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Exploring the role of peer review in computational thinking development among pre-service teachers

Xin Pei Voon [1]*, Su Luan Wong [2], Lung Hsiang Wong [3], Mas Nida Md. Khambari [2] and Sharifah Intan Sharina Syed-Abdullah [2]

*Correspondence:
xinpeivoon@gmail.com
Behavioural and Implementation Science Interventions (BISI) Yong Loo Lin School of Medicine, National University of Singapore, 21 Lower Kent Ridge Road, Singapore 119077.
Full list of author information is available at the end of the article.

Abstract

Computational thinking can be interpreted as a cognitive process that provides a new paradigm for higher-order thinking about successfully solving problems posed in a technology-mediated teaching and learning context. Peer review has been employed as an effective learning strategy to enhance cognitive practices such as critical thinking, reflection practices and collaborative experiences. A qualitative case study was conducted to explore the role of peer review as a learning strategy of computational thinking among pre-service teachers. The peer comments were coded by adopting a coding scheme of comments, and the interview transcripts were analysed to investigate the significance of the peer-review process and student perceptions of what is most beneficial. Each student was required to design a lesson by integrating the computational thinking facets into their lesson plan. Upon submitting the lesson plan, they were engaged in a blind review process. Individual student reviews the lesson designed by their peers and provides their comments. By adapting a peer-review cognitive process model, this article provides evidence that the peer-review process played a critical role in facilitating pre-service teachers' computational thinking, particularly problem-solving competencies. The findings indicate that peer review strategy can facilitate computational thinking by enhancing pre-service teachers' higher-order thinking through constructing and providing critical feedback to their peers. The students perceived the peer-review process was beneficial in improving their computational thinking-integrated lesson design. However, it was suggested that the students be informed about the purposes and learning benefits of the peer-review process to improve their learning experience.

Keywords: Computational thinking, Computational thinking competencies, Learning strategy, Peer review, Pre-service teacher

Introduction

Peer review can be interpreted as an evaluative problem-solving process that facilitates student learning outcomes (Cho & MacArthur, 2011). Problem-solving is a cognitive process through which knowledge, skills, and personal experiences are mobilised to identify problems, find solutions, and resolve conflicts effectively (Hoi et al., 2018). From a problem-solving perspective, scholars have highlighted that computational thinking (CT) is a cognitive process (Brennan & Resnick, 2012), and everyone should be given opportunities to acquire CT competencies (Korkmaz et al., 2017) to survive and thrive in the digitalised world. The cognitive aspects of CT involve the use of heuristics, a problem-solving approach that involves applying a strategy that may lead to a solution (Wing, 2006). In order to prepare future-ready students, it is crucial to develop the pre-service teachers' CT competencies so that they are able to integrate CT into their teaching contexts (Yadav et al., 2017). A case study was conducted to explore peer review as a learning strategy in facilitating pre-service teachers' learning of CT. The students were required to comment on their peers' CT-integrated lesson design. A cognitive model was adapted to analyse the peer review process in facilitating the learning of CT. The following research questions guided this study:

RQ1. Does the peer review process significantly affect the pre-service teachers' computational thinking development after attending the CT module?

RQ2. How do pre-service teachers perceive the peer review process in CT-integrated lesson design?

Literature review

Peer review as a problem-based learning (PBL) strategy

The rationale for conducting this study stems from the significance of peer review emphasised in the literature. A review of the literature on peer review as an instructional strategy reveals the following insights that facilitate teaching and learning process. First, peer review engage learners in providing guidance for them to: promote meaningful learning as it fosters students' critical thinking skills (Li & Steckelberg, 2004; Tsai et al., 2001), effectively improve critical reflective skills and social skill in their writing (Woodhouse & Wood, 2020), enhance self-regulation skills to provide constructive feedback on peer assignments (Ku & Lohr, 2003; Ozogul et al., 2008), and comprehend the problem-solving nature of professional practices, including instructional design practice (Woolf & Quinn, 2001). Second, peer review benefits instructors by reducing the time required to evaluate complex assignments (Bangert, 2001; Ozogul et al., 2008), potentially providing more time to provide more advanced consultative guidance.

Peer review in PBL serves as a pivotal strategy to enhance student engagement and learning outcomes. The peer review process allows students to identify and address misconceptions in their understanding (Pelaez, 2002). Discussing and resolving these issues with their peers leads to a more accurate and comprehensive grasp of the content. Students take more responsibility for their own and their group members' learning by actively solving problems and evaluating their peers' contributions. This process fosters deeper understanding and retention of the subject matter (Papinczak et al., 2007). Additionally, a study conducted by Petersen and Groenewald (2021) on anonymous peer reviews using the Sakai platform revealed that students felt empowered and improved their understanding through peer feedback.

Empirical studies reported that the implementation of peer review strategy among undergraduate students demonstrated greater improvement in problem-solving and reflection processes (Crouch & Moore, 2019). This is beneficial in preparation for their future career, for instance peer review skills are critical for engineering and information technology (IT) industries. The study indicated that there is significant correlation between students' peer review skills and their problem-solving skills among undergraduate students, particularly those enrolled in software engineering course (Spichkova, 2022). In the Information Technology (IT) industry, review and analysis of code and artefacts created by other colleagues is seen as a critical part of software development process (Fitzgerald et al., 2013; Spichkova, 2022). Further, peer review has been recognised as an effective learning strategy in the learning of CT, which is an essential 21st century competency (Cui et al., 2023). A study indicated that peer learning techniques (peer code review) improve on the undergraduate students' CT, learning engagement, and learning satisfaction in a blended learning environment (Lin et al., 2021).

CT and cognitive abilities: Plugged and unplugged approaches

In educational contexts, CT is holistically defined as a conceptual framework required to "solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that can be reapplied in different contexts" (Shute et al., 2017). This definition recognises CT as a cognitive ability rather than just being a practical skill in a specific learning context and therefore emphasising the broad applicability of CT. This is particularly important, as there are common misconceptions in the definitions of CT, and the terms between plugged and unplugged CT, computer science, programming, and coding. CT knowledge and skills can be taught in a variety of educational contexts using (a) plugged approaches, such as programming tools, robotics, and simulations, or (b) unplugged approaches, such as a paper-and-pencil programming strategy (PPS) (Shute et al., 2017). Students need to comprehend both techniques when solving problems using computational tools or developing computational ideas.

CT is considered as a broader cognitive concept that is connected with computer science but has been broadly applied in various other – non-computerised disciplines (Armoni, 2016). CT is more than just problem-solving based on concepts derived from the world of computer science (CS), it “promises the skills and competencies necessary for understanding, controlling, and automating information processes as well as for interpreting the world as information processes” (Denning & Tedre, 2019, p.4).

While it is assumed that basic CT competencies are essential for acquiring practical coding and programming skills, CT, generally reflects a broader cognitive skill that is crucial for computational literacy (Garcia-Penalvo, 2016). Further, Resnick (2017) broadened the definition of CT by using the term computational fluency to represent CT not only as a comprehension of computational concepts and problem-solving strategies, but also as a creative ability to express oneself through means of digital technologies. CT is viewed as a broad problem-solving framework that involves skills, processes, and methods to solve problems, while “programming” is a key practice to cultivate the cognitive skills involved in CT (Kanika et al., 2020).

CT can foster problem-solving abilities and allow students to tackle problems like a computer scientist (Grover & Pea, 2013). Under this circumstance, unplugged CT is considered as a broader cognitive concept that can be applied in various domains (Armoni, 2016) and it helps learners to understand informatics concepts effectively (Rodriguez et al., 2017). Various unplugged activities, such as board-games, pen-and-paper exercises were implemented to support plugged activities given that humans are central in computing (Caeli & Yadav, 2020). Further, plugged CT can be introduced to students through digital programming environments, such as Scratch and Open Roberta Lab (Brennan & Resnick, 2012) and it is effective in the development of CT skills (Yünkül et al., 2017). In terms of CT practicality, researchers believed that CT would influence the effectiveness of the application of information technology and performance in daily tasks (Faber et al., 2017; Lee et al., 2014).

Computational thinking and problem-solving skills

The CT concept introduced by Papert (1980) was to develop a cognitive ability in problem-solving through a programming language (Romero et al., 2017). In 2006, Wing expanded the concept of CT by describing CT as a way humans think about solving problems and stated that it was a fundamental skill and almost suitable for everyone (Wing, 2006). Hence, CT is a critical skill set to prepare future-ready learners in the 21st century, as the skills may improve one’s problem-solving competencies. CT has been interpreted as a cross-disciplinary mental skill set that should be integrated across multiple subjects, starting from primary grades upward (Yadav et al., 2017). Thus, it provides a crucial viewpoint on the connection between humans and computers and triggers global interest in research in CT (Shute et al., 2017).

CT is an important skillset for the next generation and has been embedded in K-12 curricula across the globe (Cutumisu et al., 2019; Shute et al., 2017). Plugged and unplugged CT have been introduced into curriculum across various school levels. Studies have integrated plugged CT into various school levels, including pre-school (Bers et al., 2014; Critten et al., 2022), elementary schools (Tran, 2019; Zhong et al., 2016), high schools (Atmatzidou & Demetriadis, 2016; Weintrop et al., 2016), universities (Günbatar & Bakırcı, 2019), as well as teacher professional development (Angeli et al., 2016; Marcelino et al., 2018). Likewise, unplugged CT is an accessible and age-appropriate approach for introducing CT to learners from various school levels, including the pre-school level (Piatti et al., 2022), elementary school level (Brackmann et al., 2017; Li et al., 2023; Zhan et al., 2022), high school level (Threekunprapa & Yasri, 2020), universities (Bell et al., 2012; Oliveira, 2022), and teacher professional development (Curzon et al., 2014; Jagušt et al., 2018).

CT is a focused approach to problem-solving that can be developed by incorporating the thought processes that employ the facets of evaluation, abstraction, decomposition, algorithmic design, and generalisations across disciplines (Selby & Woollard, 2013). According to Shute et al. (2017), the conceptual foundation of CT facets encourages individuals to address problems from a CT perspective and emphasises how this CT perspective can be used to scaffold students' learning. Six CT facets are widely accepted and serve as a guideline to facilitate CT learning, including abstraction, algorithm, decomposition, generalisation, iteration, and debugging (Shute et al., 2017). To summarise, CT facets are considered as the approaches of problem-solving from a CT perspective, which can be integrated into the lessons across various disciplines to develop CT competencies.

Computational thinking competencies

CT competencies can be interpreted as the thinking skillset that has been discussed in the literature (Korkmaz et al., 2017). When the skillset is considered together, it is known as CT competencies (Korkmaz et al., 2017). Within this framing, the definition for each thinking skill set is crucial to facilitate the students' understanding.

According to Korkmaz et al. (2017), the five CT competencies refer to creativity, problem-solving, critical thinking, algorithmic thinking, and cooperativity. Problem-solving emphasises the engagement of individuals in sustained investigative processes to produce solutions. Critical thinking refers to an individual's ability to analyse and make assessment-oriented conscious judgments that lead to appropriate decision-making or problem-solving. Creativity is the ability to develop genuine ideas that differ from ordinary ones by combining new ideas and using problem-solving and critical thinking skills. Algorithmic thinking refers to an individual's ability to think in a detailed way by planning the proceedings in sequence to generate solutions. Cooperativity means individuals help each other throughout the learning process by using different methods to achieve a common purpose.

Theoretical framework: The role of peer review in facilitating CT learning from cognitive and social learning approaches

This study aims to develop students' cognitive ability in problem-solving through CT learning. From the cognitive standpoint, revision is a process that actively draws on students' existing knowledge and also developing new knowledge (Flower et al., 1986). Peer review benefits students' CT learning by encouraging them to actively engage in the task-specific processes and criteria. According to Flower et al. (1986), three specific processes come into play when a student reviews a text (refer to Figure 1). First, there is problem detection, which allow students to identify the problems. Second, there is problem diagnosis, which is beneficial to improve writing when potential revision strategies are not obvious, i.e., do not involve relatively straightforward corrections. Third, revision strategies that occur after a problem has been detected and diagnosed. The task of providing peer feedback engages students in problem detection and diagnosis, which subsequently contemplate solutions and propose revisions. As a result, students who provide peer review

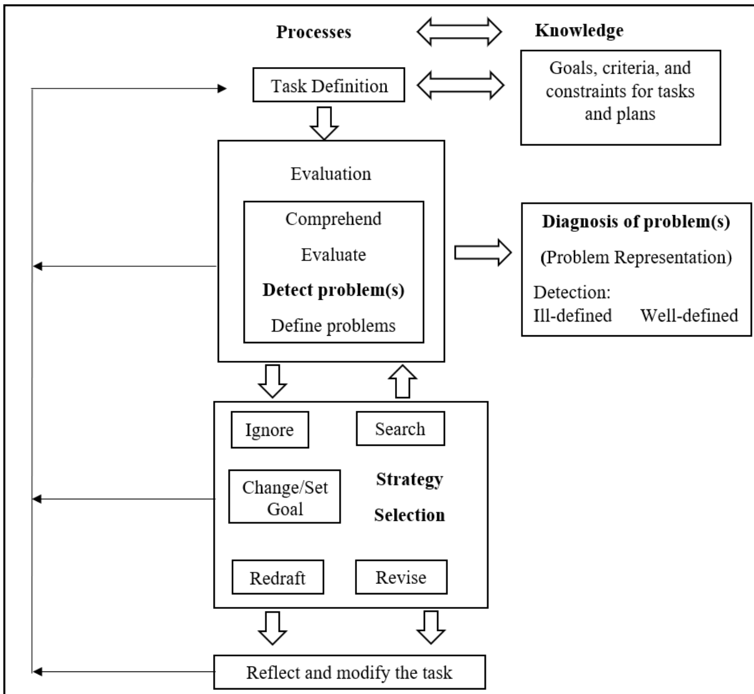

Fig. 1 Cognitive model in the peer review process, adapted from Flower et al. (1986)

gain experience in problem detection, may become more aware of (types of) problems, and may discover different revision strategies (Patchan & Schunn, 2015). These review and feedback processes include students taking various perspectives, comparing others' work to their own and the assimilation of new knowledge, all of which can be collectively referred to as reflective knowledge building (Tsui & Ng 2000; van Popta et al. 2017).

From a social learning perspective, learning is socially constructed through meaningful negotiation and interaction between learners, underpinned by Vygotsky's sociocultural theory (Rahimi, 2013; Vygotsky, 1978). In this study, peer learning is considered as knowledge acquisition and learning through providing and receiving feedback from learning peers. Students were given a rubric and guiding questions to facilitate the review process. Peer learning occurs in real educational settings where equal-status students are attempting to support each other and paying compliments on their knowledge to learn together (Topping, 2017). Peer learning has recently been used as a highly flexible and applicable strategy for improving a wide variety of processes or outcomes of task performance, including improving quality of students' domain-specific learning (Latifi et al., 2019; Noroozi & Mulder, 2017; Valero Haro et al., 2018) and CT learning (Hsiao et al., 2023; Lin et al., 2021). In this study, peer learning is employed as a learning strategy that is underpinned by cognitive and social learning theories.

Research design

This study used a mixed-methods case study design (Creswell & Clark, 2018) to explore peer review as a learning strategy for developing pre-service teachers' problem-solving competencies. The participants attended a twelve-week CT module consisting of two main components: (1) plugged CT and (2) unplugged CT. A web-based pre-and post-survey was conducted to measure 78 participants' CT competencies throughout the CT module. The survey took approximately 15 minutes to complete. The questionnaire was adapted from the Computational Thinking Scale (CTS) developed by Korkmaz and colleagues (2017). Five factors in CTS were used to measure the CT competencies among students, namely algorithmic thinking, problem-solving, critical thinking, cooperativity, and creativity. Although the survey instrument was found to be reliable by earlier studies, the researcher has assessed the reliability for the sample in this study. The reliability of each factor was calculated using SPSS, as presented in Table 5. The Cronbach's alpha values for each of the four dimensions (critical thinking, creativity, cooperativity and problem-solving) ranging from .69 to .88. The dimension of algorithmic thinking is excluded due to the low internal consistency in this study.

There are three units for the plugged CT component and three units for the unplugged CT component, validated by two experts in the field. Each unit lasted for three hours. The unplugged CT component is underpinned by a framework focusing on the definition and applications of CT facets (Shute et al., 2017). The students were encouraged to observe and relate the learning of CT facets in solving their problem, akin to individuals' way of thinking in daily activities and real-life challenges. For example, the facet of algorithms can be applied to create a cooking recipe. Thus, the unplugged CT component represented the integration of CT in the K-12 educational setting with concrete pedagogical activities into different disciplines. Next, CT competencies and the importance of developing CT competencies were explained to the students (Korkmaz et al., 2017).

Conversely, the plugged CT component employed Scratch to provide a basic understanding of the CT concepts and practices in the context of programming (Brennan & Resnick, 2012). The students were required to apply the CT practices by designing a quiz (small project) using Scratch. The unplugged and plugged CT components aim to transform the students' content knowledge into pedagogical content knowledge, i.e., the pedagogical practices inspired by CT concepts.

For the learning outcome of the CT module, each participant was required to integrate CT facets into their lesson plan (CT-integrated lesson). Subsequently, the participants were divided into groups of four to review each other's lesson plans using an online peer feedback system known as TEAMMATES. In implementing the anonymous peer review, each student was given a code as identification and submitted feedback through the TEAMMATES (see Figure 2). Students were given a rubric and guiding questions to facilitate the review process (see Figure 3). The researcher acts as the instructor of the CT module. The lessons were conducted online due to the closure of the campus because of the Covid-19 pandemic. The lesson recordings were uploaded onto Google Drive, where the students could view and download them. In data analysis, all participants were assigned a serial number as identification.

Subsequently, purposive sampling was conducted in which four students who were volunteered to share their perspectives in designing their lessons. One-to-one semi-structured interviews that lasted around 40 minutes with each student were conducted. Eight open-ended interview questions were prompted to explore their perspectives of the

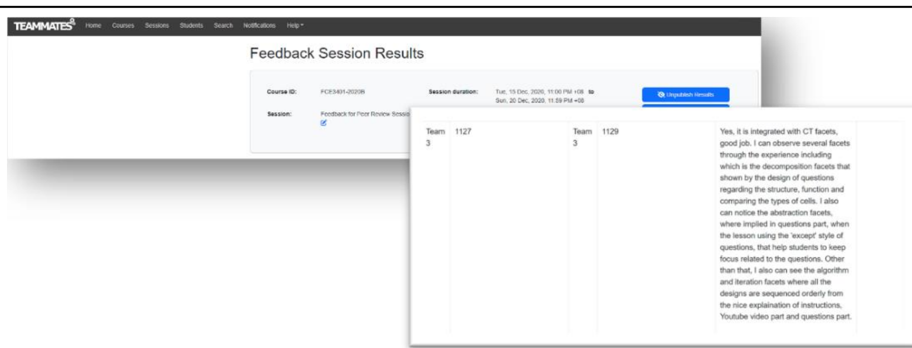

Fig. 2 Sample of students' feedback posted on TEAMMATES

Please review each of the lesson plan given. Support your arguments with evidences based on that particular lesson plan:

(1) The appropriateness of CT facets that have been integrated into the lesson plan. Why do you think so? (Justify your comment).

(2) How do you think the lesson activities can be improved to develop students' CT competencies?

(3) How do you think the lesson plan can be improved? (Please specify relevant part(s) of the lesson plan)

Fig. 3 Guiding questions given to facilitate the peer review process

peer review strategy in designing CT-integrated lessons, examine their learning experience throughout the peer review, and further explain the qualitative findings.

Participants

In order to control the possible factors that may affect the peer review strategy on students' CT development, the participants were selected based on the following criteria: (1) they were pursuing their Bachelor's Degree in Education; (2) they were enrolled in the Educational Technology course. There were 78 participants in their third-year undergraduate studies (fifth semester, ages ranged between 22 and 23 years old) at a public university in Malaysia. They all reported no prior knowledge of CT before attending the CT module. The students have signed the consent form to protect their confidentiality throughout the research.

Design and structure of the computational thinking modules

The CT module was designed based on innovative pedagogical practices that hybridise unplugged and plugged approaches of CT. The intention was to facilitate the students to construct knowledge on CT at an introductory level. The CT module focused on the students' content knowledge (CT knowledge) and pedagogical content knowledge (or content-specific pedagogical strategies).

There are three units for the plugged CT component and three units for the unplugged CT component (see Table 1 and Table 2), validated by two experts in the field. The unplugged CT component employs the framework of the unplugged CT approach, which focuses on the CT facets (Shute et al., 2017). To facilitate the students' deeper understanding of CT, they were encouraged to observe and relate the learning of CT facets in solving their problem, akin to individuals' way of thinking in daily activities and real-life challenges. For example, the algorithm can be applied to create a cooking recipe. Subsequently, unit 2 of the unplugged CT component focused on integrating CT in the K-12 educational setting by providing concrete pedagogical activities for different disciplines. Unit 3 focuses on sharing CT competencies and the importance of developing

Table 1 Learning content and learning outcomes of the unplugged CT component

Week	Unit	Learning content	Learning outcomes (Students will be able to)	Learning time (minutes)
1	1	• Definition of unplugged CT. • Definition of the six unplugged CT facets (adopted from Shute et al., 2017, refer to Appendix IV). • The importance of unplugged CT facets.	• Define unplugged CT.	180
2	2	• Examples of integrating the CT facets into the K-12 teaching context.	• Identify the CT facets that are being integrated into different disciplines. • Apply the CT facets that are being integrated into different disciplines.	180
3		• Examples of the integration of CT facets in K-12 contexts	• Justify the CT facets into their teaching context. • Evaluate the integration of e-learning tools using the rubric given.	180
4		• Benefits of the integration of e-learning tools into K-12 contexts • Benefits of the integration of CT facets into K-12 contexts	• Apply the e-learning tools based on the function of the tools and the design of the lesson. • Justify the integration of e-learning tools based on their teaching context. • Justify the integration of CT facets based on their teaching context.	180
5		• Class discussion on the lesson plan	• Justify the integration of CT facets by using appropriate e-learning tools in their teaching context. • Evaluate the integration of CT facets by using appropriate e-learning tools in their teaching context.	180
6	3	• The definition of five CT competencies (adapted from Korkmaz et al., 2017) • The importance of developing CT competencies among students.	• Explain the importance of CT competencies in the teaching and learning processes. • Design the lesson with the integration of CT and e-learning tools to develop students' CT competencies.	180

Table 2 Learning content and learning outcomes of the plugged CT component

Week	Unit	Learning content	Learning outcomes (Students will be able to)	Learning time (minutes)
1	1	• CT concepts in the context of programming	• Define the CT concepts in the context of programming.	180
2		• The application of CT concepts using Scratch	• Explain the application of CT concepts using Scratch. • Apply the CT concepts using Scratch. • Create a project using Scratch.	180
3	2	• The application of CT practices in the context of programming.	• Identify the CT practices to be used in Scratch.	180
4		• The application of CT practices using Scratch	• Apply the CT practices using Scratch. • Evaluate their CT practices throughout the class discussion.	180
5	3	• The application of CT perspectives using Scratch.	• Describe the importance of CT perspectives in the context of programming. • Differentiate the CT perspectives using Scratch.	180
6		• The application of CT concepts, practices and perspectives using Scratch.	• Justify the CT concepts, practices and perspectives using Scratch.	180

CT competencies among students (Korkmaz et al., 2017). The students were required to design a CT-integrated lesson as the deliverable of the unplugged CT component.

The plugged CT component employed Scratch to provide a basic understanding of the CT concepts and practices in the context of programming (Brennan & Resnick, 2012). For the learning outcome of the plugged CT component, the students were required to apply the CT concepts and CT practices by designing a quiz (small project) using Scratch. The plugged CT component aimed to transform the students' content knowledge into pedagogical content knowledge, i.e., the pedagogical practices inspired by CT concepts.

Throughout the CT module, the students were encouraged to think critically by justifying the integration of CT facets in their lesson design. They are encouraged to think creatively and develop their future secondary school students' CT competencies in designing their CT-integrated lessons. For the learning outcome of the CT module, the students will be able to design a CT-integrated lesson to reflect and demonstrate their understanding of CT.

Data analysis

Qualitative content analysis was carried out based on the coding scheme (refer to Table 3; Cho & MacArthur, 2011; Cho et al., 2006). Each comment generated by the participants

Table 3 Coding scheme of comments (Cho & MacArthur, 2011)

Category	Definition	Example
Strength		
Praise	Good remarks on what constituted the strength.	Your result section is great, and your graph and tables are accurately defined.
Weakness		
Problem detection	Statement about what is wrong or weak in the task.	I think you convey that the open-closed tubes are very similar in your introduction, which I believe is a mistake.
Problem diagnosis	Statement about the explanation of why the problem happened.	I know you were trying to be original by including the equations in the instruction, but this makes it confusing to the reader.
Solution suggestion	Statement about how to improve the problem.	If you just briefly reported your numbers, it would be even better. For example, state the numbers obtained for beat velocities while describing the section.
Off-task	Task-unrelated comments.	Good luck with your vacation!

through the reviewing process was coded and first assigned into three categories: strength, weakness or off-task. When a comment was allocated to the weakness category, it was coded as to whether it involved "problem detection" only, "problem diagnosis," or "solution suggestion." Under these three sub-categories, a comment was categorised as (1) problem detection if the comment identified a problem without diagnosing the problem; (2) problem diagnosis if the comment detected and diagnosed a problem without suggesting any possible solution; (3) the solution suggestion if the idea included a solution to improve the problem regardless of whether the idea had a statement of problem diagnosis.

The investigator triangulation involved two researchers in the data analysis, and the inter-coder reliability was evaluated using Cohen's kappa. In particular, the inter-coder reliability was assessed by categorising the students' comments on their peers' lesson design. For the evaluation of inter-coder reliability, one researcher coded all of the comments, whereas the second coder independently coded 50% of randomly selected comments. When there were discrepancies in the coding results, the two researchers discussed the conflict issues until a consensus was reached. Subsequently, a thematic analysis was conducted. Four interview transcripts were analysed and categorised under common themes to help explain students' perceptions, learning experiences, and mental processing throughout the peer review process.

Rubric validation

Cohen's Kappa is a widely accepted statistical measure for evaluating inter-rater agreement when two raters are involved (McHugh, 2012). In this study, two raters of the research team had prior familiarity with the task and programming application (Scratch) and helped develop and refine the rubrics. Both raters underwent rigorous training and calibration to ensure consistency. Discrepancies were discussed and resolved through consensus, further improving rating consistency.

Initial inter-rater reliability calculations resulted in a Cohen's Kappa of 0.61 (approximately 60% agreement). After meeting to discuss results, it was discovered that each coder had different interpretations to differentiate the scales for the facets of debugging and generalisation. After resolving the scale differentiation, the raters re-coded new lesson plans with the rubric. Inter-rater reliability calculations for this rubric resulted in a Cohen's Kappa of 0.87 (approximately 90% agreement).

Results and discussion

The activation of problem-solving processes throughout the peer review process

To answer research question 1, 'Does the peer review process significantly affect the pre-service teachers' computational thinking development after attending the CT module?', qualitative and quantitative data analysis were conducted. In qualitative data analysis, students' comments were coded and analysed. The inter-coder reliability for the coding was 0.83, which suggested a near-perfect agreement (Cohen, 1960). A total of 480 comments from 78 students were analysed and assigned into five categories.

Based on Table 4, the findings indicated that the students were actively engaged in the problem-solving processes, at which they needed to review their peers' work by identifying and diagnosing the problem(s) and proposing appropriate solutions. There were 76.88% of comments categorised under the strength (praise). Some comments that were categorised under praise also indicated the weakness of their peer's work. Therefore, the comments that were categorised as weakness made up 53.33%, including problem detection (20.42%), problem diagnosis (12.08%), and solution suggestion (20.83%), whereas there were 4.17% of comments were categorised as off-task, as presented in Table 4. The problem-solving abilities was activated through learning-by-reviewing, where the students were engaged to think critically and creatively to identify and solve a problem. Thus, the analysis of students' comments supported the pre-and post-survey results, demonstrating that the reviewing process helped develop students' CT competencies, particularly critical thinking and problem-solving competencies in commenting on their peers' CT-integrated lesson designs.

In quantitative data analysis, a paired-samples t-test was conducted to examine the changes in the participants' self-perceived CT competencies before and after the CT modules. Table 5 shows the means (M) and standard deviations (SD) of the self-rated scores for the four dimensions of CT and their respective t-values and effect sizes. There was a statistically significant increase in (i) critical thinking scores from pre-test (M=3.83,

Table 4 Students' comments on their peers' lesson designs using TEAMMATES

Code	Percentage (%)	Example of excerpts from the comments
Praise	76.88	It was integrated with CT facets, nicely done!...decomposition can be seen in part 2, where the questions are divided into different parts, emphasising the concepts of the photosynthesis process (presented in different scenes)...
Total	**76.88**	
Problem detection	20.42	...I encountered an error during the lesson... ...I noticed a missing instruction - after the 7th step, which is collecting the trophy after answering all questions correctly, there is a video before reaching the last layover, but it was not mentioned in the step-by-step instructions...
Problem diagnosis	12.08	...as a student who attends the class, I am struggling with the 360º image since it is unclear. Thus, it affects someone's ability to answer the questions correctly...
Solution suggestion	20.83	...perhaps you can add another video that provides further information on cells, followed by a few more questions...
Total	**53.33**	
Off-task	4.17	Best and fascinating!

Table 5 Comparison of mean scores of CT competencies across pre-and post-test for all participants

CTS	N	Pre-test		Post-test		*t*
		Mean	SD	Mean	SD	
Critical thinking	78	3.83	.55	4.02	.56	2.10***
Creativity	78	3.83	.35	4.13	(.44)	3.40***
Cooperativity	78	4.39	.46	4.57	(.46)	1.18
Problem-solving	78	3.28	.65	3.56	(.76)	2.16***

***p < .01

SD=.55) to post-test [M=4.02., SD=.56, t(78)=2.10, p<.01]; (ii) creativity scores from pre-test (M=3.83, SD=.35) to post-test [M=4.13, SD=.44, t(78)=3.40, p<.01]; and (iii) problem-solving scores from pre-test (M=3.28, SD=.65) to post-test [M=3.56, SD=.76, t(78)=2.16, p<.01]. Although there was a slight improvement in the mean scores for cooperativity from pre-test (M=4.39, SD=.46) to post-test [M=4.57, SD=.46, t(78)=1.18, p<.01], but the difference was not statistically significant. The eta squared values suggest large effect sizes (more than .14) for the dimensions of creativity (.24), whereas medium effect size (more than .06) for critical thinking (.11) and problem-solving (.11), the small effect size for cooperativity (.04) dimension.

Students' perceptions of peer review: A reflective comparison learning strategy

The analysis of peer comments reported that the peer review process facilitated the integration of CT into the lesson design and developed the students' CT competencies. The interview transcripts were analysed to answer research question 2, 'How do pre-service teachers perceive the peer review process in CT-integrated lesson design?'. This analysis further supports the results of pre-and post-surveys and students' comments. All students agreed that the peer review strategy was beneficial for their learning. They were asked how the process of producing and receiving feedback helped their learning. The students realised and reported that giving feedback was more beneficial, especially when they could have a 'conversation' with the feedback and thought deeply about the task given. Despite that, all students agreed on potential values to be engaged in both processes. This can be seen based on one of the student's comments:

> "It is easier for us to 'discuss' about it within ourselves, then we have different opinions, we are able to choose a better idea. It was excellent (Calsy, post-interview)."

Students reported that the peer review engaged them in higher-order thinking, for instance, critical thinking. The development of creativity and critical thinking guided them to make more objective judgements about their work; as the students pointed out, "Through commenting and getting commented by my peers, it provides me the new ideas to improve my learning (Fiq, post-interview)." "It requires me to think critically to correct my mistakes…we help each other succeed (Naz, post-interview)."

During the interview, this student highlighted 'comparing explicitly' the work of others with what she has completed. It shows that she has produced work in a similar domain as her peers; she has already set a 'self-internal standard' to assess her peers' work. Therefore, this comparison between the 'self-internal standard' and the peers' work resulted in a backward reflection on the student's work. "…it was really helpful because I did not realise the problem until my friends pointed it out (Calsy, post-interview)."

However, when the students were asked about collaborative learning throughout the peer review process, they mentioned that they faced time constraints as they needed to review the other three of their peers' work. All of them suggested having three students in a group; for instance, "I would like to suggest two or three people in one group so that I can have ample time to prepare the feedback (Fiq, post-interview)."

The considerable insight is that while commenting on others' lesson designs, the students responded to the reflective process by actively comparing others' work with theirs. Indeed, this is the defining feature of peer review; the students are engaged in the reflective comparison process to produce work in a similar domain as their peers. This type of reflective comparison would not happen if students were merely asked to explain their peers' ideas in the process of peer tutoring (Roscoe & Chi, 2008). Hence, this suggests that the benefits of peer review are not just derived from producing explanations (Cho & MacArthur, 2011) but from students producing critical feedback grounded in comparison with their work (Nicol et al., 2014).

Implications of the peer review as a problem-solving process in facilitating computational thinking among pre-service teachers

The results indicated that peer review provides a fertile context for enhancing student learning through review processes. The findings reported from the analysis of peer comments have demonstrated that peer review facilitates students' CT learning experience while receiving feedback from peers and producing feedback for peers, concurring with the studies conducted by Cho and Cho (2011) and Cho and MacArthur (2011). Developing an individual's criticality involves affective and cognitive domains (Wellington, 2015). The students' perspectives on the differences between receiving and generating reviews, teasing out the higher-order thinking (HOT) processes activated by reviewing, and highlighting the role of these processes in enhancing their learning. The results of this study concur with Nicol et al. (2014), i.e., the peer review process is perceived as beneficial because it actively engages students in HOT, for instance, critical thinking, reflection, and learning transfer.

The cognitive aspects of CT involve the use of heuristics, a problem-solving approach that involves applying a strategy that may lead to a solution (Wing, 2006). In this case, the reviewing activity actively engaged the students in problem-solving. The problem-solving process stimulates the students' HOT to identify the problems or deficiencies in the CT-integrated lesson design, thus prompting them to diagnose and propose appropriate solutions based on their interpretation of the lesson design. In particular, the HOT processes activated through peer review and their practical implications help develop the student's problem-solving competencies.

The peer review constitutes a feedback-oriented learning process. It scaffolds the students' learning process by enabling students to evaluate their peers' performances. Students experience cognitive dilemmas during the peer review that trigger them to explore and elicit new information, justify their thoughts, and propose ideas from different viewpoints. Evidence emerged that the benefits of engagement in peer review resonated with the work of Goh et al. (2019), Hounsell et al. (2008) and Mulder et al. (2014). This engagement enabled students to develop their self-directed problem-based learning, at which students assess their peers' problem-solving processes, provide advice, regulate and reflect upon their problem-solving processes using the rubric.

The findings of this study support the effectiveness of peer review in scaffolding problem-solving and critical thinking processes by considering problems, constructing the problem spot, and articulating contextual constraints. The findings are also congruent with those from Crouch and Moore (2019) and Li and Steckelberg (2004), at which the peer review strategy positively contributes to students' problem-solving skills. The students' problem-solving skills improved more substantially by providing feedback than receiving feedback because students engaged in problem-solving processes while providing the feedback, such as identifying and analysing problems, developing, evaluating and justifying solutions.

Conclusion

This study examined the impact of peer review on facilitating students' CT learning. The results of this research suggest three main key insights: (1) peer review facilitates students' CT learning in designing CT-integrated lessons. (2) peer review can be used as a learning strategy to develop students' HOT; in particular, reviewing process develops students' problem-solving competencies. (3) group processing should be considered based on the nature of the task given to maximise students' collaborative learning.

The significance of this study lies in its being one of the early empirical studies that investigated the effects of peer review on students' CT learning and explored the peer review process in nurturing the students' problem-solving skills. This study builds upon this by examining students' perceptions of the impact of peer review in developing their HOT and CT. As the studies on CT learning have been increasing in recent years, the current study may shed some light on future research, specifically the use of peer review strategy in enhancing students' CT. As teachers are key agents of change in teaching and learning (Voon et al., 2019), the results of this study provide important implications for educators, researchers and practitioners. The findings of this study demonstrated that the peer review was effective in facilitating CT learning and fostering students' HOT. This strategy will facilitate reshaping teaching and learning norms, as the students see reviewing process as an opportunity to improve their lesson design.

Recommendations and limitations

Recent developments in CT have significantly influenced pre-service teacher education, emphasising the integration of CT into teaching practices. To summarise, the studies identified essential aspects to consider for effective professional development, including: (i) well-structure and long-term training programs combining theoretical and practical components are essential for effective CT development (Mouza et al., 2022; Rodrigues et al., 2024; Yun & Crippen, 2024), and (ii) the role of school culture and resources in fostering effective CT teaching (Saxena & Chiu, 2022).

Further, instructional strategies to foster CT development among pre-service teachers have evolved to ensure that future educators can both understand and effectively teach CT concepts. The most effective approaches combine theory with hands-on experience, emphasise integration with existing curricula, and build confidence in using CT tools. The key strategies currently used include (i) plugged activities (Voon et al., 2023; Yun & Crippen, 2024); (ii) unplugged activities (Mouza et al., 2022; Voon et al., 2023);

(iii) project-based and problem-based learning (Yun & Crippen, 2024; Rodrigues et al., 2024); (iv) TPACK Framework Integration (Mouza et al., 2022); (v) lesson planning and microteaching (Voon et al., 2023); (vi) curriculum-embedded professional development (Saxena & Chiu, 2022).

This study proposed peer review as a problem-based learning strategy. In order to improve students' learning experiences in peer review, the researchers suggest that all students be informed about the purposes and learning benefits of peer review process, regardless of whether anonymity is provided. Students' concerns should be addressed in the design and implementation process if conducted in open environments. Furthermore, the changes in students' learning behaviour that happened while engaging in the plugged and unplugged approaches could be analysed, and this may be a future recommendation to improve teaching and learning processes.

Despite the significance of this study, there are a few limitations to take into account. First, the sample of this study comprises a homogenous group of participants who are pre-service teachers taking an educational technology course; hence, the results may not be generalised across other settings. Second, the modules were conducted online, and minor participants could not attend the synchronous class due to the unstable internet connection; hence they could only watch the lesson recordings. Third, two raters may limit the generalisability and stability of the reliability estimate because it may be influenced by individual biases or errors in judgement (Cole, 2024). Therefore, it is recommended that future research consider employing additional raters to strengthen inter-rater reliability.

Abbreviations

CT: Computational Thinking; PBL: Problem-based Learning; IT: Information Technology; PPS: Paper-and-pencil Programming Strategy; CS: Computer Science; CTS: Computational Thinking Scale; HOT: Higher-order Thinking.

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Authors' contributions

Xin Pei Voon was the lead author and contributed the majority of the writing. Su Luan Wong and Lung Hsiang Wong revised and edited the manuscript. Mas Nida Md. Khambari and Sharifah Intan Sharina Syed-Abdullah finalized the manuscript. All authors contributed important ideas to the conceptualization of the research.

Authors' information

Xin Pei Voon is a Research Fellow at the National University of Singapore (NUS), Singapore. Dr. Su Luan Wong is a professor at the Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia. Dr. Lung Hsiang Wong is a Senior Education Research Scientist at the National Institute of Education, Nanyang Technological University (NTU), Singapore. Dr. Mas Nida Md. Khambari is an Associate Professor in Instructional Technology and Learning Design at the Department of Science and Technical Education, Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia. Dr. Sharifah Intan Sharina Syed-Abdullah is a senior lecturer at the Department of Foundation of Education, Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia.

Xin Pei Voon holds a doctorate in Educational Technology and is currently a Research Fellow at the National University of Singapore (NUS), Singapore. She was awarded the High Achiever's Scholarship by Taylor's University, where she also obtained her MSc in Teaching and Learning. Additionally, she received the APSCE Merit Scholarship in recognition of her academic excellence. Xin Pei is an interdisciplinary researcher with a strong passion for conducting research

across the fields of education and the application of technology in public health and healthcare settings. Her research interests include learning sciences, artificial intelligence (AI) in education, implementation science, and AI in healthcare. In recognition of her contributions as a scholar, Xin Pei received an Outstanding Service Certificate from the National Institute of Education, Nanyang Technological University (NTU), Singapore.

Su Luan Wong received her PhD in Educational Technology from Universiti Putra Malaysia (UPM), Malaysia in 2003. She is a Professor at the Faculty of Educational Studies, UPM. Her current research interests focus on interest driven learning and HyFlex learning environment. In recognition of her active role as a scholar, she was elected executive committee member for the Asia-Pacific Society for Computers in Education (APSCE) in 2006, a post that she still holds. In 2011, she established a Special Interest Group —Development of Information and Communication Technology in the Asia-Pacific Neighbourhood — under the auspices of APSCE to bridge the research gap between scholars from developing and developed countries. Her hard work and dedication to serve the research community in the Asia-Pacific region has led to a highly coveted association to APSCE as its President for 2016-2017.

Lung-Hsiang Wong received his Ph.D. degree in computer engineering and with a focus on artificial intelligence in education from Nanyang Technological University (NTU), Singapore. He is a Senior Education Research Scientist at National Institute of Education, NTU. His current research interests are in the areas of mobile and seamless learning, computer-assisted language learning and science learning, computer-supported collaborative learning, teachers' professional development, and AI in education. Drawing upon his vast experience in conducting design-based research and school-based longitudinal intervention studies, he developed his niches in both seamless learning and computer assisted language learning. In particular, he has become a key researcher on mobile seamless learning by leading the synthesis efforts.

Mas Nida Md. Khambari is a Graduate Technologist and Associate Professor in Instructional Technology and Learning Design at the Department of Science and Technical Education, Faculty of Educational Studies. She is the deputy Director at the International Institute for Online Learning (IIOE UNESCO-ICHEI) Malaysia. Previously, she has served as the Deputy Director (Innovations in Teaching and Learning) at the Centre for Academic Development and Leadership Excellence (CADe-Lead), UPM. She is currently the Executive Committee of the prestigious Asia-Pacific Society for Computers in Education (APSCE) and is actively involved in the Special Interest Group: Practice-driven Research, Teacher Professional Development and Policy of ICT in Education under the APSCE flagship conference – the International Conference on Computers in Education, since 2014. Mas Nida has actively participated and won several medals at innovative teaching and learning competitions at both the university and national level. She was awarded the Putra InnoCreative Award for Best Innocreative Educator (Face To Face Immersive Learning Experience) in 2019, Vice Chancellor Fellowship Award in Teaching and Learning in 2020, Outstanding Supervision Award in 2023, and Early Career Researcher Award (ECRA) in 2024 under the auspices of APSCE.

Sharifah Intan Sharina Syed-Abdullah received her Ph.D. in sustainability education from the University of Edinburgh in 2018. Previously, she received her M.Ed. (science education) from the National University of Malaysia and B.Ed. (Education with Science) from Universiti Malaysia Sabah. She is a senior lecturer at the Faculty of Educational Studies, Universiti Putra Malaysia. Her research interests are mainly in the areas of environmental education, sustainability education, science education, curriculum and instruction, and non-formal learning. Drawing on this interest, she has been involved in the aforementioned areas at the national level.

Availability of data and materials
Not applicable.

Declarations

Competing interests
The authors declare that they have no competing interests.

Author details
[1] National University of Singapore, Singapore

[2] Universiti Putra Malaysia, Malaysia

[3] Nanyang Technological University, Singapore

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