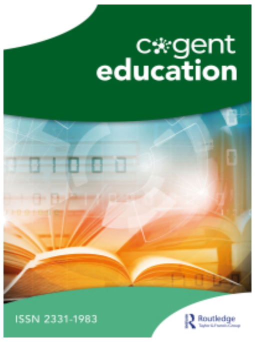

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Enhancing computational thinking skills in Thai middle school students through problem-based blended learning approaches

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ABSTRACT
This study aimed to compare Computational Thinking Skills (CTS) and Academic Achievement (AA) in students exposed to a Problem-Based Blended Learning (PBBL) model in a quasi-experimental setting. The research involved 43 Mathayom 2 students at a Rajabhat University Demonstration School in Thailand, selected through cluster random sampling. The participants were divided into an experimental group ($n = 21$) and a control group ($n = 22$). The CTS test employed a scoring rubric, and the AA test included multiple-choice questions. Data analysis used statistical measures such as mean, standard deviation (SD), and One-Way MANOVA. Results showed that the experimental group achieved significantly higher scores, with 91% in CTS and 89% in AA, compared to the control group's 56% in CTS and 60% in AA. These findings demonstrate the effectiveness of the PBBL model in enhancing both CTS and AA in middle school students. This research contributes new insights by confirming that blended learning approaches can be effectively integrated into middle school education to foster critical thinking and academic success when combined with problem-based methodologies. The study provides evidence supporting the potential of innovative educational frameworks like PBBL in improving student outcomes, offering valuable implications for educators and curriculum designers.

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Computation; Computer Science (General); Information & Communication Technology (ICT); Theories of Learning; Information Technology; Education – Social Sciences

1. Introduction

The global landscape is witnessing profound economic and social changes, particularly in countries with advanced economic development, such as China, the United States, Singapore, South Korea, Japan, and Sweden. These nations have successfully nurtured individuals equipped with advanced skills in technology creation and innovation (Fukuda, 2020), enhancing their overall potential and competitiveness on the world stage. Acknowledging the significance of computational thinking skills (CTS) in this context (Brennan & Resnick, 2012; Wanglang et al., 2024), it becomes imperative for nations like Thailand to embrace innovation as a crucial step towards securing a prosperous future as a high-income country. Additionally, of the 64 countries ranked in 2023 for their competitiveness, Thailand was in 30th place (Wanglang et al., 2024).

The preparation for an innovative society hinges on the development of individuals with a profound understanding of science, technology, and creativity—transforming them into drivers of innovation (Fukuda, 2020). Tomorrow's knowledge workers need to find practical solutions to real-life problems while being able to work in online communities using CTS, creativity, and innovation (Boateng, 2023). Microsoft underscores the significance of CTS as a problem-solving method utilizing computer

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programming languages. Moreover, computational thinking concepts form the bedrock of fostering creativity, curiosity, and imagination in students, cutting across age and gender boundaries (The Nation, 2024).

These ideas are consistent with recent studies. For example, Songkram et al. (2024) investigated the use of CT and robotics instruction with 532 Thai primary school student teachers, noting the significant contribution to students' digital innovation skills. Similarly, Kim et al. (2024) in the USA examined CT design skills in kindergarten teachers, emphasizing the need for curriculum design that fosters social skills, growth mindset development, and essential CT competencies. In South Korea, Ahn and Oh (2024) used blended learning and CT to enhance graduate student artificial intelligence (AI) competencies, aiming to prepare society for the future. Mäkitalo et al. (2024) in Finland discussed the skills and competencies required for a 21st-century digital society, highlighting that CT has become a broad catchphrase encompassing various computing skills and parts of other school subjects. In Sweden, Nouri et al. (2020) underscored the importance of CT and programming skills for K-9 students, reflecting a growing global effort.

On a larger scale, the introduction of CT in K-12 schools has been the subject of numerous global studies, curriculum guidelines, and frameworks, including those from America's Computer Science Teachers Association (Selby & Woollard, 2013), the UK's Computing at School (CAS), the Australian Curriculum, Assessment and Reporting Authority (ACARA), Informatics Europe (Informatics Europe & ACM Europe, 2015), and ACM Europe (Nouri et al., 2020).

A meta-analysis by Wang et al. (2024) of 17 CT studies focused on students aged 3–8 years highlighted significant statistical evidence supporting the effectiveness of CT development in young children. Åkerfeldt et al. (2024) reviewed 57 CT and programming studies concerning K–12 students, noting a concentration of studies in the USA and Greece, with a growing interest in the subject since Wang's 2006 paper.

Aligned with these global trends, Thailand has outlined an educational framework in the National Education Plan 2017–2036 (The National Scheme of Education, 2017) that corresponds to the nation's needs. This framework aims to cultivate learners with 21st-century skills, including critical thinking (Srikan et al., 2021; Yang et al., 2013), problem-solving, creativity (Boateng, 2023), and digital literacy (Rizal et al., 2021). The interconnected development of economic and educational skills underscores the crucial role of the education system as an upstream factor in propelling human development toward an innovative society.

1.1. Problem-Based Learning in Middle school education

Problem-Based Learning (PBL) has been examined for its ability to increase CT and problem-solving skills, particularly among middle school students. Research demonstrates that PBL promotes self-directed learning, collaboration, and the application of real-world problem-solving techniques, all of which are integral to CTS. These skills are often needed for 21st-century learners, who must develop CT and the ability to decompose abstract problems and design algorithms.

Numerous studies have investigated PBL's success in middle and high school contexts. Sholihah and Lastariwati (2020) found that implementing PBL significantly improved CT and problem-solving competencies among vocational high school students. Their study showed an increase in students' performance from 37% in the first cycle to 78% in the second cycle, demonstrating PBL's capacity to enhance key competencies required for academic success.

Similarly, Ahdhianto et al. (2020) conducted a quasi-experimental study in an Indonesian elementary school and found that PBL improved students' mathematical problem-solving and critical thinking skills (CrTS). Their findings align with the broader literature emphasizing PBL's role in encouraging students to actively engage with content and apply critical thinking to real-world problems, which is crucial for developing CTS.

Moreover, Lapuz and Fulgencio (2020) examined PBL's effect on the CrTS of secondary school students in economics. The results revealed a substantial improvement in students' critical thinking abilities following the PBL intervention. This study and others reinforce the idea that PBL enhances content understanding and students' ability to think critically and solve complex problems.

In the e-learning context, Martyaningrum et al. (2021) demonstrated that applying PBL through an online learning environment improved critical thinking ability. Their research, conducted among eighth-grade students in Central Java, highlights the adaptability of PBL in different learning environments and its impact on students' critical thinking, even in a virtual setting. This suggests that blended learning models, such as the one used in the current study, can effectively integrate PBL to enhance CTS in various learning contexts.

Given the crucial role of CTS in the foundational education of students, this research explores the enhancement of CTS among middle school students using the Problem-Based Blended Learning (PBBL) Model. This study seeks to contribute to the ongoing efforts to prepare students for an innovative and technologically advanced future.

1.2. Research focus and questions

This study focuses on Computational Thinking Skills (CTS), the ability to solve problems using computational methods and logical reasoning, and the Problem-Based Blended Learning (PBBL) Model, an instructional approach combining traditional classroom methods with online problem-solving activities. These concepts are critical to understanding the innovative educational framework we propose, designed to better prepare students for the demands of a technology-driven world.

This study explores the effectiveness of the PBBL Model in enhancing CTS among middle school students. Building on recent studies (Huang & Looi, 2021; Lee & Yang, 2023; Yildiz Durak, 2020), this research addresses gaps in the literature from the investigation of how the PBBL Model can improve CTS and academic achievement.

The authors pose the following research questions:

1. How does the PBBL Model impact the development of CTS in middle school students?
2. What is the comparative effect of the PBBL Model on students' academic achievements compared to traditional learning methods?

This approach highlights our study's contribution to the current body of knowledge and its importance to the latest research in the field. This research offers an empirical analysis of the PBBL Model's dual impact on enhancing CTS and academic achievement, providing valuable insights for educators and policymakers aiming to integrate CTS effectively into the curriculum, particularly within the Thai education system.

1.3. Research hypotheses

The study was guided by the following hypotheses:

1. The Problem-Based Blended Learning (PBBL) model significantly enhances Computational Thinking Skills (CTS) among middle school students compared to traditional instructional approaches.
2. The PBBL model significantly improves academic achievement in computational concepts among middle school students compared to traditional instructional approaches.

2. Literature review

2.1. Problem-based learning (PBL)

PBL is grounded in constructivist learning theory (Srikan et al., 2021), which posits that knowledge is constructed through active learning and problem-solving. The theory behind PBL is that students learn best when they are engaged in solving real-world, complex problems that do not have straightforward solutions (Zuberi, 2011). This approach emphasizes critical thinking, collaboration, and the application of knowledge in new contexts. In PBL, students work in groups to solve open-ended problems, with the teacher acting as a facilitator rather than a source of solutions. The learning process is student-centered, encouraging inquiry, self-directed learning (SDL), and the application of concepts to practical situations. While BL focuses on the mode of delivery (combining online and in-person instruction), PBL emphasizes the method of learning (learning through solving problems) (Yew & Goh, 2016). Blended learning can incorporate teaching methods, including PBL, to enhance the learning experience.

Educators, in the context of problem-solving, leverage learning models to actively engage and stimulate students' thinking skills (Leasa et al., 2020). Increasingly, instructors are incorporating actively engaging students in authentic and meaningful problem exploration across different disciplines. Positive outcomes, such as increased digital literacy and motivation, have been reported when online learning is connected with PBL (Tudor Car et al., 2019; Wahyudi, 2020). Various researchers have also emphasized that critical thinking and creativity skills can be enhanced when integrated with digital devices and PBL activities (Changwong et al., 2018; Chao et al., 2022; Hunsaker, 2020; Tudor Car et al., 2019; Yang et al., 2013). PBL also facilitates learning, actively engaging learners in self-directed research (Yang et al., 2013; Yew & Goh, 2016).

As an apt teaching method for 21st-century learners, PBL utilizes situations and real-world problems as a base for learning and knowledge acquisition (Dwyer et al., 2014). This fosters problem-solving skills development, collaboration, and self-directed learning (Yew & Schmidt, 2009). PBL thus transforms the traditional 'chalk and talk' approach, enlivening classroom environments and fostering cooperation and collaboration among departments or agencies (Srikan et al., 2021).

2.2. Blended learning (BL)

Blended learning integrates traditional face-to-face classroom methods with online digital media (Al-Qatawneh et al., 2020; Yu et al., 2022). The theory behind Blended Learning is that by combining these two modes of instruction, students can benefit from the strengths of both. This approach leverages the accessibility and flexibility of online learning while maintaining the personal interaction and immediacy of in-person teaching (Bonk & Graham, 2012). In Blended Learning, instruction is partially delivered online, with some control over the time, place, path, or pace of learning left to the student (Cao, 2023; Inal & Korkmaz, 2019). The other part is face-to-face interaction, which allows immediate feedback, social interaction, and hands-on activities.

Performance in BL denotes measurable student achievement in offline and online settings (Kanawapee et al., 2022; Spanjers et al., 2015). Evaluation encompasses diverse aspects, including critical thinking (Deechai et al., 2019; Yang et al., 2013), knowledge delivery, disposition improvement, and language skills (Banditvilai, 2016). Studies consistently report positive outcomes, revealing that BL excels in motivation, attitudes, and satisfaction, leading to enhanced performance across various domains (Hill et al., 2016; Mueller et al., 2020).

BL significantly improves language proficiency, affecting reading, writing, listening, and speaking skills (Macaruso et al., 2020; Yang, 2012; Yang et al., 2013). Moreover, BL fosters high-order thinking (HOTS) abilities, including reasoning, problem-solving, and communication (Liu, 2016; Monteiro & Morrison, 2014; Shorey et al., 2018). Positive evaluations abound, indicating that blended learning enhances English skills, vocabulary acquisition, and communication skills, with favourable attitudes noted among various student groups (Chang et al., 2014; Inal & Korkmaz, 2019; Istenič, 2024; Shorey et al., 2018).

BL consistently outperforms traditional approaches, contributing to higher academic achievements, improved learning outcomes, and enhanced efficiency in various contexts (Baepler et al., 2014; Bazelais & Doleck, 2018; López-Pérez et al., 2013). BL promotes higher engagement levels, demonstrated by increased frequency and efficiency of learning activities (Botts et al., 2018; George-Walker and Keeffe, 2010; Monteiro & Morrison, 2014; Pérez-Marín & Pascual-Nieto, 2012; Yen & Lee, 2011).

However, it should be noted that there is conflict in the literature regarding the impact of BL on academic achievement, attitude, performance, and engagement. Some studies report inconclusive evidence, noting variations based on factors such as instructional design and contextual differences (Al-Qatawneh et al., 2020; Berga et al., 2021; Botts et al., 2018; Chang et al., 2014; Olitsky & Cosgrove, 2014; Yen & Lee, 2011). Overall, the impact of BL on these aspects remains a nuanced and context-dependent matter.

2.3. Computational thinking skills (CTS)

The importance of CTS and programming skills in the 21st-century economy has been emphasized in numerous studies for various professions, including accounting (Muchsini et al., 2023), student-teachers (Chinchua et al., 2022), robotics (Songkram et al., 2024) and programmers (Prommun et al., 2022). CTS is a fundamental tool for analysing problems, designing workflows, and understanding human behaviour, extending beyond computer science (Pimdee & Pipitgool, 2023). Described as the '5th C' of 21st-century skills, CTS is recognized for its engaging methodology that inspires student learning (Shute et al., 2017).

However, CTS is not a novel concept; its roots trace back to 1980 when Seymour Papert introduced the concept in the context of a constructionist approach to education (Lodi & Martini, 2021). Papert highlighted the computer's significance as a meta-tool for making abstract concepts tangible, with potential applicability across disciplines. Wing's (2006) essay further ignited interest in computer science education for K-12 learners (Lodi & Martini, 2021), aligning with studies that underscore the connections between Computational Thinking Problem Solving, CTS, and STEM skills (Kules, 2016; Lee et al., 2020; Pimdee & Pipitgool, 2023). Additionally, CTS extends its benefits to the humanities, arts, social sciences, and sciences, contributing to human potential and social development on a global scale (Cansu & Cansu, 2019).

In the United Kingdom, Polat et al. (2021) emphasized the importance of CTS as a critical component for assessing secondary school students' CTS. Results revealed gender and grade-based differences, with boys outperforming girls. Mathematics achievement positively influenced CT performance and perception, while IT achievement had a lesser impact. Palts and Pedaste (2020) also recognized the crucial role of CTS in diverse subjects and proposed a three-stage model for its development. Their focus was on emphasizing problem definition, solution, and analysis. Additionally, Hunsaker (2020) emphasized the necessity for students to possess critical thinking abilities to navigate complex and ill-defined problems in today's fast-paced world.

2.3.1. Reason for enhancing CTS with PBL and BL

Enhancing CTS is the study's effort to achieve a specific educational outcome from the combinations of each approach. In today's digital world, CT has become a critical skill for students, which involves problem-solving abilities essential for success in technology-driven fields. Enhancing CTS prepares students to think logically, decompose problems, recognize patterns, and develop step-by-step solutions, necessary skills in programming, data analysis, and many other areas (Aytekin & Topçu, 2024).

PBL's effectiveness in enhancing CT has been supported by research showing its ability to improve decomposition, pattern recognition, abstraction, and algorithmic thinking. Rodríguez del Rey et al. (2021) emphasized that PBL helps students develop these key computational thinking components by engaging them in solving open-ended problems that mimic real-world challenges. Similarly, Azizah et al. (2022) found that high school students who engaged in PBL demonstrated strong abilities in decomposition and abstraction, which are critical for computational thinking.

These studies support the current research's use of a Problem-Based Blended Learning Model (PBBL) to enhance computational thinking skills in Thai middle school students. By incorporating problem-solving and blended learning strategies, students can apply computational thinking principles in varied, real-world contexts, improving their CTS and academic achievement.

2.3.2. Blended learning and CTS

By using Blended Learning, students can access a wide range of resources and activities online that specifically target CTS. For example, online coding exercises or simulations can help students practice these skills, while face-to-face sessions provide support and discussion opportunities.

2.3.3. PBL and CTS

Problem-based learning naturally lends itself to enhancing CTS because it requires students to tackle complex problems that require computational thinking solutions (Hunsaker, 2020; Zuberi, 2011). Through PBL, students practice breaking down problems, identifying patterns, and creating algorithms—core components of CTS. Therefore, including *Enhancing Computational Thinking Skills* is essential in the study because both Blended Learning and PBL are effective strategies for developing critical skills in students, preparing them for the demands of modern, technology-driven careers.

3. Methods

3.1. Research design

This study used a quasi-experimental design to investigate the effectiveness of the PBBL Model on enhancing CTS among secondary school students aged 12–15. The research design integrated qualitative and quantitative methodologies to analyse the model's impact comprehensively.

Figure 1 visually represents the research methodologies employed, illustrating the study's historical development and the four main steps from the literature review to the field group try-out.

3.2. Sample

The study's population consisted of 215 Mathayom 2 students from a Rajabhat University Demonstration School in Thailand. A cluster random sampling technique was employed to select 43 students, who were then divided into an experimental group (RE, $n = 21$) and a control group (RC, $n = 22$). An additional pilot group of 30 students, with a distribution of high, medium, and low academic performance (10:10:10), was used for preliminary testing of the PBBL Model.

3.3. Measures/instruments

The primary instrument used to assess CTS was the CTS Test. This test was designed to measure students' abilities in several key areas of computational thinking, including solving daily problems,

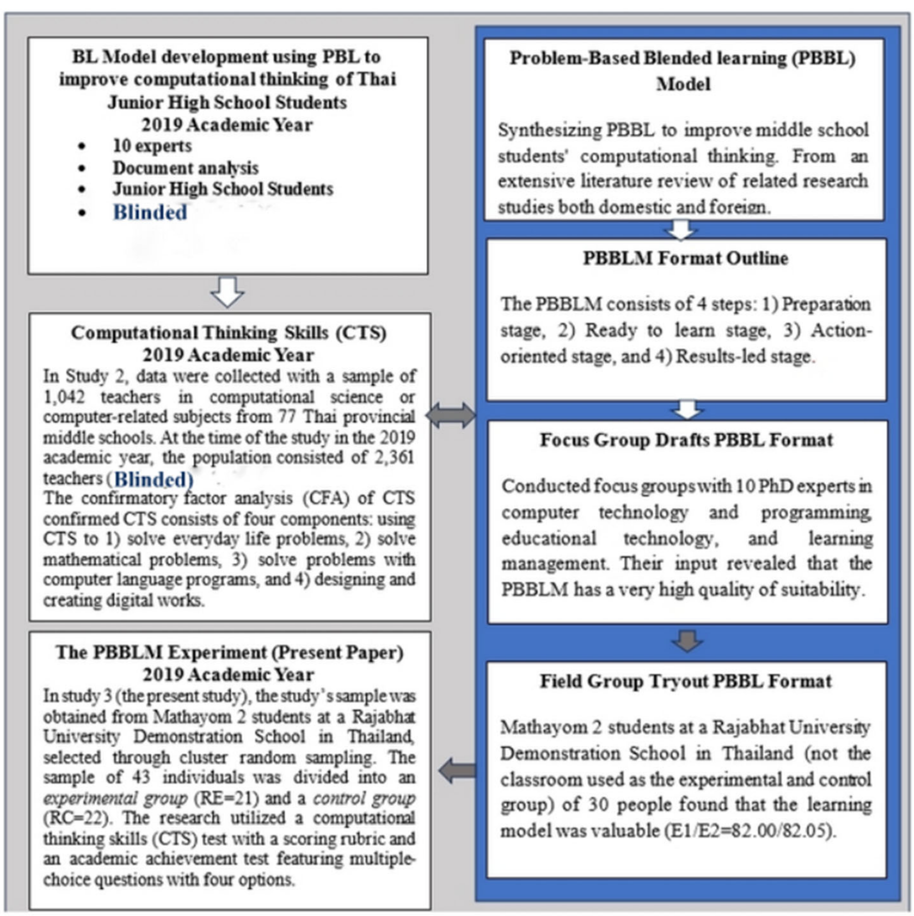

Figure 1. Foundational research methodologies employed.

mathematical problem-solving, and creating digital works using computational concepts. The test consisted of multiple components, each designed to evaluate a specific aspect of CTS.

3.3.1. Validity and reliability

- Content Validity: The test's content validity was established using the Index of Item-Objective Congruence (IOC), with values ranging from 0.60 to 1.00, confirming that the items accurately represented the intended content.
- Reliability: The instrument's reliability was confirmed through inter-rater reliability, with a correlation of 0.83 between evaluators, ensuring consistency in the assessment process. Additionally, internal consistency was measured using Cronbach's alpha, with a high value of $\alpha = 0.97$, indicating excellent reliability.

3.3.2. Achievement test

An additional Achievement Test was administered to assess student performance in computational concepts, problem-solving, and specific examples of computational thinking in action, such as sorting data efficiently. The test covered cognitive skills based on Anderson and Krathwohl's (2001) taxonomy, focusing on Remembering, Understanding, Applying, and Analysing. Item difficulty levels (p) ranged between 0.27 and 0.80, and the discrimination indices (r) were 0.74, confirming the test's ability to differentiate between high and low performers.

3.3.3. Key CTS measurements

Enhancing CTS was defined and measured using the following dimensions:

1. Problem Decomposition is the ability to break down complex problems into smaller, more manageable parts.
2. Pattern Recognition is used to identify patterns or trends within data or processes, aiding problem-solving.
3. Abstraction is the ability to focus on the essential details of a problem while filtering out irrelevant information.
4. Algorithmic Thinking is the proficiency in creating step-by-step instructions (algorithms) to solve problems logically and efficiently.
5. Automation is the needed competence in using technology and computational tools to automate processes or solutions, enhancing efficiency.

Therefore, these dimensions provide a structured framework for assessing the development of CTS among students, offering a clear and comprehensive way to measure the effectiveness of the PBBL Model in enhancing these skills.

3.4. Validity and reliability

The validity of the CTS test was ensured through expert review, leading to an IOC range of 0.50 to 1.00 and a final value of 0.83. The reliability of the test was demonstrated through a pilot study with a Cronbach's alpha of 0.97, indicating excellent internal consistency. The instruments were pre-tested with a pilot group to ensure clarity and appropriateness for the target population.

3.5. Procedure

The study was conducted over 12 weeks, with each week involving 2 h of instructional time. The experiment was structured into several phases, starting with a pre-test, then implementing the PBBL Model in the experimental group, and concluding with a post-test. The control group received traditional instruction during the same period.

Table 1. Results of the efficiency analysis try-out of the PBBL model.

		Students (n = 30)				
Scoring Metric	Possible Points	Mean	SD	%	Criteria	Analysis
In-class activities (E1)	30	26.80	8.77	89.33	80	Acceptable
Skills/performance after learning (E2)	30	26.65	5.31	88.83	80	Acceptable

3.6. Data collection

Data collection occurred at three points: pre-test, during the experiment, and post-test. The pre-test established a baseline for CTS and computational concept achievement. Data were gathered from in-class activities (E1) and post-experiment performance assessments (E2) throughout the experimental period. The post-test measured changes in CTS and achievement levels, providing data for comparative analysis between the experimental and control groups.

3.7. Data analysis

Data analysis was conducted using both descriptive statistics and inferential techniques. Descriptive statistics included means, standard deviations (SD), and percentages to summarize CTS and academic achievement. To evaluate the effectiveness of the PBBL Model, a one-way MANOVA was used to compare the experimental (RE) and control (RC) groups. The efficiency of the PBBL Model was also analysed using the E1/E2 ratio, with benchmarks set at 80% (Sinchai et al., 2023). The results revealed that the PBBL Model exceeded the benchmark, with an E1/E2 ratio of 89.33/88.83 (Table 1).

3.8. PBBL model development process

The development of the PBBL Model began with a systematic synthesis of relevant documents, including a comprehensive review of Thai and international studies using a qualitative research approachand a carefully designed recording form. The validity of the recording form was assessed by experts, leading to the creation of a detailed graphical model of the PBL format.

To refine and evaluate the PBBL Model, small group discussions were held with 10 PhD-level experts, selected through purposive sampling. The evaluation results indicated unanimous agreement among the experts regarding the model's high quality (mean = 4.58, SD = 0.53).

Figure 2 illustrates the PBBL Model designed to improve the CTS of secondary school students.

3.9. Research tools

The research tools included a CTS Test (with an IOC of 0.83) and an Achievement Test regarding computational concepts. The CTS test focused on students' ability to solve problems in everyday life, solve math problems, use computational concepts in solving math problems, and solve problems using computer programs. The Achievement Test assessed students' understanding and application of computational concepts in practical scenarios.

3.10. PBBL model activities, steps, and results

Table 2 details the study's PBBL Model steps, activities, and results designed to enhance students' CTS progressively. Each step is accompanied by evidence of student expressions, skills, and attributes developed throughout the process.

4. Results

The data analysis results provide insights into students' Computational Thinking Skills (CTS) and Academic Achievement (AA) in the experimental and control groups. Table 3 summarizes the mean

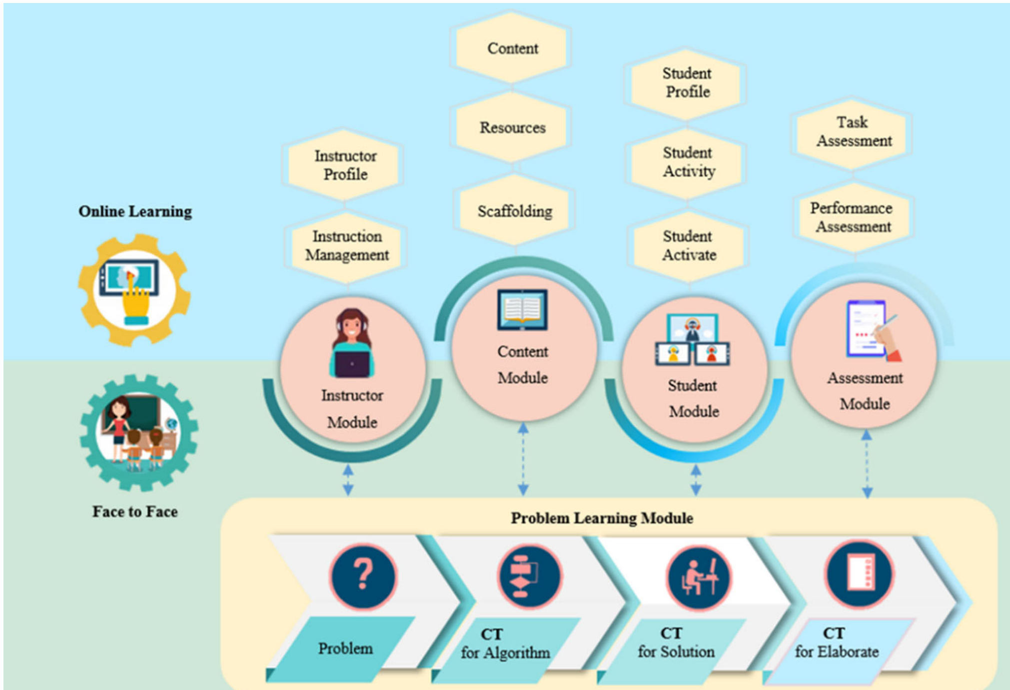

Figure 2. The PBBL Model for improving the CTS of secondary school students.

scores and standard deviations for both variables, revealing apparent differences between the two groups.

Students in the experimental group who engaged in Problem-Based Blended Learning (PBBL) demonstrated notably higher average scores in both CTS and academic achievement than those in the control group, who followed a traditional learning plan. The average score for CTS in the experimental group was 91%, compared to 56% in the control group. Similarly, academic achievement was higher in the experimental group, with an average score of 89%, compared to 60% in the control group. These initial findings suggest a positive effect of PBBL on student performance, but further analysis using One-Way MANOVA was conducted to determine the statistical significance of these differences.

4.1. Preliminary tests for One-Way MANOVA assumptions

Before proceeding with the One-Way MANOVA test, preliminary checks were conducted to ensure the data met the necessary assumptions for multivariate analysis. These tests included Bartlett's Test of Sphericity, Box's M Test, and the Shapiro–Wilk Test for normality.

The results from Bartlett's Test ($p = .00$) confirmed that the dependent variables—CTS and AA—were not related until multicollinearity occurred, ensuring independence between them. Box's M Test ($p = .07$) indicated that the variance-covariance matrices were equal, satisfying the assumption of homogeneity of variance-covariance. Lastly, the Shapiro-Wilk Test ($p > .05$) verified that the data was normally distributed, meeting the assumption of normality. Collectively, these results confirmed that the dataset was suitable for One-Way MANOVA analysis (Table 4).

4.2. One-way MANOVA test results

A One-Way MANOVA was conducted to compare the post-study CTS and academic achievement scores between the experimental and control groups. As seen in Table 5, all four multivariate test statistics (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root) indicate a statistically significant difference between the groups ($p = .00$), with F-ratios confirming the high confidence level ($p < .01$). These results show that the PBBL model significantly improves academic achievement in computational concepts among middle school students compared to traditional instructional approaches.

Table 2. PBBL model steps, activities, and results.

Step/Activity	Evidence of student expressions: Work Piece & Expression	Evidence of student expressions: Skills/Attributes
1. Preparatory Stage:	1. Pre-test results. 2. Acceptance of study rules and roles.	Through the process of collaboration, enthusiasm is generated.
1.1. The teacher facilitates students' access to the lesson website on the computer network.		
1.2. The teacher presents a video demonstrating the preparation of an omelette for breakfast and the creation of bubble milk tea drinks.		
1.3. The teacher instructs students on how to complete a pre-class test.		
1.4. Evaluation and group membership determination: Based on the assessment of the student's performance, each student is assigned to a group. The teacher explains each group's roles and responsibilities. The group leader then encourages collaborative thinking and discussions to find answers. One student is assigned the task of completing the activity sheet based on the consensus reached within the group.		
2. Ready to Learn Stage:	Student group members create Mind Maps.	Building relationships and consensus within each group.
2.1. The teacher prepares Activity Sheet 1 on Computational Thinking for every group and lists each student.		
2.2. Students create Activity Sheet 1, which has three questions. The learning results for each question are then summarized.	Students complete Activity Sheet 1 as follows. Point 1: Everything is made up of smaller components. Point 2: Choose only what is necessary to solve the problem. Section 3: Algorithms and sequential operations.	From completing Activity 1, the result is that students better understand the *principles of separation*. From completing Activity 2, students will gain an understanding of using only what is necessary to solve problems. From completing Activity 3, students will develop an understanding and awareness of creating a mind map to ensure accurate execution based on cause-and-effect principles.
2.3. When all groups have finished their activities. The teacher will draw lots for representatives from each group to summarize the results until all three questions are complete.	Learning outcomes summary	Knowledge and presentation summaries
2.4. The teacher shows the video on system components and how to solve problems by separating them.	–	Students achieve a better understanding of computational thinking.
2.5 Teachers and students summarize the issues again so that students can understand the knowledge gained from doing activities that are linked to the knowledge information in the video.	–	Teachers check students' knowledge and understanding of computational thinking.
3. Action Steps	Stitch together the images according to the given format.	Students have an understanding of the format.
3.1. The teacher distributes Activity Sheet 2 on the subject of patterns. Do Section 1 with three items and write a summary of the results.		
3.2. The teacher opens the video 'loop' and lets the students do Activity 2' items 4–6.	Do Visual Program items 4-6.	Students understand the format and apply the model in Visual Programming situations.
3.3. The teacher draws lots for group representatives to summarize the results until all six items are complete.		Teachers check students' knowledge and understanding of computational thinking in terms of format
4. Steps Leading to Success Success steps include allowing students to import data into the teaching system, with each student individually writing down what they learned from the course. After each session students are asked to take	assessment quizzes in which they record their learning information and take a final test.	

4.3. Result differences between the experimental and control groups

Further data analysis revealed significant differences between the experimental and control groups across both dependent variables. Table 6 outlines these differences regarding the Sum of Squares (SS), Mean Square (MS), and F-ratio values for CTS and AA. For both variables, the results show that the F-

Table 3. Final CTS and academic achievement scores for both the experimental and control groups.

		Experimental Group			Control Group		
Variables	Full score	mean	SD	%	M	SD	%
Computational Thinking Skills	40	36.40	0.83	91	22.44	1.67	56
Academic Achievement	30	26.75	0.25	89	18.10	0.49	60

Table 4. Results of the preliminary agreement test of multiple analysis of variance (MANOVA).

Test statistics	Agreement criteria	Data analysis	Test results
Relationship of variables using Barlett's Test	Sig. $<\propto$	0.00*	The dependent variables are only related to one another once multicollinearity occurs.
Variance-covariance metric using Box's M Test.	Sig. $>\propto$	0.07	The variance-covariance matrices are equal.
Distribution of data using Shapiro-Wilk.	Sig. $>\propto$	>0.05	Data is distributed normally (Normality).

$p<.05$ indicates statistical significance.

Table 5. One-way MANOVA test results.

Source of variation	Test Statistic	*F*	Sig
Group	Pilla's trace	49.19	0.00
	Wilks' Lamda	49.19	0.00
	Hotelling's Trace	49.19	0.00
	Roy's Largest Root	49.19	0.00

$p<.01$ indicates statistical significance.

Table 6. Result differences between the experimental group and the control group.

Source	Dependent Variable	Sum of Squares	df	Mean Square	F-ratio	Sig
Group	computational thinking	748.22	1	748.22	97.52	.00
	academic achievement	1241.8	1	1241.88	100.31	.00
Error	computational thinking	291.55	38	7.67		
	academic achievement	470.42	38	12.38		
Total	computational thinking	21,155.00	40			
	academic achievement	37,621.17	40			

*$p<.01$ indicates statistical significance.

ratios are statistically significant ($p<.01$), reinforcing the effectiveness of the PBBL model in improving student performance.

The experimental group exhibited a much larger high mean score for CTS (91%) than the control group (56%). Likewise, the AA score was substantially higher in the experimental group (89%) than in the control group (60%). These results confirm that using the PBBL Model significantly enhanced both CTS and AA among middle school students in Thailand.

4.3.1. Statistical explanation of key results

The Sum of Squares (SS) quantifies the total variability within the data for each dependent variable. In this case, it reflects the differences in CTS and AA between the experimental and control groups. The Mean Square (MS) is the average of SS, calculated by dividing the SS by the degrees of freedom (df), and the F-ratio compares the variability between groups to the variability within groups, serving as the test statistic for determining significance.

For CTS, the F-ratio of 97.52 and for AA, the F-ratio of 100.31 indicate substantial differences between the two groups, supporting the hypothesis that the PBBL Model significantly enhances Computational Thinking Skills (CTS) among middle school students compared to traditional instructional approaches. These results are further validated by the low *p*-value ($<.01$), confirming that the observed differences are not due to chance.

4.3.2. Clarification

In Table 6, the Sum of Squares (SS) represents the total variability within the data for each dependent variable (CTS and AA). For example, SS is calculated in test scores by summing the squared differences between each score and the mean. The Mean Square (MS) is the average of the SS, calculated by dividing the SS by the degrees of freedom (df). The F-ratio (F), used in ANOVA, compares variability between groups to variability within groups, providing the test statistic to determine significance (Connelly, 2021).

In this study, the F-ratios of 97.52 (for computational thinking) and 100.31 (for academic achievement) show substantial differences between the experimental and control groups, confirming that the PBBL Model significantly enhanced student performance. The standard error of the mean represents an estimate of the standard deviation in the sample means, which you would expect to find if you sampled an infinite number of times from the same population (with that particular sample size). The mean square (MS) is the average sum of squares representing the average variability within the data for each dependent variable (Bors, 2018). The MS is obtained by dividing the SS by its degrees of freedom (df). If you have the SS for a set of values, dividing it by the df gives you the MS. In the context of the table dependent variable, it specifies whether the analysis is for computational thinking or academic achievement. The SS quantifies the total variability within the data for each dependent variable. The df reflects the number of values in the final calculation of a statistic. The MS represents the average variability within the data for each dependent variable, calculated by dividing the SS by its df. The F-ratio (F) is the test statistic used in ANOVA, comparing the variability between groups to the variability within groups (Connelly, 2021).

5. Discussion

This study aimed to investigate the impact of a Problem-Based Blended Learning (PBBL) Model on Computational Thinking Skills (CTS) and Academic Achievement (AA) among Thai middle school students. The results revealed significant improvements in both CTS and AA for the experimental group, confirming the effectiveness of the PBBL model in enhancing student outcomes.

5.1. Enhancement of computational thinking skills (CTS)

The PBBL model demonstrated a significant positive impact on the students' CTS. This aligns with previous research highlighting the role of problem decomposition, pattern recognition, and abstraction in CT (Azizah et al., 2022; Palts & Pedaste, 2020; Yasin & Nusantara, 2023). These measures are also in line with Çakiroğlu and Çevik (2022), who developed a framework to measure abstraction in CT through task-based assessments. By employing such a rubric, the study was able to quantitatively assess the improvements in CTS, providing strong evidence for the effectiveness of the PBBL model.

The hands-on, problem-based approach encourages students to actively engage with content and apply computational principles to real-world problems, resulting in measurable improvements in learners' ability to think critically and solve complex problems. The blended learning component also allows learners to find resources and engage in self-paced learning, reinforcing the CT processes they practiced during face-to-face problem-solving activities (Saini & Baba, 2024).

These findings are consistent with Rodríguez del Rey et al. (2021), who reported that PBL promotes a deeper understanding of computational concepts through active problem-solving. Integrating online and face-to-face learning elements also helps learners transition from understanding abstract computational theories to applying them in practice, which is an essential element in CTS development.

The PBBL model's success in enhancing CTS can also be attributed to its ability to facilitate collaborative learning. Hmelo-Silver (2004) also emphasized that collaboration is essential to promoting CT and problem-solving skills. By working together on complex tasks, students could learn from one another, exchange ideas, and refine their understanding of computational principles, leading to more substantial CTS outcomes.

5.2. Impact on academic achievement (AA)

In addition to enhancing CTS, the study revealed a significant increase in AA for the experimental group. This is consistent with Sholihah and Lastariwati (2020), who determined that PBL fosters critical thinking and problem-solving, which are closely linked to improved AA. Combining PBL's problem-solving focus with blended learning's flexibility allowed students to explore concepts more deeply, resulting in higher achievement scores.

Alternating independent online learning and collaborative problem-solving in a classroom setting was critical in improving academic outcomes. This combination mirrors findings by Lapuz and Fulgencio (2020), who showed that problem-based learning enhances critical thinking, which is directly related to better academic performance in various subjects. The opportunity to revisit content at their own pace via the blended learning platform gave students a deeper understanding of the material, improving their overall academic achievement.

5.3. Problem-based learning (PBL) in Middle school education

Problem-Based Learning (PBL) has been extensively examined for its ability to enhance critical thinking (CT) and problem-solving skills among middle school students (Boateng, 2023; Hafizah et al., 2024; Pimdee et al., 2024; Pimdee & Pipitgool, 2023; Srikan et al., 2021; Pimdee et al., 2024; Yang et al., 2013; Zhang et al., 2024).

Research demonstrates that PBL promotes self-directed learning, collaboration, and the application of real-world problem-solving techniques—skills that are integral to critical thinking skills (CrTS) and computational thinking (CT) in the 21st century (Hafizah et al., 2024). These skills enable learners to decompose complex problems and design algorithms effectively. Additionally, in a rapidly digitizing society, CT and CrTS are essential attributes for cultivating aptitude and expertise (Zhang et al., 2024). In nursing, these pedagogies, combined with virtual simulation, can also be an effective training technique (Lin et al., 2024).

Moreover, as this study has suggested, numerous studies highlight the success of PBL in middle and high school settings (Ertmer & Simons, 2006; Hmelo-Silver, 2004; Laili et al., 2024), including Ates and Aktamis (2024) who highlighted the additional factor of student-centered learning. This is consistent with Laili et al. (2024), who stated that CTS creation depends on PBL in combination with search, solve, create, and share (SSCS) models. Furthermore, Saad and Zainudin (2024) confirmed PBL's positive impact on secondary and elementary students' CT skills. They suggested that diverse inquiry approaches and scaffolding techniques are essential for effective learning outcomes.

5.3. Linking blended learning (BL) to problem-based learning (PBL)

One of the unique contributions of this study is its successful integration of BL and PBL to enhance student outcomes. While previous research has explored the benefits of each approach individually, this study demonstrated that the combined use of BL and PBL creates an optimal learning environment that supports both theoretical knowledge and practical application.

Martyaningrum et al. (2021) highlight that integrating PBL with e-learning environments enhances critical thinking abilities, particularly when students can access digital resources and revisit concepts at their own pace. In this study, the online component of the PBBL model allowed students to engage with instructional content independently, while the problem-based component facilitated collaborative learning and practical application. This combination of self-paced learning and teamwork fostered CT and AA, demonstrating the potential of blended problem-based approaches in modern education.

Furthermore, research from Ahdhianto et al. (2020) supports the idea that PBL, when integrated with BL, creates an enriched learning experience that promotes deeper cognitive engagement. This integration is crucial in developing CTS, which requires students to understand and apply theoretical concepts in real-world problem-solving situations.

5.4. Implications for educational practice

The study's findings offer significant implications for middle school education, with the demonstrated effectiveness of the PBBL Model underscoring the potential for integrating problem-based and blended learning approaches to enhance CTS and PBL (Jaswal & Behera, 2024; Kusumawardani & Aminatun, 2024). This is particularly relevant as the demand for computational and critical thinking skills grows in today's digital age (Stamatios, 2024).

Moreover, the collaborative nature of the PBBL model fosters interpersonal and communication skills critical for academic and professional success. By encouraging students to tackle complex, real-world problems together, this model aligns with global educational trends advocating for active and collaborative learning environments (Pimdee et al., 2024).

To further support the robustness of this study, additional methodological details have been provided, including the purposeful sampling strategy used to select participants, the integration of blended learning technologies, and the validation measures employed to assess CT skills. These clarifications ensure transparency and enhance readers' confidence in the study's findings and contributions.

5.4. Implications for educational practice

The findings from this study have important implications for educational practice, particularly in the context of middle school education. The demonstrated effectiveness of the PBBL model suggests that educators and curriculum designers should consider integrating both problem-based learning and blended learning approaches to foster critical thinking and problem-solving skills (Jaswal & Behera, 2024; Kusumawardani & Aminatun, 2024; Pimdee et al., 2024). As the demand for computational skills grows in today's digital age (Stamatios, 2024), educational frameworks that combine PBL with BL are well-positioned to prepare students for future challenges in technology-driven fields.

Additionally, this study reinforces the importance of collaboration in learning environments. By encouraging students to work together on complex tasks, the PBBL model enhances CTS and helps develop interpersonal and communication skills critical for academic and professional success.

6. Conclusion

This study set out to address two primary research questions:

1. How does the PBBL Model impact the development of Computational Thinking Skills (CTS) in middle school students?
2. What is the comparative effect of the PBBL Model on students' academic achievement compared to traditional learning methods?

The findings of this research provide clear answers to both questions.

First, implementing the PBBL Model had a significant positive impact on the development of CTS. Students in the experimental group, exposed to the PBBL Model, demonstrated a substantial improvement, achieving an average score of 91%, compared to 56% in the control group, which followed traditional instructional methods. These results align with current literature (eg Huang & Looi, 2021; Lee & Yang, 2023), supporting the argument that active, problem-based learning environments are more effective than traditional approaches in fostering essential computational skills.

Second, in terms of academic achievement, the study revealed that students in the experimental group achieved an average score of 89% post-intervention, significantly higher than the 60% average score of the control group. This confirms the PBBL Model's effectiveness in developing CTS and enhancing overall academic performance. The findings are consistent with research suggesting that blended learning models yield superior educational outcomes when combined with problem-based approaches (Ahn & Oh, 2024; Wanglang et al., 2024).

The statistically significant results at the 0.01 level validate the superiority of the PBBL Model over traditional methods. Developing the PBBL Model involved a rigorous process, including reviewing over 30 documents, expert consultations, and field trials, ensuring the model's high quality and applicability. Evaluations from experts gave the PBBL Model an average suitability score of 4.58 out of 5, further confirming its excellence. Additionally, group testing demonstrated its effectiveness with an E1/E2 ratio of 89.33/88.83 (Sinchai et al., 2023).

This research aligns with and reinforces existing studies that innovative learning models like the PBBL Model are highly effective in improving CTS and academic performance. It contributes to the ongoing discourse in education by providing empirical evidence supporting the integration of problem-based and blended learning models in middle school curricula.

In conclusion, this study establishes the PBBL Model as a superior educational framework for enhancing CTS and AA among middle school students. These findings have crucial implications for educators and policymakers, underscoring the need for the adoption of innovative learning strategies that prepare students for the demands of an evolving, technology-driven world.

In summary, the results demonstrate that the PBBL Model significantly enhances CTS and AA, with statistically significant observed improvements in the experimental group compared to the control group. finally, the study contributes valuable insights for educators and policymakers seeking to integrate problem-based learning into blended learning models, meeting the needs of students in today's rapidly changing technological landscape.

7. Limitations and recommendations

Despite the positive outcomes of this study, there are several limitations and areas for future research including small sample size which restricts the findings generalizability, so future research should involve larger and more diverse student populations across various educational settings to validate the PBBL Model's effectiveness better. Additionally, while this study focused on short-term outcomes, there is a need for longitudinal studies to assess the long-term impact of integrating Problem-Based Learning (PBL) and Blended Learning (BL) on Computational Thinking Skills (CTS) and academic performance. These studies help determine whether students retain and apply the skills and knowledge gained over time. Customizing the PBBL Model for different subjects or educational levels is another potential area for exploration, as modifying the model could better address the specific needs of diverse student groups, from younger learners to those in advanced academic tracks.

Moreover, as educational technology evolves, future research should examine how emerging technologies, such as AI-driven personalized learning platforms, could enhance the PBBL Model. Integrating these technologies could provide more tailored learning experiences within the BL component, complementing the problem-based approach. By exploring these areas, future studies can contribute to improving instructional models that prepare students for the challenges of the 21st century.

8. Declaration of generative AI and AI-assisted technologies in the writing process

In the preparation of this manuscript, the authors utilized Google Translate to assist in translating the work from Thai to English. Grammarly AI Premium was also used to review grammar and structure before submission and revisions. It is important to emphasize that AI detection tools consistently return false positive results when applied to translations and grammar checking, as demonstrated by the authors' Grammarly Premium analysis, which shows error rates at 24%. In addition to the use of AI tools for translation and language correction, all the content underwent a thorough review and editing by a native English speaker working in collaboration with the authors. Therefore, the authors assert full responsibility for the accuracy, originality, and quality of the final manuscript.

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Ethics statement

Before the study's commencement, a study author attended a National Research Council of Thailand (NRCT) sponsored Forum for Ethical Review Committees in Thailand (FERCIT) and obtained a '*Research Ethics Training Course*' certificate of completion on 27 May 2023. After that, the Research Ethics Committee at the authors' university certified that the study complied with the Helsinki Declaration's international guidelines for human research protection. Furthermore, all study participants were notified of the confidentiality of their information. The informed consent form version 1 was dated 27 July 2023.

Disclosure statement

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