

# Development of an Enhancement Program to Promote AI-TPACK Competency for Computer Science Student Teachers

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## Abstract

Artificial intelligence (AI) has become an essential component of computer science education, requiring teachers to integrate technological, pedagogical, and content knowledge effectively. This study aimed (1) to develop an enhancement program to promote AI-TPACK competency among computer science student teachers and (2) to examine the effectiveness of the program through an action research approach. The study adopted a mixed-methods action research design conducted over three iterative cycles. The participants were 35 second-year computer science student teachers enrolled at Guangxi College for Preschool Education during the 2025 academic year. Research instruments included an AI-TPACK enhancement program, a rubric-based AI-TPACK competency assessment, and structured classroom observation forms. Quantitative data were analyzed using descriptive statistics, while qualitative data were analyzed through thematic analysis. The results revealed a progressive improvement in students' AI-TPACK competency across the three cycles, with overall performance increasing from a needs-improvement level in the first cycle to a good level in the final cycle. Notable gains were observed in both foundational and integrative AI-TPACK components, as well as in educational readiness for AI. The findings demonstrate that a structured, practice-oriented enhancement program implemented through action research can effectively develop AI-TPACK competency among preservice computer science teachers. This study contributes practical evidence for integrating AI-TPACK development into teacher education through iterative, reflective instructional design.

**Keywords:** AI, TPACK, teacher education, computer science teachers

## 1. Introduction

Rapid advances in digital technology and artificial intelligence (AI) have fundamentally transformed educational contexts, particularly in computer science education (Gleisner Villasmil, 2024; Sanusi et al., 2024; Wang et al., 2024). Computer science teachers are no longer expected merely to possess technical knowledge of programming or hardware systems; rather, they are required to integrate technological tools meaningfully into pedagogy and curriculum to support effective learning outcomes (Kalniņa et al., 2024; Slimi, 2023). In this context, the Technological Pedagogical Content Knowledge (TPACK) framework has emerged as a critical model for understanding the complex knowledge base required of contemporary teachers.

TPACK emphasizes the dynamic interaction among content knowledge, pedagogical knowledge, and technological knowledge, highlighting that effective teaching occurs when these domains are coherently integrated rather than treated as isolated competencies (Chai et al., 2013; M. J. Koehler et al., 2014; M. Koehler & Mishra, 2009). For computer science teachers, this integration is especially vital. Unlike many subject areas, computer science evolves rapidly, with frequent changes in software, programming environments, digital platforms, and emerging technologies such as AI, data analytics, and automation (Doukakis & Papalaskari, 2019). Consequently, computer science teachers must continuously adapt instructional strategies and technological tools to ensure that learning remains relevant, authentic, and aligned with real-world practices.

In the current era, the role of computer science teachers has expanded beyond delivering technical content to facilitating problem-solving, computational thinking, creativity, and digital literacy (Wong & Daud, 2018). TPACK competency enables computer science teachers to design learning experiences that connect abstract concepts to

practical applications, employ appropriate digital tools to scaffold learning, and respond flexibly to diverse learner needs (Keser et al., 2015). Teachers with strong TPACK are better positioned to select, evaluate, and adapt technologies in ways that enhance student engagement and understanding rather than simply adding technology for its own sake (Agustini et al., 2019; Sonsupap et al., 2024).

Moreover, the increasing integration of AI into educational environments has further elevated the importance of TPACK for computer science teachers. AI-based tools such as intelligent tutoring systems, automated assessment, learning analytics, and generative AI applications present new instructional opportunities as well as pedagogical challenges (Liu et al., 2024). Without adequate TPACK competency, teachers may struggle to align these technologies with instructional goals, ethical considerations, and learners' cognitive development. For computer science teachers in particular, who are often expected to model advanced technology use, insufficient TPACK may lead to superficial or ineffective integration of AI in teaching practice (Tan et al., 2025).

Therefore, teacher education programs face growing pressure to prepare computer science student teachers whose future careers are expected to possess both technical proficiency and the pedagogical capacity. Developing TPACK competency among preservice computer science teachers is essential to ensuring instructional quality, supporting educational innovation, and responding to the demands of digital transformation in education systems. However, despite widespread recognition of the importance of TPACK, empirical research examining structured programs designed to systematically enhance TPACK—especially AI-TPACK—among computer science student teachers remains limited, particularly within vocational and college-level teacher preparation contexts.

Recent studies consistently indicate that enhancing AI-TPACK competency cannot be achieved through general technology training alone but requires targeted, structured, and ethically grounded interventions. Celik (2023) demonstrated that teachers' effective use of AI depends on the integration of technological knowledge with pedagogical and ethical knowledge, proposing the Intelligent-TPACK framework to emphasize that technological knowledge in isolation is insufficient for meaningful AI integration. Extending this line of inquiry, Eyal (2025) highlighted the need for authentic, artifact-based assessment approaches, revealing that synergy between AI pedagogical knowledge and integration practices is a critical determinant of professional competence. Empirical evidence further suggests that current levels of AI-TPACK among teachers remain inadequate; Hava and Babayigit (2025) reported that despite high digital proficiency, teachers' AI-TPACK competencies were below average, indicating that general digital skills do not automatically translate into pedagogically sound AI use. Psychological readiness also plays a significant role, as Ismaniati et al. (2025) found that self-efficacy mediates the relationship between TPACK and teachers' intentions to adopt AI, underscoring the need for programs that simultaneously develop knowledge, confidence, and instructional readiness. Conceptual frameworks such as the AI-TPACK model proposed by Meng et al. (2025) further stress the importance of staged professional development integrating foundational AI concepts, AI-specific pedagogy, and ethical considerations. Moreover, intervention-based evidence from Tan et al. (2025) confirms that professional development grounded in Intelligent-TPACK can significantly enhance teachers' AI-related competencies, particularly when supported by sustained engagement and structured learning processes. Collectively, these studies suggest that the development of AI-TPACK competency requires specialized enhancement programs that integrate pedagogy, technology, ethics, and reflective practice within coherent instructional designs, particularly for teachers expected to lead AI-supported learning environments.

Despite growing scholarly attention to AI-TPACK and Intelligent-TPACK frameworks, several critical gaps remain. Existing studies have primarily focused on conceptual model development, scale construction, correlational relationships, or professional development interventions targeting in-service or higher-education teachers, with limited attention to preservice computer science teachers in vocational and college-level teacher education contexts. Moreover, much of the prior research has relied on cross-sectional survey designs or short-term interventions, offering insufficient insight into how AI-TPACK competency can be systematically developed, implemented, and refined through iterative instructional cycles. Empirical evidence examining the design process of enhancement programs grounded in authentic teaching practice, as well as their impact on both pedagogical performance and AI-integrated teaching behaviors, remains scarce. To address these gaps, the present study aims (1) to develop an Enhancement Program to Promote AI-TPACK Competency for Computer Science Student Teachers in Colleges through a structured and iterative action research approach, and (2) to investigate the application and effectiveness of the program in enhancing student teachers' AI-TPACK competency and teaching skills.

## 2. Methodology

### 2.1 Research Design

This study adopted a mixed-methods action research design (Kemmis et al., 2014) conducted through three iterative cycles to examine the effectiveness of an enhancement program aimed at promoting AI-TPACK competency among computer science student teachers. Action research was selected to allow for systematic improvement of instructional practice through cycles of planning, implementation, observation, and reflection within an authentic teacher education context. Quantitative data were used to examine changes in AI-TPACK competency and teaching performance, while qualitative data provided insights into participants' learning processes and instructional experiences.

### 2.2 Participants

The participants in this study were 35 second-year computer science student teachers enrolled in the Computer Science program at Guangxi College for Preschool Education during the 2025 academic year. The participants were selected through purposive sampling, as they were enrolled in a core course related to educational technology and teaching practice and were therefore directly relevant to the objectives of the study. All participants took part in the three-cycle action research process and received the enhancement program as part of their regular coursework. The participants had previously completed introductory coursework in computer science and basic educational technology, but had not yet received systematic training in integrating artificial intelligence into pedagogical practice.

### 2.3 Instruments

#### 2.3.1 The Program to Promote AI-TPACK Competency for Computer Science Student Teachers

The program to promote AI-TPACK competency was developed through an iterative process informed by context and needs analysis, multi-source data analysis, and expert consultation. Quantitative data from baseline AI-TPACK questionnaires were analyzed using descriptive statistics to identify competency gaps, while qualitative data from semi-structured interviews, document review, and classroom observations were thematically analyzed to capture instructional needs, contextual constraints, and expectations for AI-integrated teaching. These findings informed the design of a structured program comprising eight core components: curriculum development principles, curriculum objectives, course content structure, instructional methods, development procedures, action implementation processes, effectiveness analysis, and expert synthesis. The instructional content emphasized the integration of AI tools with pedagogical strategies and subject knowledge, focusing on lesson planning, instructional decision-making, assessment, and ethical AI use. Learning activities were organized into five instructional stages—contextual activation, goal-driven learning, collaborative practice, sharing and communication, and reflection and improvement—enabling student teachers to apply AI tools in authentic teaching tasks such as lesson design and micro-teaching.

Following the trial implementation, the program was evaluated to determine its quality and readiness for use through expert review and post-implementation qualitative evidence. Experts in educational technology, curriculum and instruction, and teacher education reported a high level of appropriateness regarding program structure, content alignment, learning activities, and practical feasibility. Consistent with expert judgments, post-course interviews with vocational college instructors, primary school mentor teachers, and preservice teachers indicated positive perceptions of technology–pedagogy–content coherence, task authenticity, and relevance to real teaching contexts. Stakeholders also reported observable improvements in lesson design, AI-supported instructional decision-making, and professional confidence, while noting that remaining issues were related to refinement rather than fundamental design limitations. Overall, convergent evidence from expert evaluation and multi-case qualitative feedback confirms that the program demonstrates strong instructional quality, contextual suitability, and practical feasibility, indicating that it is ready for implementation and further application in computer science teacher education contexts.

#### 2.3.2 AI-TPACK Competency Assessment

An AI-TPACK competency assessment was conducted using a rubric-based performance evaluation covering nine dimensions: AI technological knowledge, content knowledge, pedagogical knowledge, pedagogical content knowledge, AI technological content knowledge, AI technological pedagogical knowledge, AI-TPACK design, AI-TPACK implementation, and educational readiness for AI. Each dimension was rated on a five-point scale, yielding a total possible score of 45 points. A score of 27 points (60%) was established as the minimum passing criterion, indicating acceptable competency, while scores below this threshold were interpreted as reflecting a need for further development. This assessment approach enabled systematic evaluation of students' AI-TPACK competency based on observable teaching performance and instructional decision-making in authentic learning

contexts.

### 2.3.3 Classroom Observation

Classroom observation was conducted as a complementary source of process-level evidence to document how students enacted AI-TPACK competencies in authentic teaching situations. Structured observation forms were used to evaluate students' performance during classroom teaching activities and extracurricular teaching-skill competitions. Observations focused on instructional design and organization, application of AI tools, instructional interaction, and student engagement. Classroom observations were carried out during the implementation stage, with two trained observers independently rating multiple teaching sessions, while competition observations documented students' participation and achievements in activities such as pre-service teacher contests and ICT-integrated lesson design competitions. Observation results provided direct evidence of AI-TPACK transfer to practice, while competition outcomes served as external validation of professional competency development. Inter-rater reliability analysis indicated a high level of agreement between observers (Cohen's Kappa = 0.84).

### 2.4 Data Collection

Data were collected across the three cycles of action research using multiple sources to capture both learning outcomes and instructional processes. Quantitative data were obtained from the AI-TPACK competency assessment, including rubric-based teaching performance scores and baseline academic records. Qualitative data were gathered through classroom observations, expert reviews, and post-implementation interviews with vocational college instructors, primary school mentor teachers, and preservice teachers. Data collection was conducted before, during, and after the implementation of the enhancement program to support iterative reflection, refinement, and evaluation of program effectiveness.

### 2.5 Data Analysis

Quantitative data were analyzed using descriptive statistics, including means, standard deviations, and percentage scores, to examine students' AI-TPACK competency levels and determine whether performance met the established passing criterion. Rubric scores were interpreted based on a total score of 45 points, with 27 points (60%) defined as the minimum acceptable level of competency. Qualitative data from classroom observations and interviews were analyzed using thematic analysis to identify patterns related to instructional practices, AI integration, and educational readiness. Findings from quantitative and qualitative analyses were triangulated to provide a comprehensive interpretation of program outcomes and to support evidence-based conclusions regarding the effectiveness and readiness of the program.

## 3. Results

### 3.1 Results of the First Action Research Cycle

Table 1 presents the average scores of each AI-TPACK component obtained from the first cycle of implementation. Overall performance was at the Needs Improvement level, with a mean total score of 22.86 out of 45 (50.79%), which did not meet the established passing criterion (60%).

**Table 1.** Average AI-TPACK Competency Scores in Cycle 1 (N = 35)

Component	Mean	%	Level
AI-TK	2.97	59.43	Needs Improvement
CK	2.97	59.43	Needs Improvement
PK	2.91	58.29	Needs Improvement
PCK	2.80	56.00	Needs Improvement
AI-TCK	2.63	52.57	Needs Improvement
AI-TPK	2.46	49.14	Needs Improvement
AI-TPACK-D	2.14	42.86	Needs Improvement
AI-TPACK-I	2.00	40.00	Needs Improvement
ERA	1.97	39.43	Needs Improvement
Total	22.86	50.79	Needs Improvement

*AI-TK = Artificial Intelligence Technological Knowledge; CK = Content Knowledge; PK = Pedagogical*

*Knowledge; PCK = Pedagogical Content Knowledge; AI-TCK = Artificial Intelligence Technological Content Knowledge; AI-TPK = Artificial Intelligence Technological Pedagogical Knowledge; AI-TPACK-D = Artificial Intelligence Technological Pedagogical Content Knowledge (Design Dimension); AI-TPACK-I = Artificial Intelligence Technological Pedagogical Content Knowledge (Implementation Dimension); ERA = Educational Readiness for Artificial Intelligence.*

The results indicate that students demonstrated relatively stronger performance in foundational knowledge components (AI-TK, CK, and PK), while integrative and application-oriented components (AI-TPACK-D, AI-TPACK-I, and ERA) were notably weaker. Of the 35 students, 34 (97%) were rated as Needs Improvement, and one student (3%) was rated Below Standard, indicating that most participants had not yet achieved functional AI-TPACK competency at the initial stage. This initial performance reflects students' limited prior experience in integrating AI tools with pedagogical and content knowledge, indicating that participants were still developing foundational AI-TPACK competencies.

### 3.2 Results of the Second Action Research Cycle

After instructional refinement and continued implementation, students' AI-TPACK competency showed moderate improvement in the second cycle. As shown in Table 2, the mean total score increased to 26.09 points (57.97%), approaching but still slightly below the passing threshold.

**Table 2.** Average AI-TPACK Competency Scores in Cycle 2 (N = 35)

Component	Mean	%	Level
AI-TK	3.34	66.86	Pass
CK	3.00	60.00	Pass
PK	2.97	59.43	Needs Improvement
PCK	2.97	59.43	Needs Improvement
AI-TCK	2.97	59.43	Needs Improvement
AI-TPK	2.86	57.14	Needs Improvement
AI-TPACK-D	2.80	56.00	Needs Improvement
AI-TPACK-I	2.71	54.29	Needs Improvement
ERA	2.46	49.14	Needs Improvement
Total	26.09	57.97	Needs Improvement

At the individual level, 13 students (37%) achieved the Pass level, while 22 students (63%) remained at the Needs Improvement level. No students were rated as Below Standard. The findings suggest that improvements were most evident in AI-TK and CK, whereas integrative competencies and educational readiness for AI continued to develop more gradually. The observed improvement may be attributed to students' increasing familiarity with AI tools and their opportunities to practice lesson design and micro-teaching activities during the second cycle of implementation.

### 3.3 Results of the Third Action Research Cycle

Substantial improvement was observed in the third cycle following continued practice, feedback, and refinement. Table 3 shows that the mean total score increased markedly to 38.91 points (86.48%), corresponding to a Good overall level.

In this cycle, 18 students (51%) reached the Excellent level, 16 students (46%) reached Good, and one student (3%) reached Pass. No students remained at the Needs Improvement or Below Standard levels. Improvements were evident across all components, including integrative AI-TPACK dimensions and educational readiness for AI, indicating successful development of both foundational and applied competencies through the action research process. The substantial improvement observed in the third cycle suggests that repeated practice, feedback from instructors and peers, and iterative refinement of lesson designs supported the development of integrative AI-TPACK competencies.

**Table 3.** Average AI-TPACK Competency Scores in Cycle 3 (N = 35)

Component	Mean	%	Level
AI-TK	4.80	96.00	Excellent
CK	4.74	94.86	Excellent
PK	4.63	92.57	Excellent
PCK	4.49	89.71	Good
AI-TCK	4.31	86.29	Good
AI-TPK	4.11	82.29	Good
AI-TPACK-D	4.00	80.00	Good
AI-TPACK-I	3.97	79.43	Pass
ERA	3.86	77.14	Pass
Total	38.91	86.48	Good

#### 4. Discussion

The findings of this action research indicate that the enhancement program effectively improved computer science student teachers' AI-TPACK competency through iterative cycles of practice, reflection, and refinement. The progressive improvement observed across the three cycles—particularly the delayed but substantial gains in integrative dimensions such as AI-TPACK design, AI-TPACK implementation, and educational readiness for AI—suggests that AI-related teaching competency develops gradually and requires sustained instructional support rather than short-term exposure. This pattern aligns with Celik's (2023) Intelligent-TPACK framework, which emphasizes that technological knowledge alone is insufficient and must be meaningfully integrated with pedagogy, content, and contextual judgment to support effective AI use in education.

The results are also consistent with Eyal (2025), who highlighted the importance of authentic, practice-based evidence for evaluating AI-TPACK competency. In the present study, rubric-based performance assessment and classroom observation captured how student teachers enacted AI-TPACK in real teaching tasks, revealing improvements that would not have been adequately reflected through self-report measures alone. Similarly, Hava and Babayigit (2025) reported that teachers' digital proficiency does not automatically translate into high AI-TPACK competency. This finding helps explain why foundational knowledge components improved earlier in the action research cycles, while higher-order integrative competencies required repeated application and feedback before reaching acceptable levels.

In addition, the observed improvement in educational readiness for AI supports the findings of Ismaniati et al. (2025), who identified self-efficacy and readiness as key factors influencing teachers' willingness to adopt AI in instructional practice. As student teachers gained experience designing and implementing AI-supported lessons, their confidence and preparedness increased, facilitating the transition from tool experimentation to more purposeful and context-sensitive integration. This progression echoes the staged development emphasized in the AI-TPACK model proposed by Meng et al. (2025), which underscores the need for structured professional development pathways that move beyond conceptual understanding toward applied competence.

Finally, the effectiveness of the enhancement program is in line with intervention-based evidence reported by Tan et al. (2025), who demonstrated that professional development grounded in Intelligent-TPACK can significantly enhance teachers' AI-related competencies when supported by sustained engagement. The present study extends this line of research by showing that a cyclical action research approach can serve as a practical and scalable mechanism for fostering AI-TPACK competency among preservice teachers. Taken together, the findings reinforce the view that developing AI-TPACK requires intentional instructional design, authentic practice opportunities, and iterative reflection, particularly in computer science teacher education contexts.

#### 5. Conclusion

This study implemented a mixed-methods action research approach to develop and apply an enhancement program aimed at promoting AI-TPACK competency among computer science student teachers through three iterative cycles. The program was designed to support the systematic integration of artificial intelligence with pedagogical and content knowledge in authentic teacher education contexts. The results demonstrated a substantial improvement in

students' AI-TPACK competency across all assessed components, with overall performance progressing from a needs-improvement level in the initial cycle to a good level by the final cycle. The contribution of this study lies in demonstrating how an action research-based enhancement program can effectively foster both foundational and integrative AI-TPACK competencies among preservice computer science teachers.

In terms of implications, the findings suggest that AI-TPACK development should be embedded within iterative, practice-oriented learning experiences that emphasize design, implementation, and reflection rather than isolated technology training. However, this study was limited by its single-group action research design, small sample size, and focus on a single institutional context, which may restrict the generalizability of the findings. Future research should therefore examine the effectiveness of similar enhancement programs using experimental or quasi-experimental designs, involve larger and more diverse samples, and explore the long-term sustainability of AI-TPACK competency development across different educational contexts.

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