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# Developing pre-service teachers' computational thinking through experiential learning: hybridisation of plugged and unplugged approaches

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**Abstract**

Computational thinking (CT) is one of the skills that are critical for problem-solving in a technology-driven society. Although the importance of CT as a goal in education is increasingly acknowledged, there is scant research on developing pre-service teachers' CT competencies so that they can integrate CT in their lesson design. In this study, drawing from the experiential learning framework, we discuss the design of a module using a novel approach that is a hybridisation of plugged and unplugged CT approaches. The aim is to facilitate pre-service teachers in making connections between CT and their teaching contexts. Thirty-eight pre-service teachers attended the CT module for twelve weeks. The results indicated that the participants developed better CT competencies by integrating, justifying and reflecting CT in their lesson design. This study demonstrates the importance of providing a practical CT module to conduct unplugged activities for pre-service teachers, especially for those without prior computing knowledge, before introducing CT in the context of programming.

**Keywords:** Computational thinking, Plugged computational thinking, Unplugged computational thinking, Teacher education, Experiential learning

## Introduction

In recent years, Computational Thinking (CT) has emerged as a key competency of 21st-century learning. There has been much discussion on the definition of CT, and the general consensus that its importance must be acknowledged (Grover & Pea, 2018). Nevertheless, questions about how CT can be taught effectively remain largely underexplored (Lamprou

& Repenning, 2018). Indeed, CT is crucial for all sciences, and not only for Computer Science (CS) (Wing, 2006). Thus, every learner should be given the opportunity to acquire CT (Wing, 2017). Along this line, teachers play a critical role in developing students' CT through the integration of CT in their teaching. From the pedagogical aspect, this new practice would put teachers in a new and unfamiliar role in the classroom. Hence, it is vital to build on teachers' knowledge and ensure that they are comfortable in facilitating CT (National Research Council, 2011). It is important to develop pre-service teachers' capability to integrate CT into their lessons effectively, and they need to learn and think computationally, especially in the context of the particular subject that they will be teaching. (Yadav et al., 2017). Through reflective activities, which have been emphasised as a key learning objective in pre-service teacher education (Baker & Shahid, 2003), teachers would be able to improve lesson designs that facilitate CT.

In this study, the term "pre-service teachers" refers to undergraduate students who were pursuing their studies to become secondary school teachers. In the following sections, the literature of plugged and unplugged CT approaches and CT development of pre-service teachers will be presented. An explanation of the framework of this study follows. Underpinned by Kolb's experiential learning cycle, along with its key features which support the design and the implementation of a CT module, we developed a module that adopted a novel approach which was a hybridisation of plugged and unplugged CT learning activities. Drawing upon the qualitative case study methodology, various types of data, including interviews, students' assignments, online artefacts and personal E-portfolios, were collected. The analysis focused on how the framework of experiential learning was applied in designing and implementing a CT module to enhance the students' learning outcomes. Lastly, the discussion highlighted experiential learning as a pedagogical theory that supports teaching and learning in nurturing CT development.

The main aim of the study was to investigate the effectiveness of a CT module on pre-service teachers' CT experiential learning and CT application. The study was guided by this research question: How does the CT module affect pre-service teachers' experiential learning through CT application in their lesson design?

## Literature review

### Definition of computational thinking

Computational thinking is discussed in Seymour Papert's work with LOGO aimed at nurturing children's procedural thinking through the learning of programming (Papert, 1980). CT, coined as a term, implies "solving problems, designing systems, and understanding human behaviour by drawing on the concepts fundamental to CS" (Wing, 2006, p. 33). Hence, CT can be considered as an individual's analytical thinking skills and problem-solving abilities.

According to Cuny et al. (2010), the most often cited definition of CT is that it is a thinking process whereby "… solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2010, p. 1). Since many scholars define CT based on its operationalisation in their studies, they are not generalisable (Berland & Wilensky, 2015; Israel et al., 2015). For example, researchers explicitly associate CT with programming skills by interpreting CT as the ability to develop programmes and modelling ideas using computers (Israel et al., 2015). Berland and Wilensky (2015) suggest that CT is "the ability to think with the computer-as-tool" (p. 630). No doubt, scholars have started to aggregate knowledge about CT, and hence the definition of CT is evolving (Shute et al., 2017). Existing literature encourages and supports the integration of CT within multiple disciplines in K-12 curricula (Kong et al., 2018; Weintrop et al., 2016). Barr et al. (2011) conclude that CT can be interpreted as a problem-solving skill and a personality trait (such as persistence and confidence) when encountering specific problems in K-12 educational settings.

## Computational thinking facets and computational thinking competencies

The conceptual foundation of CT facets requires individuals to approach problems from a CT perspective, and highlights how this CT perspective can be supported in the current K-12 educational setting (Shute et al., 2017). Accordingly, there are six CT facets serving as guidelines for various assessment methods, and providing the foundation of CT for K-12 students. The six facets are abstraction, algorithm, decomposition, generalisation, iteration and debugging. Abstraction refers to the extraction of the essence of a (complex) system. Algorithm can be interpreted as logical instructions and order of design that can be carried out by a human or computer to solve a problem. Decomposition involves dissecting a complex problem into smaller and manageable parts based on functional elements. Generalisation refers to the transfer of CT skills to different domains or a wide range of situations to solve problems effectively and efficiently. Iteration requires the individual to refine the solution by repeating the instruction design processes in order to reach an ideal result. Debugging refers to the detection and identification of errors, followed by fixing the errors if a solution does not perform as intended. Therefore, CT facets emphasise individuals' conceptual development in problem-solving.

As CT facets are known as approaches of problem-solving from the CT perspective, students should be taught the CT facets to develop their thinking skillset, known as CT competencies when taken into consideration together (Korkmaz et al., 2017). It is useful to define each skill of the thinking skillset so that students are able to successfully acquire CT. According to Korkmaz et al. (2017), there are five CT competencies, viz. problem-solving, critical thinking, creativity, algorithmic thinking, and cooperativity. Problem-solving focuses on the involvement of the individual in sustained investigative processes to generate solutions. Critical thinking occurs when the individual analyses and makes an assessment-oriented conscious judgment that leads to an appropriate decision. Creativity is the process of developing genuine ideas different from ordinary ones, combining a new composition of ideas using problem-solving and critical thinking skills. Algorithmic thinking refers to thinking in a detailed and purposeful way by placing proceedings in sequence to produce a solution. Cooperativity refers to individuals helping one another learn an academic subject with different methods for a common purpose.

## Plugged and unplugged approaches to computational thinking

Naur (1965) investigated the interrelationship of people, problems and tools in the computational problem-solving process. This interrelationship can be explained from the aspect of human understanding in solving the problems and requires the individual's understanding of relevant tools (Naur, 1965). Programming is used as a tool to influence the individual's way of thinking, specifically in how a problem is viewed, and subsequently creating a possible solution from the tool's perspective and its capability (Naur, 1965). For instance, to develop programming skills, individuals are required to have an in-depth understanding of programming and its capabilities. In CS, teachers should engage students in learning programming by focusing on the students' development of problem-solving skills when using programming as a tool (Caeli & Yadav, 2020; Naur,1965).

Some scholars argue that the understanding of concepts and algorithms is the most important part in solving a problem, instead of merely emphasising programming, which may obstruct the learner's understanding when designing algorithms (Greenberger, 1962; Knuth, 1974). The unplugged approach, which allows learners to use and explore computing concepts without the use of a computer, is not restricted by formal details and structures. For example, a flowchart allows the learner to design algorithms to communicate solutions. It is important, therefore, to nurture the individual's ability to create solutions by using CS concepts as they can be applied as general-purpose mental tools to develop deeper understanding in other disciplines (Knuth, 1974). Human creativity and innovation as well as problem-solving skills are central to the learning process, with computing tools playing an ancillary role. Hence, it would be useful to adopt a novel teaching technique that uses a hybridisation of plugged (computer-mediated) and unplugged approaches (supported by non-digital tools) to engage students in the learning of CS concepts and problem-solving skills.

## A constructionist approach to hybridise plugged and unplugged approaches

The hybridisation of CT approaches is underpinned by Papert's (1980) constructionist approach, which is highly influenced by Jean Piaget, who emphasises the importance of learners' ability to reflect on their thinking as "builders of their intellectual structures" (Papert, 1980, p. 7). Papert's constructionism illustrates the art of learning by focusing on "learning-by-doing" and "making things in learning" (Ackermann, 2001). By engaging learners in a conversation with their own or others' artefacts, self-directed learning and knowledge construction would ensue (Papert, 1980). Papert also stresses that the tools, media, and context are essential aspects of human development.

CT is rooted in unplugged (non-digital) human approaches to problem-solving (Caeli & Yadav, 2020) and can be taught using two approaches: (1) CT plugged approach, mediated by technologies, and (2) CT unplugged approach, without using digital tools (Shute et al., 2017). According to Naur (1965), learners need to understand the computer as a tool in problem-solving. The combination of plugged and unplugged activities allows learners to better understand the power of computing (Caeli & Yadav, 2020). Therefore, we argue that the hybridisation of the plugged and unplugged approaches could significantly enhance CT skills.

### *Learning of computational thinking through programming in K-12 education*

CT in the context of programming is an emerging field in K-12 educational settings (Kong & Abelson, 2019). CT is conceptualised in a programming learning context that consists of three main components, viz. (1) CT concepts, such as events, sequences, conditionals and loops; (2) CT practices, including abstraction, testing, modularisation, reusing, debugging, and remixing in programming; and (3) CT perspectives, such as students' viewpoints and self-expressions in the digital world (Brennan & Resnick, 2012). These components nurture students' CT-based problem-solving skills and foster digital producers (Angeli et al., 2016).

Based on the literature, novice programmers often face difficulty in understanding basic algorithmic structures such as conditions, looping, sequence, and syntactic details of the language used in creating programmes (Roy et al., 2012). Hence, scholars have developed strategies such as visualised programming tools to reduce learners' cognitive load and to engage a broader population in learning programming (Kelleher & Pausch, 2007). Visualised programming tools (e.g., Scratch) are developed in the form of block languages which enable novices to create programmes by choosing and connecting the available blocks. In addition, many studies use Scratch to conduct pre-service teachers programming courses (An & Lee, 2014; Bean et al., 2015; Bell et al., 2014). The literature acknowledges Scratch as an attractive platform to acquire the skills associated with CT (Maloney et al., 2010), and to cultivate logical reasoning and creative thinking (Tabet et al., 2016). In the context of educational reforms, many countries argue for the need to integrate CT into compulsory education (ISTE, 2016; NGSS Lead States, 2013).

### *Learning unplugged computational thinking across-discipline in K-12 education*

The fundamentals of CT concepts are drawn from CS (Yadav et al., 2017). The trans-disciplinary nature of CT competencies opens up the opportunity to integrate CT into all disciplines in K-12 settings, such as English, science, and mathematics (Weintrop et al., 2016). For instance, core CT concepts can be incorporated in social studies through population trends identification (data analysis) and the deduction of general principles from facts (abstraction) (Barr & Stephenson, 2011). Threekunprapa and Yasri (2020) reported that students' conceptual understanding of coding and CT significantly improved through the intervention of unplugged activities. The pervasiveness of CT indicates the need to expose students to CT in their early school years to help increase their awareness of how and when to apply CT. Acknowledging the importance of nurturing CT skills among students, the Ministry of Education (MOE) of Malaysia integrated CT skills into both the primary and secondary school curricula in 2017 (Bernama, 2016). Undoubtedly, plugged and unplugged approaches need to be integrated into various disciplines in the K-12 setting, but teachers must first be taught how to go about implementing it. It would be pragmatic to support and prepare pre-service teachers to apply CT as part of their pedagogical training.

## Computational thinking development among pre-service teachers

There are limited studies on CT development for pre-service teachers compared to in-service teachers (Jaipal-Jamani & Angeli, 2017). Research on CT focus primarily on definitional issues and tools that foster CT development (Grover & Pea, 2013). For the plugged CT approach, Jaipal-Jamani and Angeli (2017) examined the effect of robotics on 21 elementary pre-service teachers' learning of CT in educational science courses. These teachers developed some foundational CT skills through scaffolded programming practices. Another study proposed that teacher education courses include programming, CT, as well as methods and tools used in programming education (Kaila et al., 2018). The feedback collected from the tutorial sessions and the practice lessons at schools was mainly positive. Umutlu (2021) introduced block-based programming to explore pre-service teachers' CT and programming skills in an educational technology course. The study suggested that well-designed educational technology courses for programming might be useful for pre-service teachers who could be novice coders.

Pre-service teachers have been introduced to CT through unplugged activities. Curzon et al. (2014) explored the effectiveness of using 'unplugged' methods (constructivist, often kinaesthetic, activities without using computers) with contextually rich storytelling to introduce CT concepts in a non-threatening way. The teachers' feedback was positive, thus indicating that the approach gave them a greater understanding of CT concepts and practical teaching techniques (Curzon et al., 2014).

Nowadays, although most school curricula place much emphasis on the integration of CT in the teaching of various subjects, there is a lack of teachers with adequate CT knowledge and skills (Caeli & Yadav, 2020). A study on pre-service teachers (Mouza et al., 2017) examined the influence of an educational technology course integrating CT in the K-8 curriculum. Feedback from most of the teachers indicated positive outcomes on the self-reported survey, case reports and participants' knowledge of CT tools, concepts and practices. Understandably, some teachers could not integrate CT meaningfully into their lesson plans.

A situated understanding of CT among teachers is important to ensure that they are able to relate how and/or identify what CT skill can be demonstrated in their students' daily routine. According to Korthagen (2010), teachers establish the understanding of effective instructional practices by enabling students to use their experience and reflect on concrete examples. Applying this perspective to the integration of CT in K-12 classrooms implies that other than understanding what CT is, teachers need to learn to pay attention to the 'shimmers of CT' which occur in students' daily interactions that can develop 'deeper' CT. Additionally, pre-service teachers should be provided with introductory computing courses that integrate other disciplines such as STEM so that they can explicitly use and associate CT with programming practice (Lamprou & Repenning, 2018). This can be done by conceptualising CT as a thinking tool in relation to various disciplines in schools instead of merely focusing on CS (Lamprou & Repenning, 2018).

Yadav et al. (2017) argue that there is a need to prepare teachers to integrate the cross-disciplinary nature of CT into K-12 education. Specifically, pre-service teachers need the support provided in terms of content knowledge and pedagogical practices to incorporate CT meaningfully in the classroom. While current literature places more emphasis on in-service teachers' CT professional development (Yadav et al., 2017), the focus of this study is on pre-service teacher education to prepare future-ready teachers, especially in terms of equipping them with the requisite knowledge and practices for the integration of CT into their lesson design. Pre-service teachers who are engaged through "learning by doing" will be able to enhance their confidence in using and teaching CT as a toolkit to facilitate problem-solving.

## Framework of Kolb's experiential learning in professional development of teachers

According to Kolb (1984), learning is "the process whereby knowledge is created through the transformation of experience." (p. 38) It is widely acknowledged that Kolb's experiential learning theory (1984) is an efficient pedagogical learning model

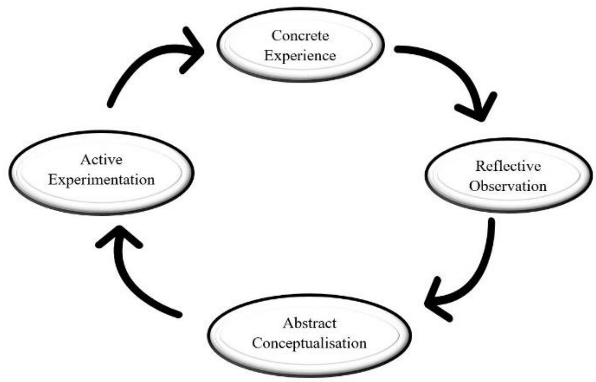



**Fig. 1** Design of the study

(Abdulwahed & Nagy, 2009). Therefore, the framework of the present study is underpinned by Kolb's experiential learning theory.

There are four interrelated phases within a cyclic process in Kolb's experiential learning cycle, namely (1) Concrete Experience (CE), (2) Reflective Observation (RO), (3) Abstract Conceptualization (AC), and (4) Active Experimentation (AE) (see Figure 1). The experiential learning cycle starts with a concrete experience, and then moves through reflective observation, followed by abstract conceptualisation, and finally the phase of active experimentation. Learning which occurs in the final phase then acts as a new concrete experience, triggering reflective observation and subsequent learning phases continuously in a repetitive cycle.

Kolb categorises the four learning phases in the experiential learning cycle into two dimensions (1) CE and AC are categorised under the knowledge prehension dimension, whereas (2) RO and AE are categorised under the dimension of experience transformation (see Figure 2). The vertical axis in Figure 2 represents the prehension dimension. Kolb

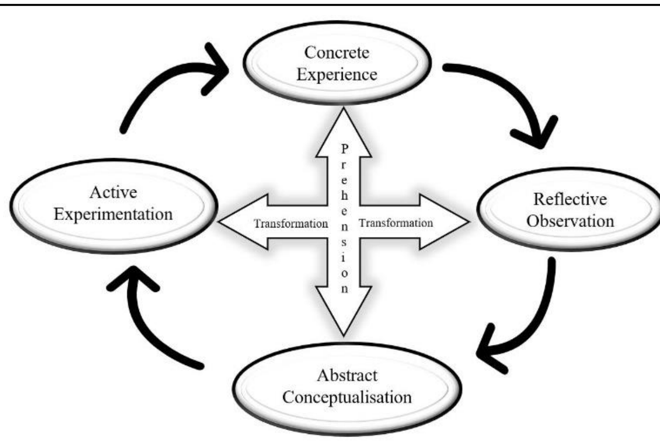



**Fig. 2** Kolb's experiential learning cycle: prehension versus transformation dimensions

suggests that learning requires individuals to first experience the prehension process, during which they detect, depict, or grasp knowledge through CE or AC, or a mixture of both. This is followed by the transformation process to complete the learning process, represented by the horizontal axis in Figure 2. The transformation process refers to the individual's experience that enables the grasped knowledge to be transformed into a mental model.

Furthermore, Kolb is of the view that the four learning phases are equally important in contributing to the learning process. However, this contradicts Piaget's (1978) opinion that AC and RO are superior processes. In a thoughtful look at the current traditional teaching methods in higher education, especially in Malaysia, the learning phases follow the Piaget's model, with emphases on the AC and RO phases. This conventional teaching method focuses on the theories taught in conventional classroom settings and reflection on these theories through written examinations (Abdulwahed & Nagy, 2009). In contrast, Kolb's experiential learning cycle implies the need for balancing each phase of learning throughout the learning process. The combination of these learning phases promotes a higher order of learning.

## Computational thinking development through experiential learning

In this study, the hybridisation of the plugged and unplugged CT approaches corresponds to the prehension and transformation dimensions of Kolb's experiential learning respectively (see Figure 3). The mapping principles are based on: (1) the constructionist approach in learning CT, and (2) Kolb's experiential learning, in particular, knowledge prehension dimension and the dimension of an experience transformation.

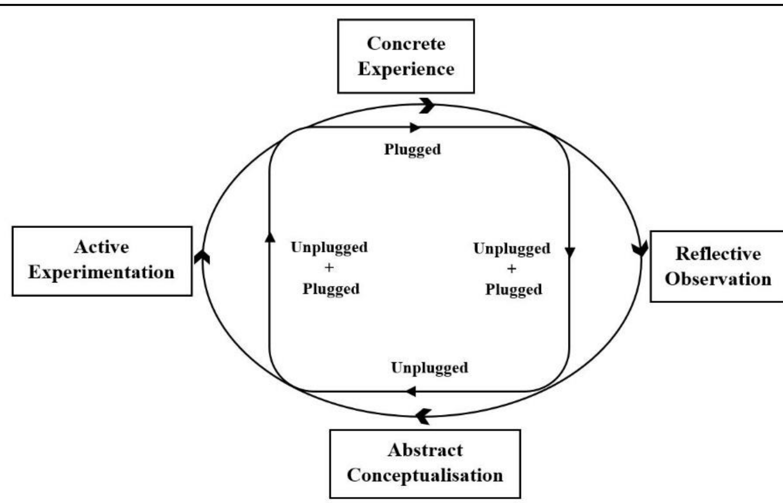



**Fig. 3** The hybridisation of plugged and unplugged approach underpinned by Kolb experiential learning cycle

The constructionist approach emphasises “learning-by-doing” (Ackermann, 2001). Students construct knowledge, and then reflect on their thinking (Papert, 1980), subsequently transforming the knowledge into practices and ‘products’. Therefore, each unit comprises a hands-on task to enhance students’ understanding of the content knowledge. The constructionist approach also encourages them to explore their interests through technologies (Bers, 2008). Additionally, they should investigate domain-specific content learning and practise meta-cognitive, problem-solving, and reasoning skills (Clements & Gullo, 1984).

“Knowledge results from the combination of grasping and transforming experience” (Kolb, 1984, p. 41). In the plugged CT approach, the pre-service teachers experienced an abstract concept (CE) while learning CT concepts in the context of programming; subsequently they reflected on the experience (RO) and practised the CT concepts (AE) by designing a Scratch project (Scratch is a block-based programming tool).

The unplugged CT approach emphasises the individual’s cognitive process (Shute et al., 2017). The pre-service teachers constructed the CT facets and practised these facets (AE), then they generalised how the facets worked by integrating them into the teaching context (AC). After learning the unplugged CT approach, the pre-service teachers then reflected on their experience (RO).

The aim of the hybridisation of plugged and unplugged CT approaches is to enable teachers to grasp CT skills and transform what they have learnt into their teaching practices (pedagogical content knowledge). This may impact their future students’ CT learning indirectly as the teacher plays a crucial role in deciding the focal points of the learning (Voon et al., 2020). When teachers complete multiple cycle iterations, their learning experience will increase in complexity. The accumulated and enriched learning experience helps foster a reflective learner’s growth (Voon et al., 2019).

## Context and methods of study

### Computational thinking development through experiential learning

This paper presents the design of the CT module as well as innovative pedagogical practices that hybridise unplugged and plugged approaches of CT, underpinned by Kolb’s experiential learning cycle. The participants who were pre-service teachers in this study were engaged in four phases of the learning cycle throughout the CT module.

The CT module focused on the participants’ content knowledge and pedagogical content knowledge (or content-specific pedagogical strategies). According to Shulman (1986), “pedagogical content knowledge includes the most regularly taught topics in one’s subject area, the most useful forms of representation of ideas and formulating the subject that make it comprehensible to others” (p. 9).

We propose that CT training be provided for pre-service teachers through an experiential learning process that leads to the application of CT in their context (activation of prehension and transformation dimensions, according to Kolb). Table 1 proposes the mapping of the different elements of the CT module for the pedagogical framework of Kolb's experiential learning cycle. In the CT module, the participants need to first grasp the CT knowledge before they are engaged in the phase of transformation. During the prehension dimension, the content knowledge 'to be grasped' is divided into two parts: (1) the (unplugged) CT approach, including CT facets and CT competencies and (2) the CT concepts in the context of programming. In the transformation phase, the participants reflect on their content knowledge, before transforming it into pedagogical content knowledge by integrating CT with their disciplinary context such as mathematics or science.

**Table 1** Mapping of CT module to Kolb experiential learning cycle

| Elements of CT module | Mapping to Kolb's experiential learning cycle | Duration/week |
|---|---|---|
| Unit 1 (unplugged): CT facets and unplugged activities. | Concrete Experience, Abstract Conceptualisation | 3 |
| Learning reflection. | Reflective Observation | |
| Learning activity: Draft a lesson design. | Active Experimentation | |
| Unit 2 (unplugged): (1) The integration of CT in K-12 educational contexts; (2) content-related quiz. | Concrete Experience, Abstract Conceptualisation | 3 |
| Learning reflection. | Reflective Observation | |
| Learning activity (anonymous peer-review): (1) Each participant justifies the lesson design; and (2) exchanges the lesson design with peers (a group of three). | Abstract Conceptualisation, Active Experimentation | |
| Unit 3 (plugged): CT concepts and practices using Scratch | Concrete Experience, Abstract Conceptualisation | 3 |
| Learning reflection. | Reflective Observation | |
| Learning activity: The participants work in pairs to create a project using Scratch. | Active Experimentation | |
| Unit 4 (unplugged): CT competencies. | Concrete Experience, Abstract Conceptualisation | 3 |
| Learning reflection. | Reflective Observation | |
| Learning activity: The participants revise and finalise their lesson plan. | Active Experimentation, Reflective Observation | |

Four CT units were designed to facilitate the participants' CT learning according to the CT module. Each unit comprised 3-hour weekly sessions, with a total of 36 hours for the entire module. The CT module would be conducted virtually as all institutions were locked down due to the Covid-19 pandemic. With regard to the learning outcomes of the CT module, the participants were required to design a lesson to demonstrate and reflect their understanding of how CT could be integrated into their teaching context and pedagogical strategies to develop middle school students' CT competencies. In addition, participants were required to reflect on their CT learning on Blogging sites, such as Wix, Google Site or WordPress.

The aim of Unit 1 was to provide the framework and details of the unplugged CT approach through the introduction of content knowledge, the CT facets (Shute et al., 2017). To nurture CT and facilitate deeper understanding, the participants were given an opportunity to observe and relate the learning of CT facets to solving their problem, as CT comprises the individual's way of thinking in daily activities and real-life problems (Shute et al., 2017). For instance, the algorithm can be used to create a recipe in cooking. To foster the participants' CT competencies, they were required to apply CT facets by drafting a lesson plan as the exit ticket for Unit 1. Unit 2 focused on the integration of CT in K-12 educational setting by providing some concrete examples of pedagogical activities for different disciplines. In order to enhance the participants' understanding, a formative content-related quiz was given at the end of the Unit 2. Figure 4 presents sample questions given during the quiz. Unit 3 employed Scratch to provide a basic understanding of CT concepts and practices in the context of programming (Brennan & Resnick, 2012). Unit 4 focused on the sharing of CT competencies as well as its importance (Korkmaz et al., 2017). At the end of Unit 4, the participants should able to transform content knowledge to pedagogical content knowledge, i.e., the pedagogical practices which were inspired by CT facets.

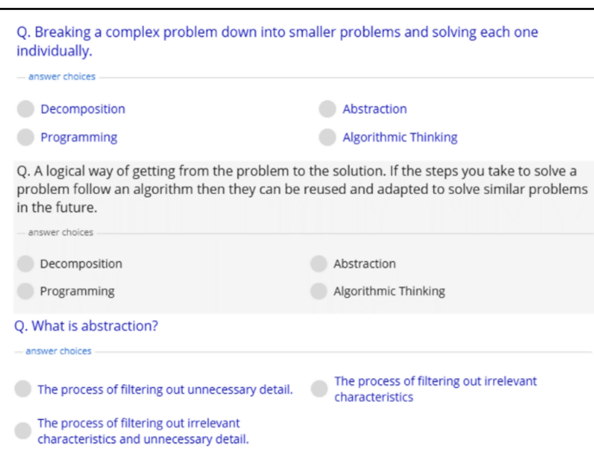



**Fig. 4** Sample questions from the content-related quiz to assess participants' CT understanding

## Research design

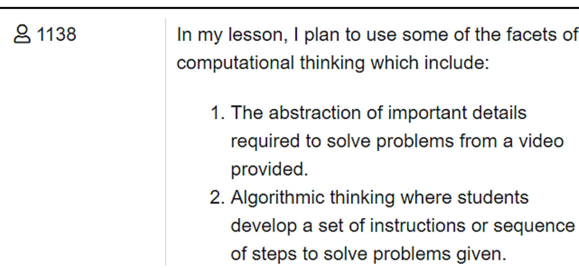
A case study was conducted to gain an in-depth understanding of the effects of pre-service teachers' experiential learning through CT application in their lesson designs. Case study research involves the study of a case (or multiple cases) within a real-life, contemporary context (Yin, 2014). This 'case' may be a concrete or less concrete entity. The concrete level for instance could be an individual, a small group, or an organisation, whereas at a less concrete level, it could be a community, a relationship, or a specific project (Yin, 2014). The purpose of a case study is to better understand a specific issue or concern (Stake, 1995) of a small group of participants. In this study, the focus of investigation were the effects of the CT module on pre-service teachers' CT development through experiential learning.

## Background of participants

A total of 38 secondary school pre-service teachers, 32 females and 6 males who majored in mathematics and biology, participated in this study. They were third year undergraduates (fifth semester, aged 22 and 23 years). All of them reported that they had no prior knowledge about CT before enrolling for the CT module in this study.

## Data sources

This study employed triangulation of multiple data sources and multiple investigators to support the findings (Merriam, 2009). The sources included interviews, documentation, and online learning artefacts including (1) participants' online artefacts (see Figure 5); (2) participants' reflective essays. One-to-one semi-structured interviews were conducted with three participants to obtain an in-depth understanding of their learning process. Each interview lasted around 45 minutes. The participants were asked to describe their CT learning experience and how the CT module had benefited them in designing their lesson. The guided questions were given to facilitate their learning reflection (see Figure 6).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In my lesson, I plan to use some of the facets of computational thinking which include:

1. The abstraction of important details required to solve problems from a video provided.
2. Algorithmic thinking where students develop a set of instructions or sequence of steps to solve problems given.

**Fig. 5** Sample of a participant's artefact to explain the CT application

- Explain how your lesson helps to develop CT skills among students.
- Do you think CT is important to be integrated into your lesson plan? Why do you think so?
- Explain how CT benefits students in the learning of your subject.

**Fig. 6** Sample questions for the reflective essay to guide learning reflection

## Data analysis

Multiple data sources were triangulated for analytical purposes in this study. A key feature of the CT module was the opportunity for participants to design CT-integrated lessons and reflect on their lesson designs. To examine the learning process of the participants' and their CT knowledge construction, we analysed lesson plan and reflective essays that were assigned to them. When analysing the lesson plan, we identified the participants' justifications as mentioned in their lesson designs to determine how they related CT to their teaching subjects; subsequently we categorised their justifications based on the CT facets adapted from Shute et al. (2017). Next, we analysed their reflective essays to identify the CT competencies that they aimed to develop among their students. We looked for the indicated keywords of CT competencies in their reflective essays based on the framework adapted from Korkmaz et al. (2017).

Investigator triangulation in this study involved two researchers who analysed the data. They carried out the coding process and the agreement between them (inter-coder reliability) was evaluated using Cohen's kappa. In particular, inter-coder reliability was assessed in terms of (1) identifying the CT facets and justification of CT facets in lesson design, and (2) identifying keywords in the reflective essays based on the CT framework. To ensure inter-coder reliability, one researcher coded all 38 essays, whereas another researcher coded half (19). The two researchers then discussed the conflict issues to reach a consensus on the appropriate code when there were discrepancies in the coding results.

# Results and discussion

## Analysis of the lesson design and reflective essays

We analysed the participants' lesson designs that were integrated with the CT facets as well as their justifications. The CT facets were adapted and coded based on the definition proposed by Shute et al. (2017). The participants' excerpts were categorised based on the CT facets, viz. abstraction, algorithm, decomposition, generalisation and iteration. The excerpt was coded in more than one category, depending on the CT facet integrated. The result of inter-coder reliability for the CT facets was .90, which suggested an almost perfect agreement (Cohen, 1960). Table 2 presents the justification in each category of the CT facet: abstraction (52.6%), algorithm (52.6%), decomposition (28.9%), generalisation (28.9%) and iteration (13.2%) The justifications indicated that the participants' improvement and understanding gained through the CT module; their ability in designing lessons that incorporated CT was reflected in their lesson design. The lesson design of 35 (92.1%) of the 38 students reflected their justifications of the CT facets (see Table 3). Only three students' justifications were not related to CT facets.

We further categorised the justifications in the lesson designs into two categories, viz. the lesson design with one CT facet, and one with more than one CT facet. The results are presented in Table 3. The Cohen's Kappa values for the category with one CT facet and that with more than one CT facet were .88 and .78 respectively, thus suggesting an almost perfect agreement and substantial agreement, respectively (Cohen, 1960). This indicated that the participants were aware that they could integrate more than one CT facet in a lesson to solve a single problem.

**Table 2** Participants' justification of CT integration in their lesson designs

| CT integration | Number (% out of 38) | Excerpts from the justification of lesson design |
|---|---|---|
| Abstraction | 20 (52.6) | "… I emphasise the basic structure of the vessels and organs involved in the circulatory system through a video so that students can visualise and get familiarised with the patterns. By identifying the pattern or the structure of circulatory system in humans, perhaps, the students can predict and recognise the common components shared by other organisms such as amphibians and reptiles." (1134) |
| Algorithm | 20 (52.6) | "… The users need to figure out the steps to answer questions such as reading all the sentences and highlighting the important key points before trying (to use it) to solve the problem." (1131) |
| Decomposition | 11 (28.9) | "… to decompose the big problem. To understand the circulatory system as a whole, it must be broken into smaller manageable problems such as understanding the function of blood, the vessels, and the heart." (1134) |
| Generalisation | 11 (28.9) | "… generalisations use the understanding of specific concepts to solve one problem given (wilting plant) to another plant-related problem, with the core (concept) of the problem to be tackled being similar." (1124) |
| Iteration | 5 (13.2) | "… to find the sum of the interior and exterior angles, students need to repeat design processes to refine the solution until the ideal result is achieved." (1111) |

**Table 3** Further analysis of participants' justifications of CT integrations

| Application of CT facets | Number (% out of 38) | Excerpts from the essays |
| --- | --- | --- |
| Only one CT facet was mentioned | 17 (44.7) | Abstraction - … the abstraction can occur when students need to choose the correct answer by identifying the important keyword in the suggested answer before choosing the correct one. (1123) |
| More than one CT facet were mentioned | 18 (47.4) | Abstraction - … The students need to analyse the video that they watch in order for them to identify the important details of photosynthesis and to answer the question … |
| | | Generalisation - … The students will able to relate the importance of photosynthesis in daily life through the videos that they watch. The specific information about photosynthesis process enables students to relate it to their daily life … (1128) |

The Kappa values of .89 for inter-coder reliability for the keywords of CT competencies in the reflective essays indicated an almost perfect agreement (Cohen, 1960). Table 4 presents the distribution of the five CT competencies associated with an exemplary excerpt for each dimension. The CT competencies were categorised based on the framework

**Table 4** Keywords of CT competencies as advocated in the reflective essays

| Keywords in the reflective essays | Number (% out of 38) | Excerpts from reflective essays |
| --- | --- | --- |
| Problem-solving | 23 (60.5) | "… CT benefits students by giving them the opportunity to 'see' their thinking and manipulate their thinking, thus allowing them to navigate the problem at hand" (1118) |
| Critical thinking | 14 (36.8) | "… Mathematics is often assumed to be an irrelevant subject. By using CT in learning this subject, students can see the relevance of the learning of Mathematics, that it is actually beneficial for their daily life. Now, students can think critically to solve the problems around them …" (1003) |
| Creativity | 13 (34.2) | "… CT encourages students' creativity because students can create their own methods to remember formulas based on the examples given …" (1009) |
| Algorithmic thinking | 11 (29.0) | "… students can develop their own algorithm, their own ways to answer the questions on that topic." (1115) |
| Cooperativity | 1 (2.6) | "CT helps to develop skills that all levels of learners need, including collaborating with others to achieve a shared goal or solution." (1122) |

proposed by Korkmaz et al. (2017). As shown in Table 4, the participants had included CT competencies in problem-solving (60.5%), critical thinking (36.8%), creativity (34.2%), algorithmic thinking (29%) and cooperativity (2.6%). The CT knowledge and the practical experience in designing a CT-integrated lesson were the two main categories of improvement after attending the CT module. The findings suggested that the learning activity, learning reflections, and the 'hands-on' task given to integrating CT in the lesson design were the key factors in improving the participants' experiential learning.

## Analysis of the effects of the CT module on knowledge comprehension and experience transformation

The CT module facilitated knowledge comprehension and experience transformation phases through (i) constructing and applying CT knowledge to the design of a CT-integrated lesson and (ii) transforming the CT knowledge by justifying and reflecting on the CT learning processes.

### *Analysis of the effects of the CT module on knowledge comprehension dimension*

The comprehension of knowledge occurs in the CE and AC phases (Kolb, 1984). In this study, the participants were actively engaged in contextually rich online learning environments. The CE and AC of Kolb cycle occurred when the participants attended every CT unit to acquire knowledge via plugged and unplugged CT.

In Unit 1, the participants were introduced to the unplugged CT facets. Then, they carried out a hands-on task to apply knowledge by designing a CT-integrated lesson for their teaching subject (CE). Contextual-specific AC occurred when the participants applied CT facets in designing their lessons. At the end of Unit 1, they were asked if the problem-solving nature of CT stimulated their interest to learn CT. An overwhelming majority (85%) of the participants said it did (see Figure 7).

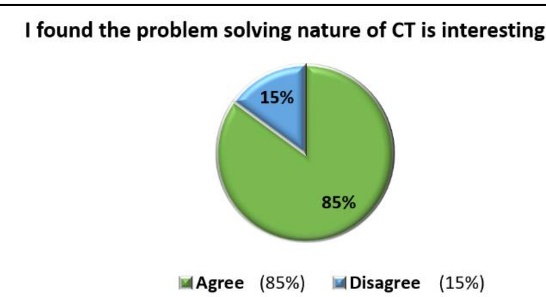


**Fig. 7** Students' self-perceived CT learning experience

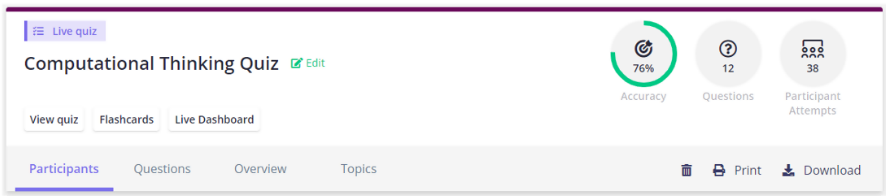


**Fig. 8** Average scores of the content-related quiz indicating participants' understanding of the unplugged approach

In Unit 2, the participants learnt about the integration of CT in the K-12 educational contexts. Putting the quizzes in the learning context after Unit 2 encouraged the participants to be more active in trying to understand the teaching content, thus enhancing the AC phase. The aim of the quiz was to test the understanding of CT knowledge via unplugged CT which emphasises human cognitive processes (Shute et al., 2017) such as creativity and innovation in problem-solving. The participants could apply their knowledge in unplugged CT to complete their project using Scratch (plugged CT approach). An average score of 76% from the content-related quiz reflected their understanding of the CT unplugged approach (see Figure 8).

To proceed with Unit 3, the participants should have introduced the CT concepts in the context of programming. They then engaged in pair-work activity to apply CT concepts by using Scratch. CE and AC occurred when the participants acquired the requisite skills to design a project using Scratch. They then explored CT competencies in Unit 4 where they were required to revise and finalise their lesson plan after taking into consideration their peers' comments, which enhanced CE and AC phases.

The arrangement of CT units facilitated the participants in the activation of the prehension dimension (as illustrated in Kolb's cycle) because they were able to grasp the knowledge needed to complete the tasks given.

### *Analysis of the effects of the CT module on experience transformation dimension*

The learning activities given in every unit appeared to have enhanced the transformation dimensions (RO and AE), in which the participants transformed new knowledge through active experimentation (AE). The 'experiments' refer to the learning activities after attending every CT unit. In Unit 1, the participants were required to design a CT-integrated lesson based on the teaching context. Then, they were required to justify why each CT facet had been integrated to indicate their understanding. They continued improving their lesson design before submitting it after attending the last CT unit.

According to Kolb (1984), activating the dimension of prehension promotes experience transformation into mental models. Based on the feedback, the participants were able to justify their lesson design and reflect on their learning after attending all the CT units. For the reflective activities, they were given guided questions as an anchor. The purpose of learning reflection was to help the participants construct a meaningful theoretical model of the knowledge based on their learning experience. They posted their learning reflections on online blogging platforms such as WordPress, Wix, and others.

After attending Unit 4, they entered the AE phase during which they were required to finalise their lesson design based on their learning reflection. A survey was then conducted to gather their opinions about the integration of CT into the teaching and learning process. The statement in the questionnaire was: "Computational thinking can be integrated into the classroom by allowing students to solve problems." The possible answers were on a scale ranging from 1 (strongly agree) to 4 (strongly disagree). The feedback showed that 68.8% of the participants strongly agreed, and 28.1% of students agreed with the statement (see Figure 9).

Kolb's experiential learning cycle provides educators with a pedagogical framework for designing their lessons and contextualising learning activities to enhance learning outcomes. It can be a large-scale design, such as a curriculum, or a smaller scale design, such as planning learning objectives. The participants completed the transformation of knowledge through RO and AE, on the provision that they had grasped this knowledge first via the CE or AC phase. This also enhanced learning outcomes as the participants progressed from one learning phase to another, as illustrated in Kolb's cycle. There should be a reasonable balance among the four phases to achieve optimal learning outcomes (Kolb, 1984). The participants' perception of the learning experience in the learning phases of Kolb's cycle throughout the CT module is discussed in the next section.

## Analysis of the participants' perception of the learning experience throughout the CT module

During the interview, the participants were asked to share their learning experience in designing CT-integrated lessons. For the Scratch project, one of them explained how she integrated CT facets in the lesson design: "I used algorithm and decomposition in my lesson.

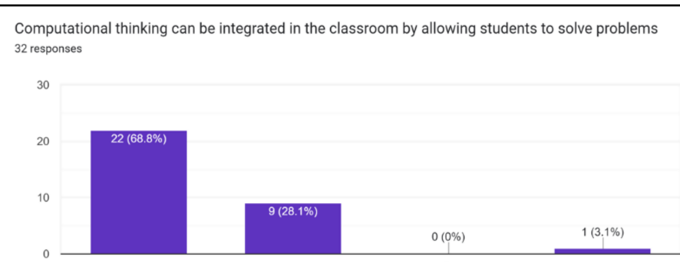


**Fig. 9** Participants' perspective on the integration of CT into teaching and learning

First, I will teach the students step by step how to answer the question ... By doing this, they can break the question down into smaller parts to understand it better" (Nazy, post-interview). Another participant shared her experience in completing the learning activity:

> "When I was designing the lesson, I justified the facets I had used. I was very clear about why I needed this thing (facet). I needed to have a solid reason for choosing the facets to use" (Cyse, post-interview).

The participant shared her experience in connecting Scratch with CT, "During the process, I could see that what I had learnt about CT facets was really applicable to what I was doing … like when I was arranging the code (using Scratch), so both of them were related." She applied the iteration facet when she needed to solve the problem by repeating the process in order to reach a correct sequence when arranging the codes.

The transformation (or construction) of knowledge was done through reflective observation (RO) and active experimentation (AE). The same participant mentioned that the reflective practices were beneficial in enhancing her understanding of the topic: "Reflection enables me to have a better understanding about the topic … when I reflect, I can see things more clearly" (Cyse, post interview).

On the whole, the results showed that the participants experienced more in-depth learning about CT by reflecting on the given guiding questions. According to one of the participants: "After reading the guiding questions, I gave them a lot of thought. Reflecting on the questions really helped me also to better understand the topic" (Cyse, post interview). Another was asked to reflect on how she applied CT in solving her problem (such as in designing a lesson). She explained: "Before I designed my lesson, I needed to understand the important aspects of the topic (abstraction). Then I planned my lesson, step by step … first step, second step …. (algorithm)" (Nazy, post-interview). Another participant was aware of the application of CT in daily life:

> "I have unintentionally used it. These CT facets and CT competencies are related to life. As a learner and a teacher, I see it more when I am planning. For example, during my study week, I planned and decomposed a topic to have a detailed understanding ..." (Fiqri, post-interview).

The participants' perceptions indicated that they had successfully demonstrated the experience transformation as mental models through learning how to reflect, and they continued to improve their prehension dimension (Kolb, 1984). This demonstrated that enhanced activation of the prehension dimension in Kolb's learning cycle motivated the participants towards further inquiry and experimentation, thus fostering a better experience for higher-order CT learning.

## Implications of the CT module on pre-service teachers' CT experiential learning

This study investigated the effects of adopting Kolb's experiential learning cycle in nurturing pre-service teachers' CT development throughout the CT module. The activation of all four phases of the learning cycle promoted optimal learning (Kolb, 1984). The implications of the learning activities in the four units are discussed below.

The prehension dimension emphasised the transfer of knowledge into a mental model when experiencing a lecture session. The lecture sessions of the CT module started with the theoretical knowledge of the unplugged CT approach (Units 1 and 2), followed by learning plugged CT (CT concepts) in the context of programming (Units 3 and 4).

The completion of the prehension dimension activated higher order learning when there was reflection on the knowledge acquired in the transformation phases. In the transformation phase of Unit 1, the participants transferred CT knowledge into a mental model and expressed their views about the CT approach in their context by designing a CT-integrated lesson plan and applying the CT facets in their teaching context (AE). Additionally, self-reflection in every unit helped the participants to make sense of their thoughts, providing a multi-perspective in understanding how they perceived their learning throughout the CT module. Therefore, the CT module has to be designed in a way to motivate participants to construct higher levels of learning, especially in teaching students without a computing background.

The peer feedback learning task promoted AC and AE. In Unit 2, the participants worked in groups of three to share their lesson design with their team members. They were able to improve their lesson design by providing constructive feedback to each other, thus enhancing AC (generalising how the CT facets work by integrating topics and learning activities) and AE (applying CT facets in developing CT competencies) as illustrated in Kolb's experiential learning cycle. One of the examples from peer feedback:

> Participant A: The lesson helps develop CT skills among students as the lesson itself is integrated with CT facets. For example, the algorithm facet is integrated into the learning activity, thus students need to explain the cell cycle process.
>
> Participant B: Yes, I agree that students can develop algorithmic skills in this lesson. In my opinion, you can diversify the questions or create open-ended problem-solving questions like "what if this kind of situation happens …" to develop students' creativity and critical thinking.

The fundamental difference between Unit 3 and the other CT units is that the plugged CT approach in the former used Scratch to teach CT concepts. The participants were immersed mainly in the prehension dimension (CE and AC) as the CT concepts in programming were delivered and demonstrated by using the Scratch platform. Transformation occurred when pair-work was conducted in the designing of a project using Scratch, which led to experiential learning during the hands-on session. This learning activity offered an opportunity to stimulate the participants interest in conducting ‘further investigation and experimentation’ (AE), i.e., they were accorded a higher-order learning experience through pair-work in designing a project using Scratch.

In Unit 4, the participants experienced the introduction of CT competencies (CE and AC). They were required to revise and finalise their lesson design (AE), and conduct online reading to have a deeper understanding of CT. The task also offered the participants a chance to refine their ideas and further reflect on the CT units, thus enhancing RO (reflecting on the experience) according to Kolb’s cycle.

Reflection can be viewed as an individual’s mode of thought in relation to a learning experience (Dewey, 1933). According to Dewey, reflection is defined by one’s ability “to look back over what has been done to extract the net meanings, which are the capital stock for intelligent dealing with future experiences” (Dewey, 1938, p.110). In this study, the participants were given the task of designing a lesson that required justification and reflection throughout their experiential learning of CT. Literature suggests that pre-service teachers’ higher levels of reflection can be achieved when support structures are provided (Dawson, 2006; Rodman, 2010). The results of this study are consistent with the literature. The quality of written reflections can be enhanced by a predetermined framework (Tripp & Rich, 2012). In this study, the CT frameworks in terms of CT facets and CT competencies were explained throughout the CT module, and there were guiding questions to help enhance the quality of the participants’ learning reflection.

In summary, experiential learning through the CT module indicated that computing concepts could be introduced to pre-service teachers with an appropriate sequence of content arrangement (from unplugged to plugged approach), depending on the computing background knowledge of pre-service teachers. The structural arrangement of the CT module is aimed at enhancing the understanding of content knowledge and transforming it into pedagogical knowledge, underpinned by Kolb’s experiential learning cycle.

## Conclusion, contributions of the study, and future work

From pre-service to in-service teachers, there is a lack of understanding of CT, typically viewed simply as mathematics or rudimentary uses of the computer (Sands et al., 2018; Yadav et al., 2018). Most studies apply either plugged or unplugged approaches in teacher education. However, a key component of building teacher capacity is to show the relevance of CT in their classroom using unplugged approaches combined with plugged approaches (Caeli & Yadav, 2020). Therefore, in this study, we propose a CT module that is a hybridisation of the ‘unplugged’ and “plugged” CT approaches.

The CT module facilitates pre-service teachers’ experiential learning of CT and integrates CT into teaching selected subjects in K-12 education. Hands-on tasks and learning reflection provide learning support for pre-service teachers with no computing background knowledge. In this study, evidence obtained from the lesson design and learning reflection tasks indicated that there was considerable improvement in the teachers' conceptual understanding of CT. The results demonstrated that the learning outcomes of the CT module were corroborated with a well-known pedagogical framework, viz. Kolb's experiential learning cycle. First, the module was found to induce continuous improvements in the teachers' knowledge of the CT approach. The justifications found in the lesson designs demonstrated their ability to integrate CT into the teaching context. Second, the findings in relation to CT competencies to be developed among middle school students further evidenced the teachers' improvements throughout the module as articulated in their reflective essays. The results indicated the effectiveness of our proposed CT module in supporting pre-service teachers' capacities upon focusing on (1) developing unplugged CT approach through CT integration in lesson design, (2) developing plugged CT approach by designing a Scratch project, and (3) practising and reflecting based on their experiential learning of CT.

In this study, the empirically validated significant contribution is the effectiveness of the CT module attained by focusing on theory and practices of CT through the hybridisation of plugged and unplugged approaches underpinned by Kolb's experiential learning to support pre-service teachers without computing knowledge. The CT module is based on key features of effective teacher education by making connections between theory and practice (Darling-Hammond, 2017). Both the design of practical coursework and the integration of learning reflection in contexts are aimed to better prepare pre-service teachers' learning and teaching. "A universal goal of teacher preparation is to nurture profession-ready individuals who can implement best practices to meet the needs of all their students in real time" (Nagro, 2020, p. 1). Additionally, in order to achieve this goal, individual teachers need to balance the construction of theory with the ability to implement evidence-based instructional practices (Brownell et al., 2005). Therefore, it is critically important to intentionally and persistently engage pre-service teachers in practising and examining expected authentic classroom teaching that is transferrable to teaching contexts later (Burn & Mutton, 2015).

Along these lines of thought, the pre-service teachers in this study were actively engaged in the process of CT framework and practice by integrating CT in their context, and sharing and reflecting on their lesson design. The empirical evidence in this study indicated that the CT module could enhance the experiential learning process of pre-service teachers.

This study explored the effectiveness of the CT module on pre-service teachers' experiential learning of CT. The integrations of CT facets in the participants' lesson design may depend on the teaching contexts; thus, we suggest that this needs to be further explored. Additionally, the findings suggest that reflective practices need to be given much consideration even after pre-service teachers graduate from their teacher education programme. According to Darling-Hammond (2017), reflective practices, perhaps, are most crucial to novice teachers given that such support is offered by experienced mentor teachers. The CT module for this study could also be adapted and applied to in-service teachers without computing background in order to facilitate their pedagogical development. It is of paramount importance that future teacher education programmes and teacher professional development courses pay more attention to CT development of pre-service and in-service teachers.

**Abbreviations**

CT: Computational thinking; CS: Computer Science; CE: Concrete Experience; RO: Reflective Observation; AC: Abstract Conceptualization; AE: Active Experimentation.

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**Author's contributions**

Xin Pei Voon was the main author of the paper who wrote the majority part of the paper. Su Luan Wong and Lung Hsiang Wong revised and edited the manuscript. Mas Nida Md. Khambari and Sharifah Intan Sharina Syed-Abdullah finalised the manuscript. All authors offered crucial ideas in conceptualising the research.

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**Availability of data and materials**

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## Declarations

**Competing interests**

The authors declare that they have no competing interests.

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