). Digital curation as a pedagogical approach to promote critical thinking. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-022-10016-x

Gamse, B. C., Martinez, A., & Bozzi, L. (2017). Calling STEM experts: How can experts contribute to students' increased STEM engagement? *International Journal of Science Education, Part B*, *7*(1), 31–59. https://doi.org/10.1080/21548455.2016.1173262

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, *7*(1), 24. https://doi.org/10.1186/s40594-020-00225-4

Glaroudis, D., Iossifides, A., Spyropoulou, N., Zaharakis, I. D., & Kameas, A. D. (2019). STEM learning and career orientation via IoT hands-on activities in secondary education. In *2019 IEEE international conference on pervasive computing and communications workshops (PerCom workshops)*, 11–15 March 2019, Kyoto, Japan. https://doi.org/10.1109/PERCOMW.2019.8730759

Good, T. L., & Lavigne, A. L. (2017). *Looking in classrooms*. Routledge.

Ha, V. T., Chung, L. H., Hanh, N. V., & Hai, B. M. (2023). Teaching science using Argumentation-supported 5E-STEM, 5E-STEM, and conventional didactic methods: Differences in the learning outcomes of middle school students. *Education Sciences*, *13*(3), 247. https://doi.org/10.3390/educsci13030247

Han, K. (2021). Fostering students' autonomy and engagement in EFL classroom through proximal classroom factors: Autonomy-supportive behaviors and student-teacher relationships [conceptual analysis]. *Frontiers in Psychology*, *12*, 767079. https://doi.org/10.3389/fpsyg.2021.767079

Horikami, A., & Takahashi, K. (2022). The tripartite thinking model of creativity. *Thinking Skills and Creativity*, *44*(1), 101026. https://doi.org/10.1016/j.tsc.2022.101026

Hou, H.-T., & Keng, S.-H. (2020). A dual-scaffolding framework integrating peer-scaffolding and cognitive-scaffolding for an augmented reality-based educational board game: An analysis of learners' collective flow state and collaborative learning behavioral patterns. *Journal of Educational Computing Research*, *59*(3), 547–573. https://doi.org/10.1177/0735633120969409

Hsiao, H.-S., Chang, Y.-C., Lin, K.-Y., Chen, J.-C., Lin, C.-Y., Chung, G.-H., & Chen, J.-H. (2022). Applying the design thinking model to hands-on mechatronics STEM activities for senior high school students to improve the learning performance and learning behavior.

International Journal of Technology and Design Education, *33*(4), 1–20. https://doi.org/10.1007/s10798-022-09778-7

Huang, H.-T., & Chang, Y.-S. (2023). Effects of virtual reality on creative performance and emotions: A study of brainwaves. *Computers in Human Behavior*, *146*, 107815. https://doi.org/10.1016/j.chb.2023.107815

Huang, Y.-M., Silitonga, L. M., Murti, A. T., & Wu, T.-T. (2023). Learner engagement in a business simulation game: Impact on higher-order thinking skills. *Journal of Educational Computing Research*, *61*(1), 96–126. https://doi.org/10.1177/07356331221106918

Huang, Y.-M., Silitonga, L. M., & Wu, T.-T. (2022). Applying a business simulation game in a flipped classroom to enhance engagement, learning achievement, and higher-order thinking skills. *Computers & Education*, *183*(10), 104494. https://doi.org/10.1016/j.compedu.2022.104494

Hwang, G.-J., Lai, C.-L., Liang, J.-C., Chu, H.-C., & Tsai, C.-C. (2018). A long-term experiment to investigate the relationships between high school students' perceptions of mobile learning and peer interaction and higher-order thinking tendencies. *Educational Technology Research & Development*, *66*(1), 75–93. https://doi.org/10.1007/s11423-017-9540-3

Idris, R., Govindasamy, P., & Nachiappan, S. (2023). Challenge and obstacles of STEM education in Malaysia. *International Journal of Academic Research in Business and Social Sciences*, *13*(4), 820–828. https://doi.org/10.6007/IJARBSS/v13-i4/16676

Jamovi. (2023). *jamovi Version 2.4*. Computer Software. https://www.jamovi.org

Jupyter. (n.d.). *Jupyter Notebook*. Jupyter. https://github.com/jupyter/notebook

Kennedy, A. A. U., Thacker, I., Nye, B. D., Sinatra, G. M., Swartout, W., & Lindsey, E. (2021). Promoting interest, positive emotions, and knowledge using augmented reality in a museum setting. *International Journal of Science Education, Part B*, *11*(3), 242–258. https://doi.org/10.1080/21548455.2021.1946619

Kennedy, T. J., & Sundberg, C. W. (2020). 21st century skills. In B. Akpan & T. J. Kennedy (Eds.), *Science education in theory and practice: An introductory guide to learning theory* (pp. 479–496). Springer International Publishing. https://doi.org/10.1007/978-3-030-43620-9_32

Kim, N. J., Belland, B. R., Lefler, M., Andreasen, L., Walker, A., & Axelrod, D. (2020). Computer-based scaffolding targeting individual versus groups in problem-centered instruction for STEM education: Meta-analysis. *Educational Psychology Review*, *32*(2), 415–461. https://doi.org/10.1007/s10648-019-09502-3

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory Into Practice*, *41*(4), 212–218. https://doi.org/10.1207/s15430421tip4104_2

Lai, X., & Wong, G. K.-w. (2022). Collaborative versus individual problem solving in computational thinking through programming: A meta-analysis. *British Journal of Educational Technology*, *53*(1), 150–170. https://doi.org/10.1111/bjet.13157

Lee, E., & Hannafin, M. J. (2016). A design framework for enhancing engagement in student-centered learning: Own it, learn it, and share it. *Educational Technology Research & Development*, *64*(4), 707–734. https://doi.org/10.1007/s11423-015-9422-5

Lee, H.-Y., Cheng, Y.-P., Wang, W.-S., Lin, C.-J., & Huang, Y.-M. (2023a). Exploring the learning process and effectiveness of STEM education via learning behavior analysis and the interactive-constructive- active-passive framework. *Journal of Educational Computing Research*, *61*(5), 951–976. https://doi.org/10.1177/07356331221136888

Lee, H.-Y., Lin, C.-J., Wang, W.-S., Chang, W.-C., & Huang, Y.-M. (2023b). Precision education via timely intervention in K-12 computer programming course to enhance programming skill and affective-domain learning objectives. *International Journal of STEM Education*, *10*(1), 52. https://doi.org/10.1186/s40594-023-00444-5

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education. *Journal of Science Education and Technology*, *29*(1), 1–8. https://doi.org/10.1007/s10956-019-09803-w

Leung, A. (2020). Boundary crossing pedagogy in STEM education. *International Journal of STEM Education*, *7*(1), 15. https://doi.org/10.1186/s40594-020-00212-9

Lu, K., Yang, H. H., Shi, Y., & Wang, X. (2021). Examining the key influencing factors on college students' higher-order thinking skills in the smart classroom environment. *International Journal of Educational Technology in Higher Education*, *18*(1), 1. https://doi.org/10.1186/s41239-020-00238-7

Mamun, M. A. A., Lawrie, G., & Wright, T. (2020). Instructional design of scaffolded online learning modules for self-directed and inquiry-based learning environments. *Computers & Education*, *144*, 103695. https://doi.org/10.1016/j.compedu.2019.103695

May, D., Morkos, B., Jackson, A., Hunsu, N. J., Ingalls, A., & Beyette, F. (2023). Rapid transition of traditionally hands-on labs to online instruction in engineering courses. *European Journal of Engineering Education*, *48*(5), 842–860. https://doi.org/10.1080/03043797.2022.2046707

Mumcu, F., Uslu, N. A., & Yıldız, B. (2023). Teacher development in integrated STEM education: Design of lesson plans through the lens of computational thinking. *Education and Information Technologies*, *28*(3), 3443–3474. https://doi.org/10.1007/s10639-022-11342-8

Murphy, S., MacDonald, A., Wang, C. A., & Danaia, L. (2019). Towards an understanding of STEM engagement: A review of the literature on motivation and academic emotions. *Canadian Journal of Science, Mathematics, and Technology Education*, *19*(3), 304–320. https://doi.org/10.1007/s42330-019-00054-w

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM education in secondary schools: Teachers' perspective towards sustainable development. *Sustainability*, *12*(21), 8865. https://doi.org/10.3390/su12218865

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, *40*(1), 1–12. https://doi.org/10.1207/s15326985ep4001_1

Reeve, J., & Tseng, C.-M. (2011). Agency as a fourth aspect of students' engagement during learning activities. *Contemporary Educational Psychology*, *36*(4), 257–267. https://doi.org/10.1016/j.cedpsych.2011.05.002

Saad, A., & Zainudin, S. (2022). A review of project-based learning (PBL) and computational thinking (CT) in teaching and learning. *Learning and Motivation*, *78*(12), 101802. https://doi.org/10.1016/j.lmot.2022.101802

Sakamoto, Y., Okamoto, S., Shimizu, K., Araki, Y., Hirakawa, A., & Wakabayashi, T. (2017). Hands-on simulation versus traditional video-learning in teaching microsurgery technique. *Neurologia Medico-Chirurgica*, *57*(5), 238–245. https://doi.org/10.2176/nmc.oa.2016-0317

Salmi, H., Thuneberg, H., & Vainikainen, M.-P. (2017). Learning with dinosaurs: A study on motivation, cognitive reasoning, and making observations. *International Journal of Science Education, Part B*, *7*(3), 203–218. https://doi.org/10.1080/21548455.2016.1200155

Schaper, M.-M., Smith, R. C., Tamashiro, M. A., Van Mechelen, M., Lunding, M. S., Bilstrup, K.-E. K., Kaspersen, M. H., Jensen, K. L., Petersen, M. G., & Iversen, O. S. (2022). Computational empowerment in practice: Scaffolding teenagers' learning about emerging technologies and their ethical and societal impact. *International Journal of Child-Computer Interaction*, *34*, 100537. https://doi.org/10.1016/j.ijcci.2022.100537

Slayter, E., & Higgins, L. M. (2018). Hands-on learning: A problem-based approach to teaching Microsoft excel. *College Teaching*, *66*(1), 31–33. https://doi.org/10.1080/87567555.2017.1385585

Srisangngam, P., & Dechsura, C. (2020, 4-6 Nov. 2020). STEM education activities development to promote computational thinking's students. In 2020 5th international STEM education conference (iSTEM-Ed), Hua Hin, Thailand, 42020–6 Nov. https://doi.org/10.1109/iSTEM-Ed50324.2020.9332734

Struyf, A., De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (2019). Students' engagement in different STEM learning environments: Integrated STEM education as promising practice? *International Journal of Science Education*, *41*(10), 1387–1407. https://doi.org/10.1080/09500693.2019.1607983

Su, Y.-S., Chang, C.-Y., Wang, C.-H., & Lai, C.-F. (2022). A study of students' learning perceptions and behaviors in remote STEM programming education [Conceptual Analysis]. *Frontiers in Psychology*, *13*, 962984. https://doi.org/10.3389/fpsyg.2022.962984.

Sun, H., Xie, Y., & Lavonen, J. (2022). Exploring the structure of students' scientific higher order thinking in science education. *Thinking Skills and Creativity*, *43*(4), 100999. https://doi.org/10.1016/j.tsc.2022.100999

Thoutenhoofd, E. D., & Pirrie, A. (2015). From self-regulation to learning to learn: Observations on the construction of self and learning. *British Educational Research Journal*, *41*(1), 72–84. https://doi.org/10.1002/berj.3128

Thuneberg, H. M., Salmi, H. S., & Bogner, F. X. (2018). How creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module. *Thinking Skills and Creativity*, *29*(5910), 153–160. https://doi.org/10.1016/j.tsc.2018.07.003

Ting, Y.-L., & Tai, Y. (2019). Tackling the challenge of hands-on learning from cognitive perspective. International Cognitive Cities Conference, Kyoto, Japan, 3–6 September.

Vygotsky, L. S., & Cole, M. (1978). *Mind in society: Development of higher psychological processes*. Harvard University Press.

Wahono, B., Lin, P.-L., & Chang, C.-Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, *7*(1), 36. https://doi.org/10.1186/s40594-020-00236-1

Wang, C., Shen, J., & Chao, J. (2022b). Integrating computational thinking in STEM education: A literature review. *International Journal of Science and Mathematics Education*, *20*(8), 1949–1972. https://doi.org/10.1007/s10763-021-10227-5

Wang, H.-H., Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L. (2020). Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system. *International Journal of STEM Education*, *7*(1), 3. https://doi.org/10.1186/s40594-019-0201-4

Wang, L.-H., Chen, B., Hwang, G.-J., Guan, J.-Q., & Wang, Y.-Q. (2022a). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education*, *9*(1), 26. https://doi.org/10.1186/s40594-022-00344-0

Wang, M.-T., & Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (STEM): Current knowledge, implications for practice, policy, and future directions. *Educational Psychology Review*, *29*(1), 119–140. https://doi.org/10.1007/s10648-015-9355-x

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33–35. https://doi.org/10.1145/1118178.1118215

Wong, K. M. (2021). A design framework for enhancing engagement in student-centered learning: Own it, learn it, and share it" by lee and Hannafin (2016): An international perspective. *Educational Technology Research & Development*, *69*(1), 93–96. https://doi.org/10.1007/s11423-020-09842-w

Wong, S. H. V., & Kowitlawakul, Y. (2020). Exploring perceptions and barriers in developing critical thinking and clinical reasoning of nursing students: A qualitative study. *Nurse Education Today*, *95*(1), 104600. https://doi.org/10.1016/j.nedt.2020.104600

Wu, B., Hu, Y., & Wang, M. (2019). Scaffolding design thinking in online STEM preservice teacher training. *British Journal of Educational Technology*, *50*(5), 2271–2287. https://doi.org/10.1111/bjet.12873

Wu, T.-T., Lee, H.-Y., Li, P.-H., Huang, C.-N., & Huang, Y.-M. (2023a). Promoting self-regulation progress and knowledge construction in blended learning via ChatGPT-based learning aid. *Journal of Educational Computing Research*. https://doi.org/10.1177/07356331231191125

Wu, T.-T., Lee, H.-Y., Wang, W.-S., Lin, C.-J., & Huang, Y.-M. (2023b). Leveraging computer vision for adaptive learning in STEM education: Effect of engagement and self-efficacy. *International Journal of Educational Technology in Higher Education*, *20*(1), 53. https://doi.org/10.1186/s41239-023-00422-5

Zhong, B., Liu, X., Xia, L., & Sun, W. (2022). A proposed taxonomy of teaching models in STEM education: Robotics as an example. *Sage Open*, *12*(2), 21582440221099525. https://doi.org/10.1177/21582440221099525

Zhou, Y., Chai, C. S., Li, X., Ma, C., Li, B., Yu, D., & Liang, J.-C. (2023a). Application of metacognitive planning scaffolding for the cultivation of computational thinking. *Journal of Educational Computing Research*, *61*(1), 07356331231160294. https://doi.org/10.1177/07356331231160294

Zhou, Y., Gan, L., Chen, J., Wijaya, T. T., & Li, Y. (2023b). Development and validation of a higher-order thinking skills assessment scale for pre-service teachers. *Thinking Skills and Creativity*, *48*(21), 101272. https://doi.org/10.1016/j.tsc.2023.101272

Ziaeefard, S., Miller, M. H., Rastgaar, M., & Mahmoudian, N. (2017). Co-Robotics hands-on activities: A gateway to engineering design and STEM learning. *Robotics and Autonomous Systems*, *97*(2), 40–50. https://doi.org/10.1016/j.robot.2017.07.013

Author Biographies

Hsin-Yu Lee received his B.S. degree in the Department of Technology Application And Human Resource Development, National Taiwan Normal University, Taiwan, R.O.C., in 2019, and received the M.S. degree in the Department of Engineering Science, National Cheng-Kung University, Taiwan, R.O.C., in 2021. He is currently pursuing his PhD degree in engineering science at National Cheng Kung University, Taiwan, R.O.C. His research interests include educational technology, learning analytics, computer vision and artificial intelligence.

Ting-Ting Wu is a distinguished professor and director of the Graduate School of Technological and Vocational Education, National Yunlin University of Science and Technology, Taiwan. Her research covers such areas as technology-enhanced language learning and applications of advanced technology to support nursing education.

Chia-Ju Lin received her B.S. and M.S. degrees from the Department of Computer Science and Information Engineering, National Chin-Yi University of Technology, Taiwan, R.O.C., in 2019 and 2021, respectively. She is currently pursuing her PhD degree in engineering science at National Cheng Kung University, Taiwan. Her research interests include educational technology, learning analytics, computer networks and artificial intelligence.

Wei-Sheng Wang received her B.S. and M.S. degrees from the Department of Computer Science and Information Engineering, National Chin-Yi University of Technology, Taiwan, R.O.C., in 2018 and 2020, respectively. He is currently pursuing his PhD degree in engineering science at National Cheng Kung University, Taiwan.

Yueh-Min Huang received the M.S. and PhD degrees in Electrical Engineering from the University of Arizona in 1988 and 1991 respectively. He is a Chair Professor in Department of Engineering Science, National Cheng-Kung University, Taiwan. He has co-authored 3 books and has published more than 250 refereed journal research papers. His research interests include e-Learning, multimedia communications, wireless networks, and artificial intelligence. He is in the editorial board of several international journals in the area of educational technology, computer communications, and web intelligence, including 3 SSCI-indexed e-Learning ones. In e-Learning area, except of publishing more than 100 SSCI-indexed journal papers and editing 3 special issues in SSCI-indexed journals, he was also serving as the directors of Disciplines of Applied

Science Education and Innovative Engineering Education in Taiwan's Ministry of Science and Technology.

Dr. Huang is a senior member of the IEEE and became Fellow of British Computer Society in 2011. Dr Huang has received many research awards, such as Taiwan's National Outstanding Research Award in 2011 and 2014, given to Taiwan's top 100 scholars. According to a paper published in BJET, he is ranked no. 3 in the world on terms of the number of educational technology papers published in the period 2012 to 2017.