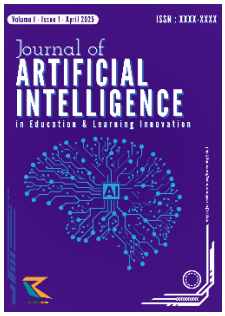

The future of teaching: Analyzing the interplay between AI literacy and TPACK among BEED pre-service teachers

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ABSTRACT

Background: As artificial intelligence (AI) continues transforming the educational landscape, pre-service teachers must develop theoretical understanding and practical skills in AI integration.
Objectives: This study explored the relationship between AI literacy and TPACK among 139 BEED pre-service teachers.
Methods: Using descriptive statistics, Spearman's correlation, and multiple linear regression analysis, the study investigated how components of AI literacy relate to TPACK.
Results: Results revealed that the pre-service teachers demonstrated high levels of AI literacy, particularly in ethical awareness and intrinsic motivation. Pre-service teachers expressed strong interest in AI's educational potential and a commitment to its responsible use. While their foundational AI knowledge was high, many reported moderate self-efficacy and lacked confidence in executing AI-related tasks. Gaps were also noted in applying AI concepts to real-world teaching scenarios and designing AI-driven solutions. Furthermore, the results showed high TPACK proficiency, with strength in pedagogical and technological knowledge, though weaknesses were observed in content areas like mathematics and technical troubleshooting. A moderate positive correlation (Spearman's $\rho = 0.48$, $p < 0.05$) between AI literacy and TPACK indicates a meaningful association. Regression analysis revealed that AI literacy components explained 25.5% of the variance in TPACK. Cognitive learning emerged as the only significant predictor.
Conclusions: The findings underscore the need for teacher education programs to provide hands-on, cognitive-focused AI training. Hence, enhancing pre-service teachers' cognitive and practical skills is essential to thoroughly preparing them for AI-enhanced teaching environments' demands.

Keywords: AI literacy, BEED pre-service teachers, TPACK.

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INTRODUCTION

Artificial Intelligence (AI) has become a transformative force in education, and its integration into the classroom revolutionizes the teaching and learning processes. AI in education demonstrates great potential to enhance learning, teaching, assessment, and educational administration by providing students with opportunities for personalized and adaptive learning, which, as a result, fosters teachers' understanding of students' learning processes (Chiu et al., 2023). As AI continues to expand its role within the educational landscape, there is a growing need for educators to possess a solid foundational understanding of AI. Moreover, pre-service teachers must be equipped with fundamental knowledge, skills, and attitudes to maximize the potential uses of AI technologies in their pedagogical practices.

Since the advancement of AI, academic communities have shown great interest in using AI for educational purposes (Chen et al., 2022). Even though applying AI in education is new among practitioners, it has a positive impact (Chiu et al., 2023). Thus, AI is becoming popular in various disciplines like science education (Gonzalez et al., 2017). Additionally, the study of Shaikh et al. (2024) indicates that ChatGPT, a generative AI, is an effective tool for English language learning. Shete, Khosti, & Pujari (2024) also revealed that using an AI-based customized learning system improved the academic achievement in math classes. AI has been a game changer, and acquiring AI-related skills can fully maximize AI's potential in the educational landscape.

AI literacy has flourished with the increasing importance of technology. AI literacy is critical to understanding, evaluating, and engaging with AI technologies. It embraces multiple competencies: technical knowledge, ethical considerations, and using AI concepts in practice. Moreover, AI literacy can be enhanced through four core aspects: understanding AI, effectively using it, evaluating its applications, and managing ethical concerns.

These dimensions align with traditional literacies while emphasizing the critical need for educators to develop the capacity to navigate the growing complexities of artificial intelligence. AI literacy encompasses the knowledge, skills, and attitudes necessary to engage meaningfully with AI technologies—preparing educators not only to integrate these tools into their practice but also to equip learners with competencies essential for thriving in the twenty-first-century workforce (Ng et al., 2023).

Hence, pre-service teachers must acquire strong AI literacy skills. The study of Anyanwale et al. (2024) stressed that when a person becomes knowledgeable about AI, it can yield positive results regarding application, detection, ethical concerns, and problem-solving. Moreover, they highlighted that this foundational AI knowledge among pre-service teachers will help them easily navigate technical and ethical concerns. This necessitates AI literacy among pre-service teachers so that they acquire skills in understanding, using, evaluating, and engaging with AI ethically.

The findings of this study can contribute to teacher education institutions planning to integrate AI literacy into their curricula. Additionally, identifying the pre-service teachers' level of AI literacy helps institutions create training and seminars that successfully fill gaps and develop AI knowledge and skills crucial in today's educational landscape.

Besides AI literacy level, pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) was also explored. This is an important model for pre-service

teachers, as it provides an in-depth understanding of integrating technology, pedagogy, and content knowledge in the educational context. Teachers must recognize how these domains interact to improve teaching and learning outcomes (Mishra & Koehler, 2006). As pre-service teachers prepare for their future roles, developing TPACK is crucial for effective classroom technology integration (Sarı et al., 2016; Baran & Uygun, 2016).

Given the limited research exploring the connection between AI literacy and TPACK, this discussion underscores the necessity of conducting the present study. For instance, Kong et al. (2024) developed an AI literacy framework based on a 14-hour project-based course for senior secondary students, primarily measuring knowledge acquisition and problem-solving skills. However, it did not address how AI literacy connects to teachers' practical expertise in the classroom. Similarly, Carolus et al. (2023) introduced the Meta AI Literacy Scale (MAILS), a valuable tool for assessing various dimensions of AI literacy, including ethics and self-efficacy. However, its relevance to teachers or instructional design was not examined. Additionally, in their review of 124 studies, Gu and Ericson (2025) highlighted the presence of conceptual frameworks related to AI literacy but noted a significant lack of empirical research linking it to instructional effectiveness.

Exploring the connection between TPACK and AI literacy is crucial in preparing pre-service teachers for modern classrooms. Teachers must know how to maximize the application of AI technologies by understanding how AI technologies interact with pedagogical and content knowledge in instructional activities. Research suggests that fostering AI literacy in pre-service teachers can improve their TPACK by equipping them with the necessary abilities to integrate AI into their content delivery and pedagogy (Ning, 2024). This may imply that pre-service teachers with higher levels of AI literacy may have a better degree of confidence in their ability to use their TPACK. Confidence is important since it can influence one's readiness to use technology in the classroom (Ng, 2023). Furthermore, the relationship between AI literacy and TPACK becomes clear when teachers modify their teaching strategies to incorporate AI tools to improve student engagement and learning outcomes (Velander et al., 2023; Yue, Jong, & Ng, 2024).

Nowadays, the growth of AI and its widespread use in education necessitates teachers to gain a comprehensive understanding of AI literacy to enhance their teaching pedagogies. Therefore, studying the interplay between pre-service teachers' AI literacy and TPACK is imperative. This will help prepare future educators for the new normal of 21st-century teaching and learning.

The present study explored the relationship between AI literacy and the Technological Pedagogical Content Knowledge (TPACK) of Bachelor of Elementary Education (BEED) pre-service teachers. It specifically sought to answer several key research questions. First, it investigated the level of AI literacy among BEED pre-service teachers. Second, it examined their level of TPACK. Third, the study aimed to determine whether a significant relationship exists between AI literacy and TPACK. Furthermore, it explored the extent to which the components of AI literacy—namely affective learning, behavioral learning, cognitive learning, and AI ethics—collectively predict the TPACK of BEED pre-service teachers. Lastly, the study identified which specific components of AI literacy significantly influence the TPACK of these future educators.

METHODS

Study Design and Participants

The study employed a quantitative, descriptive, correlational, and predictive research design to examine the relationship between AI literacy and Technological Pedagogical Content Knowledge among BEED pre-service teachers. It also aimed to determine the extent to which the components of AI literacy, affective, behavioral, cognitive, and ethical, predict TPACK levels. In this context, the study aims not only to explain current relationships but also to forecast TPACK levels based on measurable constructs of AI literacy.

The study's respondents were 139 students enrolled in the Bachelor of Elementary Education (BEED) program from Mindanao State University – General Santos, Philippines, who were purposely chosen. These students had taken subjects related to educational technology, mathematics, literacy, and teaching pedagogies, which were subject areas included in the TPACK questionnaire.

Ethical approval statement

The College of Education Research Committee at Mindanao State University – General Santos reviewed and approved the study.

Participants provided informed consent after being fully briefed on the study's purpose, voluntary nature, and data confidentiality. No identifiable information was collected, and all responses were anonymized and securely stored. Additionally, the study was conducted in line with the ethical guidance of Purvis and Crawford (2024).

Research Instruments

Ng's (2023) AI literacy survey questionnaire was adopted for this study. Upon comprehensive review, the competencies included and surveyed through the items are fit for the respondents. Moreover, the questionnaire was pilot-tested on a small sample of pre-service teachers to check for any issues. Cronbach's alpha result was 0.97, and the internal consistency was excellent. Hence, the questionnaire is acceptable and reliable for pre-service teachers. For the TPACK level of the pre-service teachers, the TPACK Assessment instrument of Shmidt et al. (2009) for pre-service teachers was adopted.

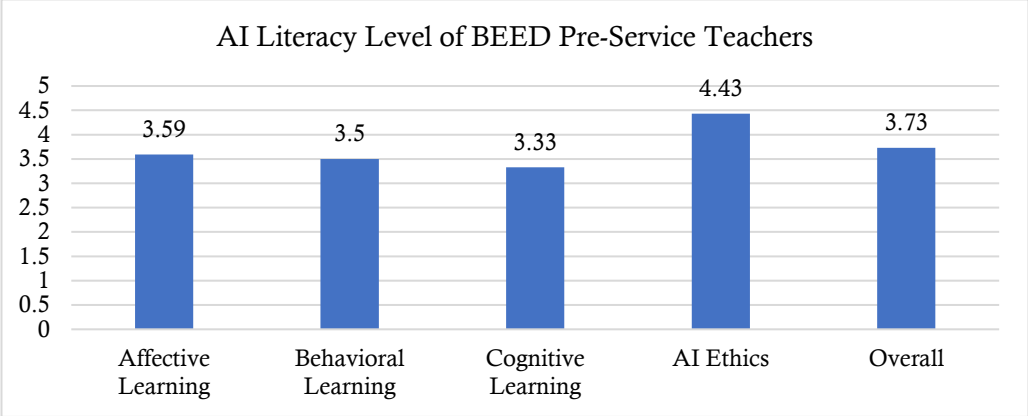
Data Analysis

Descriptive statistics, including the mean, were employed to summarize and interpret the collected data to obtain an in-depth insight regarding the AI literacy and TPACK level of the BEED pre-service teachers and their relationship. The researchers utilized Spearman's correlation coefficient to explore the relationship between the respondents' levels of AI literacy and their TPACK level since the Shapiro-Wilk test indicated a significant deviation from normality, then performed multiple linear regression to determine the extent to which the specific components of AI literacy collectively and individually predict the respondents' TPACK. An ANOVA test was used to assess the overall significance of the regression model.

RESULTS

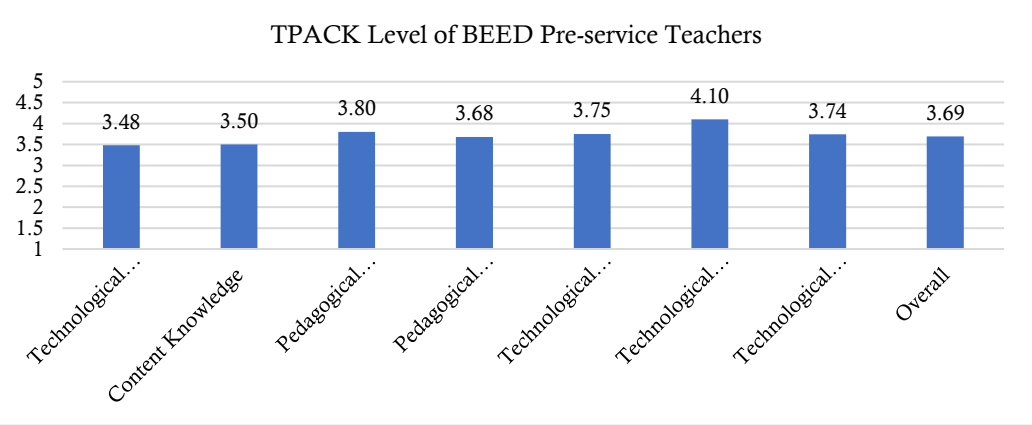
The results of the AI literacy survey, as illustrated in Figure 1, revealed the multilayered aspects of AI literacy to BEED pre-service teachers. These perspectives include their affective domains, behaviors, cognitive understanding, and ethical

considerations of AI, which resulted in an overall Mean of 3.73, classified as High. There is a positive interaction with AI's principles, tools, and applications. However, specific areas need focus and development.



* The AI Literacy Questionnaire uses a 1-to-5 Likert scale, where 1 means 'strongly disagree' and 5 means 'strongly agree.'

Figure 1. AI Literacy Level of BEED Pre-Service Teachers



* The TPACK questionnaire uses a 1-to-5 Likert scale, with 1 as 'strongly disagree' and 5 as 'strongly agree,' to assess Pre-service teachers' self-reported knowledge in technology, pedagogy, and content.

Figure 2. TPACK Level of BEED Pre-service Teachers

Within the domain of Affective Learning, BEED pre-service teachers demonstrate high intrinsic motivation towards AI. They recognize the relevance of AI in their everyday lives and find learning AI interesting. Xie et al. (2023) claim that intrinsic motivation positively influences pre-service teachers' behavioral intention. However, their self-efficacy to succeed in AI-related tasks remains moderate. This suggests a gap between their interest in AI and their confidence in mastering AI knowledge and skills.

In the Behavioral Learning category, BEED pre-service teachers firmly commit to staying engaged with AI technologies. In addition, they express intentions to continue using AI, keep updated with AI advancements, and explore new features of AI in the future. This supports the study of Karina (2024), illustrating how pre-service teachers leverage AI tools, enabling them to create more personalized and compelling learning experiences. However, their collaborative behavior is only moderate. This limited collaboration could restrict opportunities for shared learning and collective problem-solving among pre-service teachers.

The results for Cognitive Learning show that pre-service teachers have a good foundational understanding of AI concepts. They are comfortable using AI tools like digital assistants and chatbots. However, their ability to apply, evaluate, and create AI solutions is more limited. Although they can apply basic AI applications to solve

problems, they struggle with creating more complex AI-driven solutions. The study of Chenqi et al. (2023) reported a similar case where pre-service teachers lack comprehensive mastery of AI knowledge.

At a mean of 4.43, which is classified as Very High, BEED pre-service teachers have a good grasp of the ethical issues surrounding AI. They appreciate the significance of robust testing and ethical requirements for AI systems, and they can identify the dangers of AI misuse. Holden et al. (2023) state that upholding educational integrity entails acting with accountability, honesty, fairness, trust, and respect.

The results, as shown in Figure 2, revealed that BEED pre-service teachers generally have a high level of proficiency in TPACK. BEED pre-service teachers are well-prepared to integrate technology into their pedagogy. The overall mean score of 3.69 suggests that BEED pre-service teachers combine their knowledge of technology, pedagogy, and content to enhance their teaching strategies. Technological Knowledge (TK) has a high average rating, which implies that BEED pre-service teachers know how to keep up with the latest educational technologies. Diamah et al. (2022) pointed out that teachers with a strong TK foundation are well-equipped to maximize technology to enhance student engagement and learning outcomes. However, BEED pre-service teachers report that they still lack skills in solving technical issues and do not have enough chances to work with different technologies. The overall mean score of 3.50 on the Content Knowledge (CK) indicates that BEED pre-service teachers have a good grasp of subject matter content. Literacy emerges as a strong area. However, Mathematics lags, and ratings fall under the "Moderate" range. Annazar (2023) points out that CK is a foundation for effective teaching as it enables teachers to connect concepts and encourage students' participation in activities requiring higher-order thinking.

BEED pre-service teachers display strength in the Pedagogical Knowledge (PK) domain, with a mean of 3.80. They possess skills in adjusting their teaching methods and assessing student performance in various ways. Thus, these results highlight their preparedness to meet different learning needs and manage classrooms effectively. Koh and Divaharan (2011) argue that PK allows teachers to design learning experiences that accommodate diverse learning needs. Pedagogical Content Knowledge (PCK) reflects a good level of expertise. BEED pre-service teachers can guide students' thinking in literacy and social studies. However, mathematics receives a slightly lower score, suggesting a need to acquire content knowledge and teaching strategies specific to this subject. Technological Content Knowledge (TCK) results show that BEED pre-service teachers understand how technology can be used to teach literacy and science. In addition, they possess the necessary skills to apply digital tools to support different subjects. These attributes are important assets in today's technology-driven classrooms. The Technological Pedagogical Knowledge (TPK) category had the highest average score of 4.10. This infers that the BEED pre-service teachers reflect critically on the role of technology in the classroom. The high scores in selecting technologies that enhance teaching and learning suggest a strong capacity to adapt digital tools.

Lastly, the mean score of 3.74 of BEED pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) shows that they can effectively combine content, pedagogy, and technology. Moreover, they confidently use technology to teach different subjects and improve their lessons. Additionally, while they are skilled

in using technology, they could further develop their ability to guide their peers in technology integration.

Table 1. Relationship between AI Literacy Level and TPACK of BEED Pre-service Teachers

		Spearman's rho	p
TPACK	AI Literacy	0.481	< .001

As presented in Table 1, the study's finding indicates a significant and moderate positive relationship between AI literacy and TPACK among BEED pre-service teachers, with a coefficient of 0.481. As pre-service teachers become more knowledgeable about AI, their ability to integrate technology into teaching improves.

The results also suggest that AI literacy is important in helping pre-service teachers learn how to use technology effectively in their teaching. Knowledge of AI can help these future educators better understand how to apply AI tools in the classroom and adjust their teaching methods to make the most of this technology. Moreover, AI literacy may be foundational for developing even more abstract technological pedagogical competencies. When teachers modify their teaching strategies to integrate AI tools, the relationship between TPACK and AI literacy becomes clear. Learning results and student engagement are enhanced (Velander et al., 2023; Yue, Jong, & Ng, 2024). The moderate strength of the correlation also indicates that while AI literacy is a very important factor in amplifying TPACK, it is not the only one. The findings indicate an important focus on AI literacy as part of teacher education programs since it is a key component in developing a holistic approach for pre-service teachers to integrate technology into education (Rutti-Joy, 2023).

Table 2. Model Summary for the Regression Predicting TPACK

Model	R	R^2	Adjusted R^2	RMSE
M_0	0.000	0.000	0.000	0.378
M_1	0.505	0.255	0.232	0.331

Note. M_1 includes Affective Learning, Behavioral Learning, Cognitive Learning, AI Ethics

As shown in Table 2, the regression model that includes all four AI literacy components explains 25.5% of the variance in TPACK. The adjusted R^2 of 0.232 suggests that the model remains a good fit after accounting for the number of predictors. This indicates a moderate predictive capacity of AI literacy for TPACK, validating the relevance of digital literacy in teacher education.

Similarly, Hava and Babayiğit (2024) emphasized that digital proficiency significantly predicts teachers' AI-TPACK competencies, while Bautista et al. (2024) highlighted the influence of technological knowledge (TK, TPK, TCK) on pre-service teachers' TPACK. Furthermore, Pehlevan and Ünal (2024) confirmed that digital literacy significantly predicts TPACK. Given that AI literacy is an advanced form of digital literacy, the consistency among these studies reinforces the current findings.

Table 3. ANOVA Results for the Regression Model Predicting TPACK

Model		Sum of Squares	df	Mean Square	F	p
M_1	Regression	5.024	4	1.256	11.445	< .001
	Residual	14.707	134	0.110		
	Total	19.732	138			

Note. M_1 includes Affective Learning, Behavioral Learning, Cognitive Learning, AI Ethics
Note. The intercept model is omitted, as no meaningful information can be shown.

The ANOVA results in Table 3 confirm that the regression model is statistically significant (F (4, 134) = 11.445, p < .001). The results suggest that the combined influence of the AI literacy components meaningfully contributes to differences in TPACK scores among respondents.

The results conform with prior studies stressing the role of digital and AI literacy in determining the understanding of Technological Pedagogical Content Knowledge (TPACK) among educators. Fazilla et al. (2022) revealed that pre-service teachers with strong digital literacy had a more in-depth understanding and ability to apply TPACK principles since these underpinned their technological competency, leading to pedagogical effectiveness. Ng et al. (2023), therefore, supported this research by developing an AI literacy framework that highlights cognitive, behavioral, and ethical dimensions and components akin to those in the current model, which show their relevance in improving professional teachers' pedagogical knowledge. Furthermore, integrating AI literacy into TPACK was advanced by Ning et al. (2024), who stressed the harmony between technological, pedagogical, and content knowledge in today's teaching practice. Kim (2024) also stated that educators who underwent structured AI-integrated training improved their TPACK competencies significantly. All these studies give empirical evidence in support of the present study, which confirms that AI literacy accounts for a substantial amount of variance in TPACK scores.

Table 4. Regression Coefficients for AI Literacy Variables Predicting TPACK

Model		Unstandardized	Standard Error	Standardized	t	p
M_0	(Intercept)	3.685	0.032		114.901	< .001
M_1	(Intercept)	2.452	0.227		10.813	< .001
	Affective Learning	0.069	0.078	0.105	0.876	0.383
	Behavioral Learning	0.047	0.063	0.092	0.740	0.461
	Cognitive Learning	0.168	0.056	0.303	2.988	0.003
	AI Ethics	0.059	0.059	0.093	1.009	0.315

However, as detailed in Table 4, only cognitive learning showed a significant relationship with TPACK (β = 0.303, p = 0.003). This involves a basic understanding of AI concepts and higher-order skills like applying and creating with AI tools, such as designing chatbots or evaluating tools for classroom use. Teachers with strong cognitive skills in AI are better equipped to demonstrate higher TPACK, aligning with the framework's emphasis on deep integration of content, pedagogy, and technology. Meanwhile, affective (p = 0.469) and behavioral (p = 0.398) domains did not significantly predict TPACK, showing that motivation and frequent use alone is insufficient. Despite having the highest mean score (M = 4.436, see Table 4: Descriptives), AI ethics also lacked significance (p = 0.131), suggesting ethical awareness needs to be paired with cognitive mastery to impact pedagogical integration.

These findings align with previous studies. Bautista et al. (2024) emphasized that pre-service teachers with a strong cognitive understanding of artificial intelligence and the ability to apply it in teaching, such as designing AI-based tools, demonstrated

higher levels of TPACK. Saharuddin et al. (2025) supported this by highlighting the importance of practical AI knowledge in effective classroom integration.

On the other hand, affective and behavioral domains, including motivation, positive attitudes, and frequent AI use, were not significant predictors of TPACK. Runge et al. (2025) found that while AI-related training improved perceptions, these factors did not lead to actual classroom application. Similarly, Schubatzky et al. (2025) noted that self-confidence was less influential than cognitive mastery in determining how technology is applied in teaching.

Moreover, although AI ethics received the highest mean score, it did not significantly influence TPACK. This corresponds to Celik (2023) and Bautista et al. (2024), who explained that ethical awareness alone is insufficient unless it is supported by strong content and pedagogical knowledge.

These findings reinforce the TPACK framework and 21st-century education goals, emphasizing that deep cognitive engagement is essential in preparing future-ready educators. This is consistent with the insights of Cangül (2022) and Aslan et al. (2025), who stressed the need for teachers capable of working effectively in complex digital learning environments.

DISCUSSION

The findings revealed that BEED pre-service teachers exhibit a generally high level of AI literacy and TPACK proficiency. According to Grosseck (2023), educators need to have the same knowledge of AI, and both teachers and students need to know the basics of AI. In the same way, Rutti-Joy (2023) explains that teaching teachers about AI should be a part of pre-service teacher education programs so that future teachers can acquire the necessary competencies to explore AI-enhanced pedagogies.

As shown by the moderately positive association ($r = 0.485$) between AI literacy and TPACK, pre-service teachers with good foundational knowledge about AI will likely better combine technology with effective teaching methods. This finding supports the idea that AI literacy helps build up a wider range of technology skills within the TPACK framework. Zhao et al. (2022) asserted that learning more about AI can improve working together and training. Because of this, teachers need to know how to use technology well and how to teach well to incorporate AI into their lessons effectively.

One key finding that the AI literacy results show is that pre-service teachers are interested in and ethically aware of AI but do not think they can do well with AI projects. Pre-service teachers are scared and nervous about using new tools, making them doubt their abilities (Mauraji et al., 2021). The study by Ji et al. (2022) also shows that pre-service teachers often feel unprepared to deal with complicated modern technologies because of a lack of training. Because of this gap, future teacher training programs must include targeted AI learning experiences that can help build absolute confidence and basic knowledge. Also, BEED pre-service teachers must learn to handle AI well (Aglibot et al., 2024). According to Chou et al. (2023), using self-efficacy training with AI can also change how innovative pre-service teachers are and how helpful and usable AI is.

Moreover, the high proficiency in Pedagogical Knowledge (PK) and Technological Pedagogical Knowledge (TPK) among BEED pre-service teachers indicates their readiness to adapt teaching strategies that integrate AI meaningfully.

This alignment reflects that AI literacy does not exist in isolation; rather, it complements the broader TPACK competencies, empowering pre-service teachers to choose and apply technology effectively across subjects.

Additionally, moderate scores in areas like collaborative AI-related tasks and complex problem-solving applications suggest that while these teachers demonstrate foundational knowledge, further collaborative and applied learning development could strengthen their overall TPACK. Collaborative experiences, particularly in using AI tools to solve complex teaching scenarios, are essential for refining their Pedagogical Content Knowledge (PCK) and Technological Content Knowledge (TCK). Zakaria (2024) stresses the potential of AI in redesigning teaching pedagogies and learning outcomes. Hence, pre-service teachers should acquire the necessary AI skills. Furthermore, this perspective is echoed by Ghamrawi, Shal, & Ghamrawi (2024), who affirms the significance of technological skills, such as utilizing AI-powered tools, in improving teaching practices. The ability to harness AI technologies enhances instructional strategies and prepares future educators to lead an increasingly digital world.

The significance of cognitive learning suggests that knowledge-based and higher-order AI skills, such as applying AI tools, evaluating their classroom fit, or designing basic AI-driven solutions, are essential for developing robust TPACK. In contrast, while important, affective and behavioral components did not significantly predict TPACK.

The high level of ethical knowledge about AI supports the TPACK framework even more by stressing the importance of teaching teachers how to use technology responsibly as a key part of preparing them to deal with ethical issues. The ethical awareness of the BEED pre-service teachers fits with current educational trends that stress responsible AI integration. Ayanwale et al. (2024) emphasize that AI courses should clarify responsible use and ethical concerns. With the progress in the educational landscape, the only way forward is to embrace these new technologies and establish clear guidelines to mitigate potential misuse (Kamalov et al.,2023).

The study's regression analysis revealed that the components of AI literacy collectively explained 25.5% of the variance in TPACK ($R^2 = 0.255$), and the model was statistically significant ($F(4, 134) = 11.445$, $p < .001$). However, among the predictors, only cognitive learning emerged as a significant factor influencing TPACK ($\beta = 0.303$, $p = .003$). This indicates that pre-service teachers with a deeper understanding and ability to apply, evaluate, and create AI tools are better equipped to effectively integrate technology into their teaching practices. However, it is important to note that this study is limited by its single-institution scope, reliance on self-reported data, and cross-sectional design, which may affect the generalizability and causality of the findings.

Overall, findings collectively emphasize the need to foster AI literacy and TPACK in teacher education. The correlation suggests that AI literacy could be a vital skill that enhances TPACK competencies and contributes to a holistic approach to technology integration in teaching. Thus, adding organized, hands-on AI literacy programs to teacher training could make future teachers even more ready to use technology in ways that are good for teaching, moral, and adaptable to the changing needs of the digital age. To deal with problems in the classroom, teachers must always be learning new things. This includes choosing and using technologies that are improved with AI (Ng et al., 2023).

Limitations of the study

While the results of this study offer valuable insights, it is important to recognize their limitations. The findings are based solely on self-reported perceptions from BEED pre-service teachers at a single institution, which may not fully reflect actual classroom practices or be generalizable to other settings. Additionally, the study's cross-sectional design limits the ability to determine causality.

These limitations highlight the need for enhanced and future-ready teacher education approaches. Integrating AI literacy into teacher education programs is crucial for developing a comprehensive understanding of TPACK. Training emphasizing the relationship between AI literacy and TPACK can lead to more effective teaching practices as pre-service teachers learn to navigate the complexities of technology integration in their future classrooms (Mikeladze, 2024; Ning, 2024).

CONCLUSIONS

This study found that third-year BEED pre-service teachers demonstrate a high level of AI literacy regarding intrinsic motivation, ethical awareness, and fundamental knowledge of AI. They regard the responsible use of AI as relevant to their lives. However, a mismatch between their perceived interest in AI and their self-efficacy seems to hinder their confidence in practical applications in acquiring knowledge. Moreover, they seem to lack the ability to design complex AI solutions and engage in collaborative sessions regarding AI, which could limit the possible shared learning experiences.

In line with TPACK, the pre-service teachers demonstrated excellent technological, content, and pedagogical knowledge. However, weaknesses in specific areas, such as mathematics content and technical troubleshooting, highlight the need to improve teacher education programs in subject-specific and technical training.

Moreover, AI literacy is moderately positively correlated with TPACK, which means that the stronger AI knowledge is, the greater the extent to which the individual can combine pedagogy and technology. During regression analysis, AI literacy components were found to jointly explain 25.5% of the variance in TPACK proficiency, with cognitive learning being the only significant predictor. This finding highlights deep cognitive engagement with AI as essential for developing effective technology-integrated teaching practices.

In line with these observations, BEED pre-service teachers should engage themselves in activities where they develop different skills, such as using AI tools in teaching, while at the same time developing their ethical and reflective practices. It is also crucial to establish a peer collaboration setting that encourages professional development. Hence, teacher education institutions should provide targeted workshops that develop practical AI skills through experiential learning tasks, ethical discussions, and AI-based lesson design. Comprehensive and subject-specific TPACK training must prioritize the deeper integration of AI into the curriculum. Supporting this study, professional development for teachers on emerging AI tools and methodologies is essential.

For future research, expanding this study in teacher education institutions is recommended, as well as adopting longitudinal approaches and designs and

observing classroom settings in integrating AI to gain more practical, valuable insights into AI literacy and TPACK relationships.

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DATA AVAILABILITY

All data generated or examined during this study are available for sharing upon receiving an appropriate request directed to the corresponding author.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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