International Journal on Advanced Science Engineering Information Technology

Vol.14 (2024) No. 1
ISSN: 2088-5334

Development of a TPACK Educational Program to Enhance Pre-service Teachers' Teaching Expertise in Artificial Intelligence Convergence Education

Seong-Won Kim [a]

[a] *Chosun University, Dong-Gu, Gwangju, 61452, Republic of Korea*
*Corresponding author: *swkim8@chosun.ac.kr*

***Abstract*—This research focuses on developing an Artificial Intelligence (AI)-based educational program within the Technological Pedagogical Content Knowledge (TPACK) framework to enhance the competency of pre-service teachers in AI convergence education. To assess the effectiveness of this program, South Korean pre-service teachers participated in a study where they engaged in AI convergence TPACK education. Freshman students were divided into two groups: one received traditional AI education, while the other took part in the AI convergence TPACK educational program. An evaluative tool was used to measure the AI-convergence teaching skills of these pre-service teachers. The results of the study revealed that the AI convergence TPACK educational program significantly contributed to developing AI convergence teaching capabilities among the participants. Furthermore, a comparative analysis demonstrated a substantial advantage in the AI convergence education skills of teachers who participated in the TPACK program compared to those who received AI education alone. Notably, the most significant improvements were observed in Pedagogical Content Knowledge (PCK) and TPACK, which were identified as critical components of AI convergence teaching expertise. This research underscores the importance of a tailored and comprehensive approach to training pre-service teachers in the ever-evolving landscape of AI in education. It highlights the effectiveness of the AI convergence TPACK educational program in enhancing pre-service teachers' AI convergence teaching skills and emphasizes the pivotal role of PCK and TPACK in preparing educators for AI-integrated educational environments.**

***Keywords*—TPACK; artificial intelligence; teaching expertise; pre-service teachers; convergence education.**

Manuscript received 15 Dec. 2022; revised 18 Apr. 2023; accepted 27 Sep. 2023. Date of publication 29 Feb. 2024.

I. INTRODUCTION

In transmitting knowledge through traditional teaching methods involving textbooks and blackboards, pre-service teachers and educators often encounter limitations when explaining concepts beyond learners' direct experiences or phenomena that operate in three dimensions [1]–[3]. To address this issue, learners are often encouraged to engage in activities or use models and drawings to illustrate such phenomena. However, these methods frequently impose a cognitive burden on learners, particularly those who struggle with comprehension [4]–[7].

Researchers have introduced various technologies to the educational field in response to these challenges. Information and communication technology (ICT), in particular, has emerged as a promising tool for presenting complex concepts in a more accessible manner. For instance, the development of a Flash-based program to simulate the retrograde motion of the moon allows learners to visualize and comprehend the underlying principles of this phenomenon [5]. Such initiatives have demonstrated the potential of integrating technology in the classroom to enhance learner understanding and improve overall classroom efficiency [8], [9]. Researchers have thus conducted numerous studies to explore effective strategies for leveraging technology in educational settings to optimize teaching and learning processes. These investigations generally aim to identify methodologies that will maximize the benefits of technology integration, ultimately leading to more efficient and effective classroom practices [1], [2], [10].

Several studies have been conducted to integrate technological knowledge (TK) into PCK, which traditionally encompasses a teacher's expertise. In 2006, Koehler and Mishra proposed a novel framework called TPACK, which combines PCK with TK. Just as the existing PCK develops through the interaction of pedagogical knowledge (PK) and content knowledge (CK), TPACK involves the interaction of PK, CK, and TK to enhance the development of PCK, technological pedagogical knowledge (TPK), and technological content knowledge (TCK). The interaction of PCK, TPK, and TCK contributes to the cultivation of TPACK [11],[12]. The development of TPACK signifies the capacity of pre-service teachers and educators to effectively use technology while considering the content and various teaching/learning processes [13]. In 2019, Mishra proposed an extended TPACK framework that incorporates context knowledge (XK) as an additional element, recognizing the necessity of fostering knowledge of the educational context due to changes in classroom environments. With the rapid advancement of technology, researchers have focused on enhancing TPACK among pre-service teachers and educators across various subject areas [13]–[16].

Even when they have undergone TPACK education, both pre-service teachers and experienced educators have faced challenges in effectively integrating technology into their classrooms. While the aim of TPACK education is to provide the necessary knowledge and skills to use technology in alignment with the learning content and with teaching/learning contexts, pre-service teachers and educators have expressed difficulties in effectively leveraging technology within the classroom setting [4], [6], [7].

The challenges associated with incorporating technology into the classroom stem from the inherent nature of technology, which, in general, is primarily developed for industrial applications rather than educational purposes, leading to suboptimal usage for educational contexts. Comprehending the technology itself, identifying suitable applications, and designing both the technology and lessons accordingly are all imperative in order to effectively integrate technology into the classroom [11], [12].

For example, 3D printers can rapidly translate models into physical objects. Despite their non-educational origins, 3D printers can serve a number of educational purposes by swiftly generating various items, provided appropriate designs are available. The advantages of 3D printers can be harnessed for numerous educational settings, such as fabricating molecular structures to elucidate chemical bonding or constructing DNA models in biology. As one example, researchers conducted a study in South Korea in which 3D printers were introduced into schools. However, integrating 3D printers in the classroom did not yield the expected level of success. This failure could have been attributable to the functional limitations of 3D printers, which can hinder their practical usage even when teachers have been trained in their use. Although 3D printers can quickly produce items based on designs, few people can effectively leverage their functionalities. Therefore, even if pre-service teachers and educators do grasp how to use 3D printers, they often have to explore where within the curriculum they can use such technology, design lessons accordingly, and effectively incorporate the 3D printers. A particular challenge is to adapt technology that was not originally intended for educational purposes to the classroom environment, further complicating the understanding of principles and mastery of its usage by pre-service teachers and educators [4], [7]–[9].

As a result of these functional limitations, technology is frequently used in a manner akin to traditional instructional tools for knowledge transmission rather than being tailored specifically to classroom environments [7]. For instance, textbooks and blackboards are used in conventional classrooms when elucidating the concept of photosynthesis in a biology course. In contemporary settings, pre-service teachers and educators might use smart boards, tablets, and similar technologies to deliver lessons, yet ultimately, the technology merely serves as a means to explain the principle of photosynthesis.

Kim and Lee [17] conducted a study with the aim of integrating a programming language as a technical tool within TPACK to address the functional limitations of existing technologies. Unlike conventional technologies, programming languages enable developers to create programs once they possess an understanding of the programming development environment. While text-based programming languages have posed challenges for learners in the past, the advent of Scratch, a block-based programming language, has mitigated these difficulties within the learning process [18]. Both pre-service teachers and educators who are new to programming languages can easily grasp the programming development environment, allowing them to create their desired programs swiftly and effortlessly. In contrast, conventional technologies are confined to specific functions, which impedes their usage within the classroom. Programming languages surpass these limitations by empowering pre-service teachers and educators to generate custom programs tailored to their instructional needs. Researchers have consequently devised an educational model and program to incorporate programming languages as technological tools within the TPACK framework [17]–[19]. In line with this work, education programs have been implemented in South Korea to enhance the competencies of pre-service teachers and educators in using programming languages, along with the development and implementation of new curricula.

In the realm of computing, advancements in deep learning and machine learning algorithms are expanding the capabilities of artificial intelligence (AI). As a technology, AI can analyze vast amounts of data, make inferences, and learn behaviors. Various applications have emerged with the development of AI technology, including natural language processing, image recognition, and prediction and recommendation systems, which has led to increased usage of AI across diverse fields. In the field of education, AI is being employed in learning analytics and counseling systems through generative AI, which has enabled the analysis of large student datasets that previously posed various challenges [20]–[23].

South Korea has implemented various policies and initiatives to enhance the competence of pre-service teachers and educators in effectively integrating AI for efficient instruction. For instance, the Graduate School of AI Convergence Education was established to equip teachers from all disciplines with the necessary skills to use AI, and courses on AI convergence education are now mandatory in pre-service teacher education programs. The revised curriculum for 2022 incorporates AI into various subjects, with the aim of fostering "digital-AI literacy" [24].

Despite the growing importance of AI education, national-level policies have been implemented in South Korea without clear definitions or education plans for AI convergence education, which has made the cultivation of human resources in the field of AI within schools challenging; both pre-service teachers and educators tasked with delivering AI convergence education face difficulties as a result [24].

The present study used the TPACK framework to design an educational program to develop pre-service teachers' teaching expertise in AI convergence education. Specifically, an AI convergence education model was devised by integrating AI as a technological tool within the TPACK framework, and an education program for pre-service teachers was constructed based on this model. The educational program was implemented with pre-service teachers to assess its efficacy, and the effectiveness of the program was evaluated.

II. Materials and Method

A. Materials

In order to cultivate teaching expertise in AI convergence education among pre-service teachers, a TPACK teaching model was developed based on an analysis of relevant literature. Factors that might enhance pre-service teachers' teaching expertise were explored through a comprehensive examination of previous studies. The TPACK teaching model was formulated by integrating these factors.

The first component within the TPACK teaching model consists of brainstorming. This step is essential for pre-service teachers to generate and exchange ideas that they can then apply to integrate technology effectively within the context of content, teaching, learning methods, and the educational setting [25]. Brainstorming enables pre-service teachers to generate ideas for lesson planning, assess the viability of those ideas, and incorporate them into the design of their lessons. Prior research on TPACK has consistently demonstrated that when pre-service teachers engage in brainstorming as part of the lesson design, such sessions facilitate the development of TPK and TCK [26]. These findings underscore the significance of including brainstorming as a crucial component within an AI-based TPACK educational model.

The second component pertains to the incorporation of TPACK theory. Existing literature on TPACK highlights the significance of exploring theoretical frameworks related to TPACK to foster its development [25]–[27]. Koh and Chai [28], for example, emphasized that comprehending TPACK theory must precede the cultivation of TPACK, and they stressed the importance of exploring the theoretical underpinnings of TPACK in TPACK education. Specifically, pre-service teachers, who are typically in the developmental stage of PK, CK, TK, and XK, must grasp the implications of TPACK education based on their understanding of TPACK theory [11], [19], [29], [30]. This understanding will then enable them to recognize the necessity of integrating AI in the classroom and equip them with the capacity to employ AI in specific classroom contexts effectively.

The third factor involves lesson design. While pre-service teachers must explore integrating technology within their lessons, they must also actively contemplate how they might effectively use technology in the instructional process. Exploring the use of AI during lesson design can significantly contribute to developing their ability to leverage technology within an educational context. This practice will then facilitate the advancement of pre-service teachers' TPACK by fostering meaningful interactions among TK, CK, PK, and XK [11], [30], [31]. Pre-service teachers thus must design comprehensive lesson plans, activities, and instructional guides that will incorporate AI effectively.

The fourth factor pertains to the curriculum. Previous research on pre-service teachers' teaching expertise underscores the curriculum's significance [32],[33]. In the South Korean context, education is grounded in the national curriculum. Pre-service teachers can thus gain insights into the characteristics, objectives, nature, interconnections, content organization, teaching/learning approaches, and assessment methods through an understanding of the curriculum. Without such a comprehensive understanding, even with a high level of TK, pre-service teachers may encounter difficulties in effectively using technology in alignment with the curriculum content. In such instances, technology-driven education may prevail instead of leveraging technology for effective teaching practices. Pre-service teachers thus must grasp the intricacies of the curriculum, as only through this understanding will they be able to realize the development of TPACK [24].

The fifth factor pertains to finding lesson examples. Compared to experienced teachers, most pre-service teachers have limited experience designing and delivering lessons. As a result, they often encounter challenges and spend considerable time designing new lessons, even within their own subject areas. Incorporating technology into the lesson design process further adds to the cognitive load experienced by pre-service teachers [4], [5], [6]. Previous studies have demonstrated that pre-service teachers are more inclined to integrate technology into their lesson designs when they are provided with examples of lessons and when they analyze how technology was used and for what specific purposes within those lessons. The exploration of classroom examples thus alleviates the difficulties that pre-service teachers often face when incorporating technology in the classroom, facilitating the exploration of effective ways to integrate technology. This approach, in turn, will foster the development of TPK and TCK, thereby promoting the overall development of TPACK among pre-service teachers [7],[34].

The sixth factor revolves around AI. Previous studies on TPACK have predominantly focused on ICT as a technology tool [35],[36]. For instance, Baran and Uygun (2016) incorporated ICT as a technology tool within their TPACK instructional model, employing design-based instruction [37]. However, ICTs often pose challenges in diverse educational contexts due to their specific functionalities [38]. In contrast to ICTs, programming languages offer a development environment that allows the creation of educational materials and activities aligned with specific educational purposes without the same functional limitations [17]. As previous studies have indicated, simulating or visualizing complex concepts can also facilitate higher-order cognitive development among students [39]. Still, the block-based programming language used in previous studies was relatively easy for pre-service teachers to learn, but the scope of programs they could develop was limited. In contrast, AI encompasses diverse functions that can facilitate efficient learning by leveraging data-driven learning approaches. By acquiring knowledge of programming development environments and AI, pre-service teachers thus can design lessons that will promote effective learning [17],[25].

The seventh factor pertains to "microteaching." Pre-service teachers, who typically have less experience than practicing teachers, require opportunities to demonstrate their understanding of the field and ability to design lessons within educational contexts. By engaging in microteaching, they can enhance their understanding of CK, TK, and PK in relation to educational contexts [37],[38]. Since pre-service teachers may not be able to teach in actual school settings, microteaching can serve as a valuable simulation for their designed lessons [40]. Through microteaching, pre-service teachers can explore pedagogical contexts they may not have previously considered and gain insights into how CK, TK, and PK interact to create effective lessons. As a result, microteaching can play a practical role in the development of pre-service teachers' TPACK [30].

The eighth factor involves lesson reflection. Pre-service teachers can evaluate their own TPACK by reflecting on their lesson design and microteaching outcomes. By comparing their own results with those of others, they can identify their weaknesses and find areas for improvement. Thus, when pre-service teachers engage in lesson reflection, they can assess their TPACK level and determine further directions for TPACK development [40],[41]. This process can help to enhance pre-service teachers' TPACK and improve their skills in designing effective lessons [40].

The final factor is collaboration. In the complex context of education, particularly for pre-service teachers who are still in the process of developing their knowledge about education, finding a definitive answer can be challenging. Because determining how to effectively integrate AI into the classroom based on the educational context alone can be difficult, having a collaborative design process that involves colleagues with diverse perspectives is essential to identify appropriate solutions according to the specific educational context. Engaging in collaborative lesson design processes can assist pre-service teachers in comprehending the interplay between TK, PK, and CK, as well as exploring ways to incorporate technology in authentic educational settings [35], [40], [42], [43]. Collaboration among peers can greatly contribute to facilitating pre-service teachers' exploration of efficient methods for using AI [42].

Based on the educational model noted above, an education program was developed in the present study to enhance the expertise of pre-service teachers in AI convergence teaching. This education program encompasses five key phases: analysis, exploration, design, application, and evaluation. In the analysis phase, pre-service teachers examined challenges and issues within their own classroom contexts. The exploration phase involved delving into TPACK theory, curriculum, teaching practices, and AI to address any problems that were identified. In the design phase, pre-service teachers created lessons to tackle the challenges identified during the analysis phase, incorporating the insights they had gained from the exploration phase. During the application phase, microteaching sessions were implemented based on the newly designed lessons. Finally, during the evaluation phase, the pre-service teachers reflected on the lessons they had taught and made subsequent improvements to enhance their effectiveness.

B. Methods

1) Overview: The program was administered to pre-service teachers to validate the education program developed for this study. Pre- and post-tests were then conducted. The AI-based TPACK education program and AI education were implemented at two universities, and Kim and Lee [45] found that AI Convergence Teaching Expertise test tool was administered before and after the education program. The impact of the AI-based TPACK education program on the AI-convergence teaching expertise of pre-service teachers could be assessed by analyzing the test results.

2) Participants: The subjects of the present study were pre-service teachers from A and B Universities in South Korea. The experimental group consisted of pre-service teachers from A University. Initially, 50 pre-service teachers were recruited for the study, but after exclusion of those who had not fully participated in the treatment or test, 26 pre-service teachers were selected as the final study subjects. The control group consisted of 13 pre-service teachers from University B who participated in both the treatment and the test. All the pre-service teachers in the study were freshmen. The majors of the participants in the experimental group included history, math, education, and informatics (in South Korea, the major for pre-service teachers who teach computer science, computing, or computers is referred to as informatics). The control group comprised students majoring in informatics, biology, history, physics, and math. Gender distribution was balanced between males and females in both groups.

3) Treatment: The study was conducted during the first semester of the 2022 academic year, from March to June. The participants received 2 hours of lectures per week for a total of 15 weeks, amounting to 30 hours in total. The lecture content was delivered using an AI-based TPACK education program. The experimental group underwent the treatment in a step-by-step manner, following the analyze-explore-design-implement-evaluate sequence.

During the analysis phase, the participants examined the problems they had encountered in their own teaching practices. Pre-service teachers often face challenges when seeking ways to incorporate technology (in this case AI) in the classroom due to their limited experience in actual school settings. The purpose of introducing technology was thus to identify solutions to classroom issues based on their own teaching experiences. Students had an easier time integrating technology in this context [7], [17], [44].

The participants identified the requirements for effective lesson design during the subsequent exploration phase. This step involved exploring TPACK theory to promote technology integration, investigating curriculum and relevant teaching examples to inform lesson design, and exploring programming development environments and AI to use such technology properly. In the design phase, the participants organized the problems identified during the analysis phase, and they designed AI convergence lessons based on the knowledge they had acquired during the exploration phase.

During the application phase, students conducted microteaching sessions with their peers. In the final evaluation stage, students assessed their peers' lessons, compared them with their own, and reflected on the outcomes in order to make improvements [17], [37], [44] (see Table 1).

TABLE I
ORGANIZING AN AI CONVERGENCE EDUCATION PROGRAM FOR PRE-SERVICE TEACHERS

Phase	Content
Analysis	Analysis of a problem in class
Exploration	Exploration of TPACK theory Exploration of TPACK class with AI Exploration of the curriculum Exploration of AI and the programming development environment
Design	Design of an AI convergence lesson
Application	Microteaching
Evaluation	Reflection Elaboration of lesson and feedback

The control group received treatment targeted at enhancing their understanding of AI. They acquired knowledge and principles related to AI and engaged in practical exercises to develop AI programs using a block-based programming language. In contrast, the experimental group learned about AI and designed lessons that incorporated AI. Thus, while the experimental group focused on both AI learning and lesson design, the control group primarily emphasized AI program development.

4) Measurements: Kim and Lee [45] revealed that AI Convergence Teaching Expertise test tool was used as the screening tool in this study. This test tool was built upon the TPACK test tool and incorporates AI as a technology component. Generally, PCK serves as a crucial indicator of teaching expertise in teacher and pre-service teacher education. With the increasing integration of technology in education, the significance of TPACK, a framework that merges PCK and TK, has also grown. Consequently, TPACK can be regarded as the teaching expertise of pre-service teachers. The present study thus used TPACK as an assessment tool for measuring the teaching expertise of pre-service teachers [45].

The screening tool comprises a total of 41 questions and uses a 5-point Likert scale for responses. The test encompasses various factors, including CK, TK, PK, XK, TCK, PCK, TPK, and TPACK. This test is distinct from existing TPACK assessments in that it introduces XK as an additional factor, structures TK-related questions around AI, and incorporates the content of AI convergence into the TCK, TPK, and TPACK questions [45]. The items in the instrument were derived through an analysis of prior research and expert review, and their reliability and validity were assessed with pre-service teachers. As a result, a total of 41 items were validated. The overall reliability of the test instrument was found to be 0.973, with the sub-factors demonstrating reliability ranging from 0.818 to 0.946 [45].

III. RESULTS AND DISCUSSION

When comparing the teaching expertise in AI convergence between the experimental (M = 3.10, SD = 0.45) and control groups (M = 2.89, SD = 0.70) at the pre-test, no significant difference was found (t = 1.16, p = 0.26). This lack of significant difference was observed in all sub-domains, including CK (t = 0.37, p = 0.72), TK (t = 0.60, p = 0.55), PK (t = 1.20, p = 0.24), XK (t = 1.54, p = 0.13), TCK (t = 0.52, p = 0.61), PCK (t = 1.38, p = 0.18), TPK (t = 0.76, p = 0.45), and TPACK (t = 0.68, p = 0.50). These findings indicate that the experimental and control groups had comparable levels of expertise in teaching AI convergence prior to the education program. Table 2 presents the expertise of both groups in AI convergence teaching at the pre-test.

TABLE II
EXPERIMENTAL AND CONTROL GROUPS' TEACHING EXPERTISE IN ARTIFICIAL INTELLIGENCE CONVERGENCE EDUCATION AT PRE-TEST

Domain	Group	*N*	*M*	*SD*	*t*	*p*
CK	Exp.	26	2.52	0.66	0.37	0.72
	Con.	13	2.42	0.96		
TK	Exp.	26	2.79	0.55	0.60	0.55
	Con.	13	2.67	0.68		
PK	Exp.	26	3.45	0.39	1.20	0.24
	Con	13	3.21	0.84		
XK	Exp.	26	3.27	0.42	1.54	0.13
	Con.	13	2.99	0.72		
TCK	Exp	26	2.71	0.72	0.52	0.61
	Con.	13	2.56	0.94		
PCK	Exp.	26	3.26	0.64	1.38	0.18
	Con.	13	2.92	0.84		
TPK	Exp.	26	3.22	0.66	0.76	0.45
	Con.	13	3.05	0.69		
TPACK	Exp.	26	3.10	0.67	0.68	0.50
	Con.	13	2.93	0.79		
Total	Exp.	26	3.10	0.45	1.16	0.26
	Con.	13	2.89	0.70		

Note. CK: content knowledge, TK: technological knowledge, PK: pedagogical knowledge, XK: context knowledge, TCK: technological content knowledge, PCK: pedagogical content knowledge, TPK: technological pedagogical knowledge, TPACK: technological pedagogical content knowledge.

In contrast to the experimental group, the control group focused on acquiring knowledge about AI and developing AI programs. An examination of the changes among pre-service teachers resulting from these treatments showed that their AI convergence classroom expertise had improved significantly from the pre-test (M = 2.89, SD = .70) to the post-test (M = 3.50, SD = .40); t = -2.44, p = .03. A significant difference in AI convergence teaching expertise was also noted between the two groups. These findings confirm that pre-service teachers who received AI education also experienced improvements in their AI-integrated teaching expertise. Specifically, significant changes were observed in the sub-factors of TK (t = -2.55, p = .03), XK (t = -2.58, p = .02), TCK (t = -2.72, p = .02), PCK (t = -2.17, p = .05), and TPACK (t = -2.33, p = .04), all of which showed improvement from the pre-test to the post-test. The changes in AI convergence teaching expertise within the control group are presented in Table 3.

TABLE III
CHANGE IN TEACHING EXPERTISE OF THE CONTROL GROUP

Domain	Test	*M*	*SD*	*t*	*p*
CK	Pre	2.42	0.96	-1.87	0.09
	Post	3.10	0.84		
TK	Pre	2.67	0.68	-2.55	0.03*
	Post	3.33	0.56		
PK	Pre	3.21	0.84	-1.58	0.14
	Post	3.66	0.47		
XK	Pre	2.99	0.72	-2.58	0.02*
	Post	3.63	0.46		
TCK	Pre	2.56	0.94	-2.72	0.02*
	Post	3.46	0.71		
PCK	Pre	2.92	0.84	-2.17	0.05
	Post	3.53	0.42		
TPK	Pre	3.05	0.69	-2.03	0.06
	Post	3.55	0.43		
TPACK	Pre	2.93	0.79	-2.33	0.04*
	Post	3.54	0.41		
Total	Pre	2.89	0.70	-2.44	0.03*
	Post	3.50	0.40		

*$p < .05$

The experimental group received an understanding of AI (like the control group) and AI-based TPACK instruction. As a result of these interventions, pre-service teachers' expertise in teaching AI convergence significantly increased from the pre-test (M = 3.10, SD = .45) to the post-test (M = 3.82, SD = .50); t = 5.10, p < .01. These findings provide evidence that the AI-based TPACK education program effectively enhanced pre-service teachers' teaching expertise in AI convergence.

Significant differences were observed between the pre-test and post-test for all factors when examining the detailed factors of AI-integrated teaching expertise. An overall increase in the post-test scores was also noted compared to the pre-test scores. This finding indicates that the AI-based TPACK education program positively impacted the development of pre-service teachers' AI-integrated teaching expertise. The changes in AI convergence teaching expertise within the experimental group are presented in Table 4.

TABLE IV
CHANGE IN TEACHING EXPERTISE OF THE EXPERIMENTAL GROUP

Domain	Group	*M*	*SD*	*t*	*p*
CK	Pre	2.52	0.66	-3.59	0.00*
	Post	3.26	0.83		
TK	Pre	2.79	0.55	-3.22	0.00*
	Post	3.45	0.79		
PK	Pre	3.45	0.39	-4.40	0.00*
	Post	4.02	0.47		
XK	Pre	3.27	0.42	-4.09	0.00*
	Post	3.92	0.59		
TCK	Pre	2.71	0.72	-4.47	0.00*
	Post	3.67	0.77		
PCK	Pre	3.26	0.64	-4.61	0.00*
	Post	4.06	0.60		
TPK	Pre	3.22	0.66	-3.92	0.00*
	Post	3.94	0.63		
TPACK	Pre	3.10	0.67	-4.79	0.00*
	Post	3.95	0.51		
Total	Pre	3.10	0.45	-5.10	0.00*
	Post	3.82	0.50		

*$p < .05$

In the post-test, the experimental group (M = 3.82, SD = .50) demonstrated higher expertise in teaching AI convergence than the control group (M = 3.50, SD = .40), which was statistically significant. While no initial differences were noted between the experimental and control groups in the pre-test, the post-test results revealed a significant difference (t = 2.07, p = .05). This finding suggests that the treatment effectively improved the expertise of both groups in AI-integrated teaching, but the pre-service teachers in the experimental group showed greater improvement compared to the control group. Thus, the conclusion may be drawn that the AI-based TPACK education program was effective in enhancing pre-service teachers' AI convergence teaching expertise (see Table 5).

TABLE V
EXPERIMENTAL AND CONTROL GROUPS' TEACHING EXPERTISE IN ARTIFICIAL INTELLIGENCE CONVERGENCE EDUCATION AT POST-TEST

Domain	Group	*N*	*M*	*SD*	*t*	*p*
CK	Exp.	26	3.26	0.83	.58	0.57
	Con.	13	3.10	0.84		
TK	Exp.	26	3.45	0.79	.47	0.64
	Con.	13	3.33	0.56		
PK	Exp.	26	4.02	0.47	2.22	0.03*
	Con	13	3.66	0.47		
XK	Exp.	26	3.92	0.59	1.58	0.12
	Con.	13	3.63	0.46		
TCK	Exp	26	3.67	0.77	.80	0.43
	Con.	13	3.46	0.71		
PCK	Exp.	26	4.06	0.60	2.85	0.01*
	Con.	13	3.53	0.42		
TPK	Exp.	26	3.94	0.63	1.99	0.05
	Con.	13	3.55	0.43		
TPACK	Exp.	26	3.95	0.51	2.49	0.02*
	Con.	13	3.54	0.41		
Total	Exp.	26	3.82	0.50	2.07	0.05*
	Con.	13	3.50	0.40		

*$p < .05$

Regarding the sub-factors, significant differences were observed in PK (t = 2.22, p = .03), PCK (t = 2.85, p = .01), and TPACK (t = 2.49, p = .02), with the experimental group outperforming the control group in all three factors. These results indicate that the AI-based TPACK education program was not universally effective for all aspects of pre-service teachers' AI-integrated teaching expertise, but the program demonstrated greater efficacy than AI education alone in developing specific factors.

This study's findings confirmed that the AI-based TPACK education program yielded positive results in developing pre-service teachers' AI-integrated teaching expertise. Notably, however, the program did not significantly impact all factors of AI-integrated teaching expertise. Only PCK and TPACK showed statistically significant improvements compared to AI education. These findings suggest that the education program had a more pronounced effect on certain aspects of pre-service teachers' teaching expertise compared to AI education alone [7], [17], [44], [45].

According to the results, pre-service teachers were able to develop TK, XK, TCK, PCK, and TPACK even when they received AI education alone. This finding can be attributed to the interaction between the development of these factors in the pre-service teachers' curriculum and the knowledge gained through the AI education. Both PCK and TPACK showed improvement in both groups, but the improvement was more pronounced among pre-service teachers who had undergone the AI-based TPACK education program. Conversely, TK and TCK showed improvement in both the experimental and control groups, with no significant difference noted in the level of improvement between the two groups. Even though the control group received more extensive AI education, the absence of a significant difference in TK and TCK suggests that designing lessons using AI was as effective as AI education alone in developing these factors. These findings indicate the potential for identifying efficient methods to develop TK and TCK within a shorter timeframe [8], [46].

IV. CONCLUSION

In this study, an Artificial Intelligence (AI)-based Technological Pedagogical Content Knowledge (TPACK) education model was devised for pre-service teachers, and an educational program suitable for classroom implementation was developed. To validate the effectiveness of the education program, Kim and Lee [45] found that AI Convergence Teaching Expertise test tool was used to assess pre-service teachers' proficiency. Based on the findings of this study, the following conclusions may be drawn.

First, an educational model was formulated to enhance pre-service teachers' capacity to design AI-integrated lessons for the classroom. The AI-based TPACK education model encompasses brainstorming, TPACK theory, lesson design, curriculum, lesson examples, AI usage, microteaching, lesson reflection, and collaboration. An AI-based TPACK education program was also created for the professional development of pre-service teachers in AI-integrated teaching. The newly developed educational program includes analysis, exploration, design, application, and evaluation.

Second, the AI-based TPACK education program demonstrated its efficacy in enhancing the teaching proficiency of pre-service teachers in AI-integrated instruction. Those who had participated in the program exhibited substantial advancements in their AI-integrated teaching expertise from the pre-test to the post-test. The results thus showed that the AI-based TPACK education program effectively enhanced pre-service teachers' competence in AI-integrated teaching. In comparison to their counterparts who had not received AI education, those who had undergone the AI-based TPACK education program exhibited notable enhancements in their PCK and TPACK. This finding further supports the AI-based TPACK education program's effectiveness in enhancing pre-service teachers' teaching expertise.

In this study, significant improvements were observed only in the areas of PCK and TPACK when compared to the AI-trained group. The TPACK framework aims to foster TCK, TPK, and PCK by allowing interaction among TK, CK, and PK, and to cultivate TPACK by facilitating integration among these three forms of knowledge. However, this study had certain limitations as the AI-based TPACK education program exhibited a significant effect solely on the development of PCK and TPACK. Future studies should focus on enhancing the education program to yield significant effects on other factors as well. Conducting research to enhance educational programs in education is a complex task, given the many factors involved. Hence, employing design-based research, a methodology that integrates theoretical and practical knowledge to enhance educational programs, is essential for improving the AI-based TPACK education program.

This study hypothesized that the AI-based TPACK education program would have a greater impact on the development of pre-service teachers' TCK and TPK compared to the AI-based education program alone. This expectation was based on including components such as lesson design, microteaching, and reflection in the program. Contrary to expectations, however, no significant effects on the TCK and TPK of pre-service teachers were observed. As a result, further exploration will be necessary to investigate approaches that could effectively foster the development of TCK and TPK among pre-service teachers, this time employing path analysis within the framework of TPACK.

In conclusion, this study specifically focused on pre-service teachers in South Korea, which also has graduate schools and education programs for in-service teachers. This situation highlights the need to develop education programs tailored to teachers based on the findings of this study. Further research should be conducted to verify the effectiveness of such programs. The outcomes of this study are expected to make valuable contributions to the advancement of AI convergence education and TPACK research in South Korea.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2022R1G1A1004701).

REFERENCES

[1] Torun, F., "The effect of a textbook preparation process supported by instructional technology tools on the TPACK self-confidence levels of prospective social studies teachers," Review of International Geographical Education Online, vol. 10, no. 2, pp. 115-140. 2020. doi:10.33403/rigeo.691943

[2] Yeh, Y. F., Chan, K. K. H., and Hsu, Y. S., "Toward a framework that connects individual TPACK and collective TPACK: A systematic review of TPACK studies investigating teacher collaborative discourse in the learning by design process," Computers & Education, Vol. 171, 104238, 2021. doi:10.1016/j.compedu.2021.104238

[3] Celik, I., “Towards Intelligent-TPACK: An empirical study on teachers’ professional knowledge to ethically integrate artificial intelligence (AI)-based tools into education,” Computers in Human Behavior, vol. 138, 107468, 2023. doi:10.1016/j.chb.2022.107468

[4] Na, J. and Jang, B. G., "The Difficulties and Needs of Pre-service Elementary Teachers in the Science Class utilizing Smart Technologies in Teaching Practice," Journal of Korean Elementary Science Education, vol. 35, no. 1, pp. 98-110. 2016. doi:10.15267/keses.2016.35.1.098

[5] Kim, S. W. and Lee, Y., "The Changes of Self-efficacy Beliefs of Pre-service Teachers for Technology Integration through Programming-based TPACK Educational Program," Journal of The Korea Society of Computer and Information, vol. 24, no. 4, pp. 185-193, 2019. doi:10.9708/jksci.2019.24.04.185

[6] Sung, K., and Cho, Y., "A Case Study on Social Studies Teacher’s Development Process of TPACK," Korean Social Studies Association, vol. 51, no. 2, pp. 41-60, 2012.

[7] Kim, S. W. and Lee, Y., "Development of Programming-based TPACK Education Program through Design-based Research," Journal of The Korea Society of Computer and Information, vol. 24, no. 10, pp. 267-278, 2019. doi:10.9708/jksci.2019.24.10.267

[8] Kim, S. W. and Lee, Y., "The Effects of Programming-based TPACK Educational Program on Self-efficacy of Pre-service Teachers," The Journal of Korean Association of Computer Education, vol. 21, no. 5, pp. 49-59. 2018. doi:10.32431/kace.2018.21.5.005

[9] Kim, S. W. and Lee, Y., "Effects of Programming-Based TPACK Education Program on TPACK of Pre-service Teachers," The Journal of Korean Association of Computer Education, vol. 23, no. 4, pp. 79-89. doi:10.32431/kace.2020.23.4.008

[10] Aldemir Engin, R., Karakuş, D., and Niess, M. L., “TPACK development model for pre-service mathematics teachers,” Education and Information Technologies, vol. 28, no. 4, pp. 4769-4794, 2023. doi:10.1007/s10639-022-11381-1

[11] Mishra, P., “Considering contextual knowledge: The TPACK diagram gets an upgrade,” Journal of Digital Learning in Teacher Education, vol. 35, no. 2, pp. 76-78, 2019. doi:10.1080/21532974.2019.1588611

[12] Schmid, M., Brianza, E., and Petko, D., “Developing a short assessment instrument for Technological Pedagogical Content Knowledge (TPACK. xs) and comparing the factor structure of an integrative and a transformative model,” Computers & Education, vol. 157, 103967, 2020. doi:10.1016/j.compedu.2020.103967

[13] Valtonen, T., Leppänen, U., Hyypiä, M., Sointu, E., Smits, A., and Tondeur, J., "Fresh perspectives on TPACK: pre-service teachers’ own appraisal of their challenging and confident TPACK areas," Education and Information Technologies, vol. 25, no. 4, pp.2823-2842, 2020.

[14] Mishra, P., "Considering contextual knowledge: The TPACK diagram gets an upgrade," Journal of Digital Learning in Teacher Education, vol. 35, no. 2, pp. 76-78, 2019.

[15] Brianza, E., Schmid, M., Tondeur, J. and Petko, D., "Investigating contextual knowledge within TPACK: How has it been done empirically so far?," In Society for Information Technology & Teacher Education International Conference (pp. 1980-1988). Association for the Advancement of Computing in Education (AACE), Apr. 2022,

[16] Brianza, E., Schmid, M., Tondeur, J., and Petko, D., "Situating TPACK: A systematic literature review of context as a domain of knowledge," Contemporary Issues in Technology and Teacher Education, vol. 22, no. 4, pp. 707-753, 2022.

[17] Kim, S. W. and Lee, Y., "Development of TPACK-P Education Program for Improving Technological Pedagogical Content Knowledge of Pre-service Teachers," Journal of The Korea Society of Computer and Information, vol. 22, no. 7, pp. 141-152 2017. doi:10.9708/jksci.2017.22.07.141

[18] Zhang, L. and Nouri, J., “A systematic review of learning computational thinking through Scratch in K-9,” Computers & Education, vol. 141, 103607, 2019. doi:10.1016/j.compedu.2019.103607

[19] Kim, S. W. and Lee, Y., "An analysis of pre-service teachers' learning process in programming learning," International Journal on Advanced Science, Engineering and Information Technology, vol. 10, no. 1, pp. 58-69, 2020. doi:10.18517/ijaseit.10.1.5723

[20] Long, D. and Magerko, B., "What is AI literacy? Competencies and design considerations," In Proceedings of the 2020 CHI conference on human factors in computing systems (pp. 1-16), Apr. 2020. doi:10.1145/3313831.3376727

[21] Qadir, J., "Engineering education in the era of ChatGPT: Promise and pitfalls of generative AI for education," In 2023 IEEE Global Engineering Education Conference (EDUCON) (pp. 1-9). IEEE, May. 2023. doi:10.36227/techrxiv.21789434

[22] Salas-Pilco, S. Z., Xiao, K. and Hu, X., "Artificial intelligence and learning analytics in teacher education: A systematic review," Education Sciences, vol. 12, no. 8, pp. 569, Aug. 2022. doi:10.3390/educsci12080569

[23] Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., ... and Li, Y., "A Review of Artificial Intelligence (AI) in Education from 2010 to 2020," Complexity, vol. 2021, pp. 1-18, 2021. doi:10.1155/2021/8812542

[24] Lee, D., Hwang, J. Y., Lee, Y. and Kim, S. W., "Informatics and Artificial Intelligence (AI) Education in Korea: Situation Analysis Using the Darmstadt Model," JOIV: International Journal on Informatics Visualization, vol. 6, no. 2, pp. 427-444, 2022. doi:10.30630/joiv.6.2.1000

[25] Long, T., Zhao, G., Li, X., Zhao, R., Xie, K. and Duan, Y., “Exploring Chinese in-service primary teachers’ Technological Pedagogical Content Knowledge (TPACK) for the use of thinking tools,” Asia Pacific Journal of Education, vol. 42, no. 2, pp. 350-370, 2022. doi:10.1080/02188791.2020.1812514

[26] Graham, C. R., Borup, J. J. and Smith, N. B., "Using TPACK as a framework to understand teacher candidates' technology integration decisions," Journal of Computer Assisted Learning, vol. 28, no. 6, pp. 530–546, 2012. doi:10.1111/j.1365-2729.2011.00472.x

[27] Agyei, D. D. and Kafyulilo, A., “Continuation of collaborative curriculum design outcomes: Teachers’ transfer of teaching with technology,” Collaborative curriculum design for sustainable innovation and teacher learning, vol. 365, 2019. doi:10.1007/978-3-030-20062-6_20

[28] Koh, J. H. L. and Chai, C. S., "Teacher clusters and their perceptions of technological pedagogical content knowledge (TPACK) development through ICT lesson design," Computers & Education, vol. 70, pp. 222–232, 2014. doi:10.1016/j.compedu.2013.08.017

[29] Redmond, P. and Lock, J., “Secondary pre-service teachers’ perceptions of technological pedagogical content knowledge (TPACK): What do they really think?,” Australasian Journal of Educational Technology, vol. 35, no. 3, pp. 45-52, 2019. doi:10.14742/ajet.4214

[30] Jimoyiannis, A., "Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers’ professional development," Computers & Education, vol. 55, pp. 1259–1269. 2010. doi:10.1016/j.compedu.2010.05.022

[31] Li, S., Liu, Y. and Su, Y. S., “Differential analysis of teachers’ technological pedagogical content knowledge (TPACK) abilities according to teaching stages and educational levels. Sustainability, vol. 14, no. 12, pp. 7176, 2022. doi:10.3390/su14127176

[32] Schmid, M., Brianza, E. and Petko, D., “Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans,” Computers in Human Behavior, vol. 115, 106586, 2021. doi:10.1016/j.chb.2020.106586

[33] Max, A. L., Lukas, S. and Weitzel, H., “The relationship between self-assessment and performance in learning TPACK: Are self-assessments a good way to support preservice teachers' learning?,” Journal of Computer Assisted Learning, vol. 38, no. 4, pp. 1160-1172, 2022. doi:10.1111/jcal.12674

[34] Baier, F. and Kunter, M., "Construction and validation of a test to assess (pre-service) teachers' technological pedagogical knowledge (TPK)," Studies in Educational Evaluation, vol. 67, 100936, 2020. doi:10.1016/j.stueduc.2020.100936

[35] Zou, D., Huang, X., Kohnke, L., Chen, X., Cheng, G. and Xie, H., "A bibliometric analysis of the trends and research topics of empirical research on TPACK," Education and Information Technologies, vol. 27, no. 8, pp. 10585-10609, 2022. doi:10.1007/s10639-022-10991-z

[36] Habibi, A., Yusop, F. D. and Razak, R. A., “The role of TPACK in affecting pre-service language teachers’ ICT integration during teaching practices: Indonesian context,” Education and Information Technologies, vol. 25, pp. 1929-1949, 2020. doi:10.1007/s10639-019-10040-2

[37] Baran, E. and Uygun, E., "Putting technological, pedagogical, and content knowledge (TPACK) in action: An integrated TPACK-design-based learning (DBL) approach," Australasian journal of educational technology, vol. 32, no. 2. 2016. doi:10.14742/ajet.2551

[38] Niess, M. L., "Investigating TPACK: Knowledge growth in teaching with technology," Journal of educational computing research, vol. 44, no. 3, pp. 299-317, 2011. doi:10.2190/EC.44.3.c

[39] No, H. and Paik, S., "Students' Perception of Scratch Program using High School Science Class," Journal of the Korean Association for Science Education, vol. 35, no. 1, pp. 53-64. 2015. doi:10.14697/jkase.2015.35.1.0053

[40] Mouza, C., Karchmer-Klein, R., Nandakumar, R., Yilmaz Ozden, S. and Hu, L., "Investigating the impact of an integrated approach to the development of preservice teachers' technological pedagogical content knowledge (TPACK)," Computers & Education, vol. 71, pp. 206–221. Feb. 2014. doi:10.1016/j.compedu.2013.09.020

[41] Lyublinskaya, I. and Kaplon-Schilis, A., "Analysis of differences in the levels of TPACK: Unpacking performance indicators in the TPACK levels rubric," Education Sciences, vol. 12, no. 2, 79, 2022. doi:10.3390/educsci12020079

[42] Shafie, H., Majid, F. A. and Ismail, I. S., "Technological pedagogical content knowledge (TPACK) in teaching 21st century skills in the 21st century classroom," Asian Journal of University Education, vol. 15, no. 3, pp. 24-33, 2019.

[43] Lachner, A., Fabian, A., Franke, U., Preiß, J., Jacob, L., Führer, C., ... and Thomas, P., "Fostering pre-service teachers' technological pedagogical content knowledge (TPACK): A quasi-experimental field study," Computers & Education, Vol. 174, 104304, Dec. 2021. doi:10.1016/j.compedu.2021.104304

[44] Kim, S. W., "Educational Model for Artificial Intelligence Convergence Education. Proceeding of The Korea Society of Computer and Information, vol. 31, no. 1, pp. 229-231, 2023.

[45] Lee, E. and Kim, S. W. "Artificial Intelligence Convergence Teaching Expertise for Pre-service Teachers," The proceeding of Korean Association of Computer Education, vol. 26, no. 2, 189-191, 2022.

[46] Choi, J., Jun, S., Kim, S. and Park, J. "AI-TPACK Model Design for Cultivating AI Convergency Teaching Professionalism of Pre-service Teachers," The Journal of Korean Association of Computer Education, vol. 25, no. 2, pp. 79-89, 2022.