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RESEARCH ARTICLE

Computer Education Student Teacher Complex Problem-Solving Skills Development using Computational Thinking and Visualization Tools

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ABSTRACT

This research explores the impact of a Collaborative Learning Management Model (CLMM) integrating Computational Thinking (CT) and Visualization Tools (VT) on the development of Complex Problem-Solving Skills (CPSS) in first-year computer education student teachers in Thailand. The study, conducted with 15 student-teachers from Dhonburi Rajabhat University, involved a six-module CPSS learning intervention. Notably, Unit 2's Alternative Flowchart Writing (AFW) and Unit 4's Sequential Python Writing (SPW) excelled, while Units 1 and 3 showed initial shortcomings. The overall evaluation, however, revealed that CLMM yielded a final mean of 90.40 and SD of 5.59, emphasizing its effectiveness in enhancing student-teacher CPSS. The research advocates for educators to prioritize advanced tools, including emerging Artificial Intelligence (AI) visualization tools, to further elevate CPSS education, preparing a new generation of educators for the challenges of educating digitally enabled knowledge workers.

INTRODUCTION

ICT Skill Development Challenges

In the 21st century, essential skills such as critical thinking, problem-solving, creativity, and computational thinking (CT) have become increasingly vital in adapting to global changes. Employers worldwide, including those surveyed by the World Economic Forum (2016), prioritize these skills, particularly complex problem-solving skills (CPSS), emotional intelligence, and teamwork, in university graduates.

The relationship between CT and problem-solving has been well-documented, with studies showing that improvements in CT correlate with enhanced programming self-efficacy (PSE) and overall problem-solving abilities (Durak et al., 2019; Ozturk, 2021; Günbatar, 2020). However, teaching and learning these critical skills remain challenging globally, as many students struggle to achieve high self-efficacy in programming and computational thinking (Cheah, 2020; Prommun et al., 2022).

Thailand serves as a case study illustrating broader global challenges in ICT skill development. Despite efforts under the Digital Economy and Society Development Plan (2017-2036), the country faces a significant shortage of qualified ICT professionals, leading to intense competition and rising salaries (WTW, 2023). This issue is compounded by a skills mismatch, where the current workforce's skills do not align with future job requirements, necessitating substantial investment in education, upskilling, and lifelong learning (International Labour Organization, 2019).

Furthermore, the reluctance of younger generations to pursue ICT-related studies, due to the perceived difficulty and inadequacies in mathematics and science education, exacerbates the problem. This gap highlights the need for integrated educational approaches to develop complex problem-solving skills essential for the evolving demands of the global job market (Wannapiroon & Pimdee, 2022).

Global Skill Development Challenges and the Thai Context

The 21st century demands a diverse set of skills, including critical thinking, complex problem-solving, emotional intelligence, creativity, and teamwork. These skills are crucial for adapting to global challenges, as outlined by the World Economic Forum (2016). Computational thinking (CT) has also emerged as an essential competency, fostering problem-solving and creative thinking needed in the digital era (Kong & Abelson, 2019; Zhao et al., 2022). Similarly, Thailand's 'Skills Framework Development for Basic Education' (Buasuwan et al., 2021) details how younger learners need to use the same skills to meet the demands of the 21st century and its global challenges. The Thai National Strategy (2018-2037) and the National Education Standards have outlined five core competencies. In these visions for Thailand's education of its youth, the plans highlight the need for communication capacity, problem-solving skills (PSS), life skills application, and application of ICT and digital technology (Rodrangsee & Tuntiwongwanich, 2021).

Studies have established strong connections between problem-solving skills (PSS) and CT. For instance, Durak et al. (2019) found positive relationships between CT, programming self-efficacy (PSE), and robotics programming, while other studies have shown that improvements in CT lead to enhanced PSE (Ozturk, 2021; Günbatar, 2020). However, despite their importance, teaching and learning these skills remain challenging worldwide, with students often struggling to achieve high self-efficacy in programming and CT (Cheah, 2020; Prommun et al., 2022).

In Thailand, these challenges are particularly pronounced. The country faces a significant shortage of qualified ICT professionals, exacerbated by a skills mismatch, where current competencies do not align with future job requirements (International Labour Organization, 2019). This has led to intense competition for talent, rising salaries, and difficulties in recruiting and retaining ICT workers (WTW, 2023). Furthermore, recent reports have detailed the complexity and cost of recruiting and retaining Thai ICT and AI (artificial intelligence) professionals. A WTW (2023) report also reported that Thailand's ICT worker attrition rate rose 11.4% in 2022. The report also indicated that 60% of the 620 Thai companies surveyed indicated digital talent as critical for their organization's successful digital transformation journey, a 20% jump in sentiment from an earlier study. These data points complement an earlier ILO study stating that Thai ICT workers only comprised 1% of Thailand's labor force (Economic Research Institute, 2022).

Furthermore, the younger generation in Thailand is often reluctant to pursue ICT-related studies due to the perceived difficulty of the field and weaknesses in foundational subjects like mathematics and science (Wannapiroon & Pimdee, 2022). This reluctance underscores the need for improved educational strategies that integrate complex problem-solving skills across disciplines to better prepare students for the demands of the global job market.

Therefore, this paper aims to study and enhance the complex problem-solving skills (CPSS) of student teachers enrolled in computer education courses. By utilizing a cooperative learning management model (CLMM) and computational thinking processes, the study seeks to develop skills that are crucial for both national and international contexts, ultimately contributing to the broader goal of fostering digital literacy and problem-solving capabilities.

LITERATURE REVIEW

Complex Problem-Solving Skills (CPSS) and Computational Thinking (CT)

Complex Problem-Solving Skills (CPSS) are vital for developing Computational Thinking (CT), particularly in the context of learning computer programming and coding. Employers view problem-solving skills (PSS) as essential prerequisites for employment across various industries (Durak et al., 2019). These skills are also crucial for success in computer programming, a discipline often associated with high dropout and failure rates due to its challenging nature (Cheah, 2020).

Kocak (2021) emphasizes that PSS are cultivated through a combination of creativity, cooperation, critical thinking, algorithmic thinking, digital literacy, teamwork, and communication. Collaboration and communication are highlighted by Hwang et al. (2018) as pivotal to problem-solving. Wang et al. (2023) further explore the impact of perspective-taking on effective problem-solving, underscoring the complex interplay of cognitive and non-cognitive factors in CPSS.

CT, which is closely linked to CPSS, is developed through programming and coding skills. These activities involve creating, modifying, and implementing computer code, exposing learners to computational concepts such as abstraction and decomposition, which enhance problem-solving abilities (Grover & Pea, 2013; Lye & Koh, 2014). However, the learning journey in programming is often hindered by a lack of PSS among students (Cheah, 2020).

To address these challenges, scholars advocate for computer-supported collaborative learning (CSCL) (Silva et al., 2020; Wu et al., 2019). CSCL leverages the social domain to facilitate group problem-solving, recognizing that collaborative efforts can be more effective than individual endeavors. Successful collaboration requires implementing processes like planning, self-control, information processing, problem analysis, and knowledge application (Hmelo-Silver, 2004; Sermsri et al., 2022).

Planning

Planning is crucial for setting goals and creating strategies to achieve them, encompassing both short-term and long-term perspectives (Steiner, 2010). These strategies include operational processes, activities, methods, alternative assessments, and considerations of time and cost. In creative thinking, planning is essential for refining new ideas and ensuring their successful implementation (Osburn & Mumford, 2006). Eichmann et al. (2019) emphasize the importance of early planning in CPSS, noting its significant benefits.

Self-Control

Self-control, synonymous with self-determination, involves managing thoughts, emotions, and feelings during challenging situations. It is a key dimension of self-directed learning (SDL), along with metacognition and motivation (Long, 2000). External factors, such as peer, teacher, family, and institutional support, also significantly impact a university student's SDL (Sukkamart et al., 2023).

Receiving Information

Receiving information is fundamental to communication within social contexts. Individuals with attentive senses, knowledge, and an understanding of their environment are better informed and updated. Yilmaz-Na and Sönmez (2023) suggest that computer-based mapping tools enhance student-teacher self-regulated PSS, with experimental evidence indicating a significant correlation between learning, self-regulation, and problem-solving skills.

Analytical Thinking (AT)

Analytical Thinking (AT) involves the use of reasoning to explore the details of a particular item or idea. It is a critical element of broader critical thinking (Phurikultong & Tuntiwongwanich, 2021). AT is used to classify, explain, and categorize data, establish connections between data points, and confirm or improve understanding, which leads to informed decision-making (Thaneerananon et al., 2016).

Knowledge Application

Knowledge application refers to the management and utilization of accumulated knowledge to make decisions and perform tasks (Greiff et al., 2012; Lotz, 2016; Mayer, 2011). This process includes selecting appropriate media types and content tailored to individual needs, leading to recipient satisfaction and informed decision-making. The value of knowledge application lies in efficiently disseminating created or recorded knowledge to the intended audience, ensuring the achievement of tangible outcomes (Hawkins, 2020).

MATERIALS AND METHODS

Information Collection Methods

Unit 1 - Sequential Flowchart Writing (SFW) - In the first four-hour session, 15 student teachers were administered a 42-item pre-learning achievement test (Pretest). Based on their scores, they were divided into mixed groups. Subsequently, training in Sequential Flowchart Writing (SFW) was conducted using Google Docs, Google Jamboard, Google Slides, and Flowgorithm, a beginner-level programming language based on simple graphical flowcharts (Ho et al., 2021). A group problem-solving skill assessment followed the training.

Unit 2 - Alternative Flowchart Writing (AFW) - The four-hour AFW group PSS session used Google Docs, Google Jamboard, Google Slides, and Flowgorithm.

Unit 3 - Iterative Flowchart Writing (IFW) -The four-hour IFW group PSS session utilized the same tools as in Units 1 and 2.

Unit 4 - Sequential Python Writing (SPW) - In Unit 4, a four-hour SPW group PSS session was conducted using Pycharm/Repl, a Python language tool (Islam, 2015). PyCharm, as described by Gayratovich (2019), is a modern environment for Python programming, offering various libraries and tools for creating visualizations and graphical representations.

Unit 5 - Alternative Python Writing (APW) - The four-hour APW group PSS session focused on creating alternative programs using Pycharm/Repl.

Unit 6 - Recursive Python Writing (RPW) - In Unit 6, the RPW group PSS session involved creating recursive programs using Pycharm/Repl. A post-test course learning assessment was administered at the end of the session.

DATA ANALYSIS

After completing the course, the validity and completeness of the post-test results were manually checked. SPSS for Windows was used to analyze the data, with descriptive statistics (mean and standard deviation) presented in table format. The one-sample t-test was then conducted to evaluate the differences in student-teacher CPSS after the six-session course, comparing the mean scores to the evaluation criteria.

Results from the CPSS development sessions indicated that Unit 2's AFW was performed at an excellent level (mean = 88.20, SD = 9.83). Unit 4's SPW was also rated very good (mean = 87.40, SD = 4.56). However, Units 1 and 3 fell short of the 75% achievement criteria. The overall evaluation for all six modules showed a mean of 90.40 (SD = 5.59), validating the effectiveness of the CLMM in developing student-teacher CPSS.

RESEARCH RESULTS

The evaluation criteria used 80.00 - 100.00 to indicate an outcome at an 'Excellent level.' 75.00 - 79.99 indicated an outcome at a 'good level,' with 70.00 – 74.99 indicating an outcome at an 'acceptable level.' Additionally, a score between 65.00 - 69.99 indicated an outcome at an 'almost acceptable' level, while an outcome range between 60.00 - 64.99 indicated an outcome at a 'fair level'. 55.00 – 59.99 indicated an outcome at an 'almost fair level.'50.00 – 54.99 indicated an outcome at a 'poor level.'0.00 – 49.99 indicated an outcome at a 'failed level.'

Table 1. Results of comparing the mean assessment scores measuring student teacher CPSS after each lesson (test score value compared to 75%)

Unit	**Unit name**	**mean**	**SD**	**criteria**	**t**	**p**	**Results**
1	Sequential Flowchart Writing (SFW)	70.60	11.57	75	.12	.91	Acceptable
2	Alternative Flowchart Writing (AFW)	88.20	9.83		4.14	.01*	Excellent
3	Iterative Flowchart Writing (IFW)	74.40	5.32		1.85	.14	Acceptable
4	Sequential Python Writing (SPW)	87.40	4.56		8.53	.00*	Excellent
5	Alternative Python Writing (APW)	86.80	3.77		9.97	.00*	Excellent
6	Recursive Python Writing (RPW)	85.20	3.96		8.58	.00*	Excellent
	After course results	90.40	5.59		8.15	.00*	Excellent

Note. *Statistically significant at .05

DISCUSSION

The analysis of student-teacher Complex Problem-Solving Skills (CPSS) development sessions revealed noteworthy outcomes. Modules 2, 4, 5, and 6 exhibited significantly higher average scores at the 0.05 level, indicating their effectiveness. Conversely, Unit 1's Sequential Flowchart Writing (SFW) and Unit 3's Iterative Flowchart Writing (IFW) did not reach statistical significance at the 0.05 level, scoring below the 75% benchmark. However, the overall post-course assessment yielded a statistically significant result at the 0.05 level, with a mean of 90.40 and SD of 5.59, denoting an 'excellent' outcome in student teachers' CPSS development.

These findings align with Lye and Koh's (2014) recommendations for emphasizing Computational Thinking (CT) practices and perspectives in classrooms. They highlight the effectiveness of techniques such as 'thinking out loud,' capturing and reviewing student screen activities, and utilizing scaffolding, information processing, and reflection activities.

Further support comes from Liu et al. (2018), who demonstrated the positive impact of mind mapping in teaching computer programming, fostering logical and innovative thinking. This aligns with the collaborative and blended learning approach explored by Lye and Koh (2014), integrating CT and mind mapping within the curriculum to enhance CPSS among computer education student teachers.

Concept maps, crafted by students after completing each unit, served as a compilation of -specific knowledge. This approach, consistent with Zhao et al. (2022), enhances problem-solving comprehension through group articulation and tackling individual problem segments using concept diagrams. Sriwisathiyakun (2023) emphasizes the importance of practical frameworks, covering access, evaluation, analysis, creation, and reflection, in teaching digital literacy skills.

The collaborative efforts in summarizing the problem-solving process, and drawing connections between components, resonate with Esteve-Mon et al.'s (2019) use of robotics to develop CT skills. Digital literacy, as discussed by Hall et al. (2014) and endorsed by the European Commission, extends beyond basic literacy, encompassing skills, attitudes, and knowledge essential for authentic learning in a technology-rich context.

The incorporation of Google tools in learning management, as noted in this study, is consistent with Stetter and Hughes's (2017) demonstration of the positive impact of combining competitive techniques with WebQuests on academic achievement and English reading skills. The collaborative nature of these activities fosters interest, mutual assistance, comprehension, and engagement among learners.

The discussion intertwines with theories from Newell and Simon (1972), particularly the General Problem Solver (GPS) theory, which advocates breaking down problems into sub-goals for systematic addressing. This approach aligns with Thailand's Digital Economy and Society Development Plan objectives, emphasizing the importance of motivating students to enter the information technology labor market in alignment with national needs. The study's implications are significant for higher education institutions seeking to instill critical digital literacy and CT skills in student teachers during their training periods.

CONCLUSION

The findings of this study underscore the significant impact of cooperative learning processes, combining computational thinking and concept diagrams, on the development of Complex Problem-Solving Skills (CPSS). This holds particular relevance for students aspiring to careers in computer teaching or any profession demanding advanced computer expertise. In such fields, where individuals frequently navigate unpredictable scenarios influenced by external factors, the cultivation of robust complex problem-solving skills is paramount.

The research outlined in this study places a strong emphasis on blended learning strategies, emphasizing group collaboration, cooperative study, knowledge acquisition, and practical application. The incorporation of conceptual diagrams, imagery, and symbolic representations proves instrumental in enhancing learners' ability to connect with and comprehend intricate concepts through diverse and unique techniques. The integration of computational thinking, which intricately links data, processes, behaviors, and designs, aids in breaking down information and problem-solving. This facilitates the identification of patterns in recurring problems or situations, enabling the concise summarization of problem-solving steps and the meticulous verification of solution accuracy.

Conclusively, the learning model proposed in this research emerges as highly beneficial, leaving a profound impact on the development of complex skills. It empowers individuals to plan work effectively, exercise self-control, and manage emotions when confronted with challenges and obstacles. Furthermore, the model enhances information perception, promotes meticulous analysis, and facilitates the application of knowledge gained through accumulated experience. As we navigate the demands of a rapidly evolving digital landscape, this research offers a robust foundation for educators and institutions to cultivate the essential skills required for success in computer-related professions, contributing significantly to the broader landscape of 21st-century education.

Declarations

Authors' individual contribution. Conceptualization — R.N. and S.S.; Methodology — R.N. and S.B.; Software — R.N. and S.S; Validation — R.N and W.S; Formal Analysis — R.N and W.S; Investigation — R.N and W.S; Resources — R.N and R.S; Data Curation — R.N. and R.S. ; Writing — Original Draft — R.N. and R.S; Writing — Review & Editing — R.N. and R.S; Visualization — R.N. and S.S.; Supervision — R.N. and S.B; Project Administration — R.N and W.S; Funding acquisition— R.N. and R.S. All authors have read and agreed to the published version of the manuscript.

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