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Exploring Teachers' Technological Pedagogical Content Knowledge in Utilising Artificial Intelligence (AI) for Teaching

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Abstract. Technological pedagogical content knowledge (TPACK) is a theory that describes the knowledge and skills required by a teacher to integrate technology into their teaching. This study aimed to identify the level of TPACK among primary school teachers regarding applying AI technology for teaching. This study employed a quantitative research approach using a survey design. Data was collected through structured questionnaires from in-service primary school teachers in Semporna, Sabah. An independent samples t-test and a one-way ANOVA test were used for data analysis. The results showed that the level of teachers' TPACK in applying artificial intelligence (AI) technology for teaching was high. The independent t-test uncovered no significant difference between teachers' TPACK concerning their gender. However, one-way ANOVA showed a significant difference between teachers' TPACK concerning their age in content, pedagogy, and pedagogical content knowledge compared with their technological content and technological pedagogy. These findings suggest that targeted AI training for older teachers could bridge generational gaps, thereby enhancing AI integration and educational outcomes. This highlights the importance of strong TPACK competencies for effective AI integration, with age-related variations emphasizing the need for tailored support to optimize classroom implementation.

Keywords: Technological pedagogical content knowledge, generative artificial intelligence, professional development, teaching competency, gender

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1. Introduction

In today's rapidly evolving educational landscape, integrating technology is essential for equipping students with the skills to thrive in a digital world. Teachers are expected to use digital tools effectively, especially AI offers new ways to enhance teaching and learning. Generative artificial intelligence (GenAI) such as ChatGPT, MidJourney, Bard, Dalle-E, and Bing Chat, are often used in various fields, especially education. GenAI is an AI system that can generate new content, such as written text, images, and videos, using multiple machine-learning algorithms (Abunaseer, 2023; Mishra et al., 2023). AI has the potential to address significant challenges in education, enhance innovative teaching and learning practices, and ultimately accelerate progress towards Sustainable Development Goal 4 (SDG 4) (UNESCO, 2022). Fundamentally, AI technology has changed how teaching and learning are conducted in various contexts (Wijaya & Weinhandl, 2022). Integrating technology and AI into teaching and learning has become indispensable in the Malaysian education system for helping students to comprehend, analyze, and solve problems in different disciplines (MOE, 2021). It is also stated in the Malaysian Digital Education Policy that education based on digital technology, such as GenAI, can attract student interest and diversify teaching and learning methods (MOE, 2023). However, this optimistic view glosses over significant concerns. Integrating GenAI into teaching and learning challenges is also critical and demands detailed scrutiny.

This rapid and continuous change in GenAI technology requires lifelong learning to improve the competence and skills of students so that Malaysia can remain competitive in terms of education and the economy. Therefore, it is essential to integrate technology into education to ensure that individuals from today's education system are well-equipped to meet the demands of the job market and align with the Fourth Industrial Revolution (4IR). The Ministry of Education Malaysia (MOE) (2023), through the Digital Education Policy, aims to produce a digitally savvy generation that can use digital technology creatively, innovatively, responsibly, and ethically to create and deliver innovation. Moreover, digitally savvy students are able to analyze data scientifically, solve problems, communicate, and collaborate effectively (MOE, 2023). Digital skills and competencies are essential to give every individual the opportunity to succeed in life, secure employment, and become a contributing citizen to the community and the country. These skills not only bridge the gap between individuals and opportunities but also serve as a foundation for fostering innovation, creativity, and economic development (Mahmud et al., 2022).

To produce digitally fluent students, educators' readiness and competence in incorporating technology, particularly GenAI, into the educational process are crucial. This aligns with the MOE's Information and Communication Technology (ICT) Transformation Plan 2019-2023, which emphasizes the usage of ICT and digital tools to equip students with essential skills. These include knowledge, higher-order thinking, leadership abilities, multilingual communication, and a strong foundation in spiritual and moral values (MOE, 2019). Generally, high-quality education can be attained through integrating GenAI in teaching and learning. The ICT Transformation Plan's third goal also explicitly states that it is vital to adopt technology to support educational development (MOE, 2019). The relationship between technology and teaching is well-described by the TPACK framework. This framework was developed by Mishra and Koehler (2006), who emphasized integrating technology in teaching and learning by highlighting the need to balance and master TPACK in teaching and learning.

1.1 Problem Statement

The MOE has introduced and outlined various policies and strategies that relate to the implementation of technology in the education system to enhance teaching quality, such as the Malaysian Education Blueprint 2015-2023 through the 7th Shift and seven main thrusts, focusing on strengthening digital capabilities in schools (MOE, 2023). Furthermore, in line with the various national agendas, the country's 4IR policy and the numerous challenges faced in current teaching and learning processes have also taken steps by drafting the latest policy known as the Digital Education Policy (DEP). The continuous policies and strategies demonstrate the MOE's commitment to transforming the digital education landscape to produce digitally fluent and competitive generations through various initiatives. This policy also highlights that technology-based education, such as AI, can improve students' interest and diversify teaching and learning approaches. The MOE also announced six special initiatives for teachers while celebrating the 53rd National Teacher's Day in 2024. One of these initiatives is to enhance teachers' digital skills, including through special technology empowerment courses, mainly in AI.

There is much potential in using AI to enhance active learning and the participation of students in the learning process (Xia et al., 2022). In addition, it is also used to boost their excitement and create engaging learning environments (Lin & Chang, 2020). For example, AI provides interactive tools such as chatbots and virtual tutors that can interact with students in real time to answer their questions and provide immediate guidance. Other than that, several studies have shown that AI technologies can significantly boost academic achievement (Kim et al., 2021). AI tutors provide real-time, one-on-one assistance and explanations to help students overcome learning challenges and better understand complex subjects. However, teachers face several issues when integrating AI technology in schools. Studies have shown that teachers may not have the understanding and capabilities to teach AI knowledge effectively (Nazaretsky et al., 2022). The absence of AI teacher training, the slow development of AI curricula, and challenges such as insufficient funding, inadequate teaching resources, and limited technical infrastructure all contribute to teachers’ negative perceptions and lack of competence in teaching AI (ISTE, 2023).

It is generally acknowledged that the theoretical framework TPACK helps evaluate teachers' proficiency in integrating technology into teaching and learning (Azam et al., 2023; Huang et al., 2022). As a result, for teachers to apply effective pedagogical techniques when integrating AI into their teaching and learning, their TPACK competencies are essential (Yue et al., 2024). Moreover, understanding teachers' characteristics is important because this information can provide insights into how their gender and age have shaped their TPACK readiness (Lau et al., 2020). Despite the numerous studies on AI, there has been limited research on exploring teachers' TPACK in the context of using AI technology in teaching and learning. In addition, the relationship between teachers' characteristics, such as their gender and age, and teachers' TPACK has rarely been explored (Linder & Berges, 2020).

Therefore, this study aims to evaluate and assess the extent of teachers' TPACK knowledge in utilizing AI technology in teaching and learning. Additionally, it will analyze variations in teacher knowledge based on gender and age. The goal is to ensure that AI technology can be effectively integrated and practised in teaching and learning.

1.3 Research Questions

The three research questions that guide this study are as follows:

1. What is the teachers' TPACK level in utilizing AI technology in teaching and learning?
2. Is there any significant difference between teachers' TPACK knowledge regarding their gender?
3. Is there any significant difference between teachers' TPACK knowledge regarding their age?

2. Literature Review

2.1 TPACK Framework

The TPACK framework was originally developed by Schulman in 1986. At that time, it only consisted of pedagogical content knowledge (PCK). It was a way of thinking about the knowledge required by teachers to integrate content knowledge (CK) and pedagogical knowledge (PK). Later, this PCK framework was improved to make teaching and learning more effective by incorporating technology elements (Mishra & Koehler, 2006). At that time, the framework was known as TPCK. Thompson and Mishra added the word "and" to make it easier to remember and pronounce ("tee-pack"), and thus, the framework became known as TPACK.

TPACK is a teaching framework that integrates three elements: CK, PK, and technology knowledge (TK) to explore how the relationship between these three elements influences teacher professionalism (Koehler & Mishra, 2009). The TPACK framework also serves as a guide and knowledge base required by teachers to integrate technology into teaching and learning more effectively (Koehler et al., 2014). Several researchers have studied various technological tools and diverse pedagogical methods in education using the TPACK framework because it is flexible and broad (Mishra et al., 2010). The three main knowledge elements in the TPACK framework are i) TK, ii) PK, and iii) CK. These three knowledge areas then overlap to form four additional knowledge areas, which are iv) technological content knowledge (TCK), v) technological pedagogical knowledge (TPK), vi) PCK, and vii) TPACK.

CK pertains to a teacher's knowledge about the subject matter that needs to be learned or taught, including concepts, theories, and other content-specific information (Schmidt et al., 2009). CK also varies according to discipline and educational level. For example, the content and concepts required for elementary school science are less complex than those needed for an undergraduate science course. TK refers to the understanding of the capabilities and challenges of technology, as well as the skills required to use technology effectively (Mishra & Koehler, 2006). It also encompasses the interest in keeping up with new technological developments. Teachers with high levels of TK can apply technological tools in their daily tasks. Additionally, they can easily understand the extent to which technology can support or hinder the completion of a task (Koehler & Mishra, 2009). Moreover, PK is the knowledge about the processes and practices of teaching and learning, referring to methods, techniques, processes, and procedures integrated during teaching and learning in the classroom (Schmidt et al., 2009). Teachers with high levels of PK can understand students' learning styles, manage the classroom effectively, and plan lessons and assessments well.

Next is the PCK element. PCK combines content and pedagogy to understand how specific subject aspects can be organized, modified, and presented for teaching purposes (Koehler & Mishra, 2009). This element aims to improve teachers' teaching practices by creating a stronger relationship between content and pedagogy. This element promotes learning and identifies the relationship between pedagogy and supportive practices such as curriculum and assessment. In addition, the TPK element refers to the knowledge of how technology can be innovatively used to provide teaching methods for specific content (Koehler & Mishra, 2009). The TCK element includes knowledge of particular technologies used to implement teaching methods. It also reflects how certain technologies can contribute to the teacher's specific CK (Koehler & Mishra, 2009). Lastly, the TPACK element results from combining all three elements. TPACK refers to the competence of using various technologies in teaching and learning to deliver content using effective pedagogical strategies (Koehler & Mishra, 2009).

AI integration is increasingly emphasized in primary education, yet it demands a nuanced understanding that combines technological familiarity with adaptive pedagogical strategies. The TPACK framework is suited to this challenge as it supports educators in leveraging AI tools to enhance student learning across diverse contexts (Kim et al., 2022; Mishra et al., 2023). Studies by Yue et al. (2024) have demonstrated the framework's applicability in equipping teachers to integrate AI confidently, bridging the gap between traditional pedagogical methods and the technological demands of modern education. Overall, teachers must use appropriate teaching strategies and the right technological tools to implement AI in education successfully.

2.2 Impact of Teachers' Gender and Age on TPACK

Teacher instruction quality is affected by demographic factors such as gender, age, and years of teaching experience. Numerous empirical studies have demonstrated that teachers' characteristics play a crucial role in ICT integration, and that these factors can vary from country to country. For example, some studies have found a notable gender difference, with males showing a greater inclination towards digital instructional development than females (Marin-Dian et al., 2020). Regarding TPACK, studies also show a significant difference between gender and teaching experience (Akram et al., 2021). Scherer et al. (2017) showed that male teachers reported significantly higher capabilities than female teachers in all

TPACK technological categories. On the other hand, a study by Ortega-Sánchez and Gómez-Trigueros (2019) showed that female teachers' TCK was greater than that of male teachers. In contrast, there are inconsistent findings and no significant difference in teachers' TPACK by gender (Castéra et al., 2020; Zhakiyanova et al., 2023).

Teachers' age also impacts their teaching ability, affecting their technology usage and teaching experience (Nasir & Ngah, 2022). Generally, teachers' proficiency with digital or information and communications technology is inversely correlated with their age (Anzari et al., 2021; Saikkonen & Kaarakainen, 2021). This shows that younger teachers are more likely to be more self-assured when utilizing technology. Individuals over 25 to 40 demonstrate a better capacity and attitude toward using technology (Jiménez-Hernández et al., 2020). According to other studies, educators' attitudes and behaviours vary by age. Regarding knowledge, digital literacy, and managing instructional content, people over 40 are less proficient with technology (López Belmonte, 2020). In contrast, Cetin-Berber and Erdem (2015) found that age groups were not a significant factor in TPACK perceptions. In the field of AI education, little research has been done on differences in the level of teachers' TPACK based on the gender and age of the teacher.

3. Methodology

3.1 Research Design

This study used a quantitative research approach utilizing descriptive and inferential analyses. A cross-sectional survey method was adopted to analyze the extent of teachers' TPACK in applying generative AI within the teaching and learning process. Data was collected through structured questionnaires administered via Google Forms. The target population for this study consisted of primary school teachers in Semporna, Sabah.

3.2 Population and Sampling

The researcher used a population of primary school teachers in the Semporna district, Sabah, Malaysia. This district's primary school teachers' population numbers 1,242 (Sabah Education Department, 2024). Using the Krejcie and Morgan (1970) table, the suitable sample size for a population of 1,242 teachers was 297 samples. However, owing to practical constraints such as response rates and participant availability, only 110 responses were obtained. The convenient sampling method prioritized accessibility and voluntary participation during the data collection.

3.3 Research Participants

This study involved 105 in-service primary school teachers from Semporna, Sabah. Based on the descriptive statistics analysis conducted on gender demographics, 54 participants (51.4%) are male teachers, while the remaining 51 (48.6%) are female teachers. The age distribution of the participants showed that 23 teachers (21.9%) were below 30 years old, 32 teachers (30.5%) were between 31-40 years old, 29 teachers (27.6%) were between 41-50 years old, and the remaining 21 teachers (20%) were aged between 51-60 years. In terms of teaching experience, 27 teachers (25.5%) had less than five years of experience, 21 teachers (20%) had between 5-10 years of experience, 17 teachers (15.5%) had 11-15 years of experience, another 17 teachers (17.3%) had 16-20 years of experience, and 23 teachers (21.8%) had more than 20 years of teaching experience. The demographics of the participants are presented in Table 3:

Table 3: Demographic of the Participants

Category	N	%
Gender		
Male	54	51.4
Female	51	48.6
Age		
Below 30 years	23	21.9
31-40 years	32	30.5
41-50 years	29	27.6
51-60 years	21	20
Teaching Experience		
Below five years	27	25.5
5-10 years	21	20
11-15 years	17	15.5
16-20 years	17	17.3
More than 20 years	23	21.8

3.4 Research Instrument

To investigate the level of teachers' TPACK in utilizing AI technology in teaching and learning, this study adapted the TPACK survey based on the validated scale developed by Schmidt et al. (2009). This survey was adapted to assess teachers' competencies across three fundamental domains within the TPACK theoretical framework. Consequently, the survey consisted of five items for Section A and 28 items for Section B, which were adopted and adapted to align with the specific objectives of this study, as shown in Table 1:

Table 1: Research Instrument

Section	Item Components	Total Items
Section A	Demographic	5
Section B	Content Knowledge (CK)	4
	Pedagogical Knowledge (PK)	4
	Technological Knowledge (TK)	3
	Pedagogical Content Knowledge (PCK)	6
	Technological Content Knowledge (TCK)	3
	Technological Pedagogical Knowledge (TPK)	3
	Technological Pedagogical Content and Knowledge (TPACK)	5
	Total	**33**

Furthermore, the items used a five-level Likert scale, which in this instrument ranges from 1 = "Strongly disagree" to 2 = "Disagree," 3 = "Neutral," 4 = "Agree," and 5 = "Strongly agree."

3.4.1 Reliability

Creswell (2014) asserts that it is crucial to reestablish reliability during data analysis when one changes an instrument or combines instruments in a study because the original reliability might not hold for the new instrument. Hence, internal consistency tests are required. Since the instrument was created using a Likert scale, Cronbach's alpha reliability coefficient was used to conduct this test. (Tavakol & Dennick, 2011). The higher the Cronbach's alpha reliability coefficient, the more reliable the scale is (Creswell, 2014). In other words, the closer the coefficient value is to 1.00, the higher the reliability indicates that the items consistently measure the same construct. A pilot test was conducted with 30 primary school teachers in Kuala Lumpur to validate the instrument and confirm its reliability before the primary data collection.

Table 2: Cronbach's Alpha Coefficients of Reliability of all Constructs of TPACK

Constructs of the questionnaire	No. of items	Alpha value
Content Knowledge (CK)	4	0.932
Pedagogical Knowledge (PK)	4	0.911
Technological Knowledge (TK)	3	0.834
Pedagogical Content Knowledge (PCK)	6	0.960
Technological Content Knowledge (TCK)	3	0.87
Technological Pedagogical Knowledge (TPK)	3	0.957
TPACK	5	0.944
Overall	28	**0.976**

Table 2 shows the reliability of all TPACK constructs investigated using Cronbach's alpha scale. According to Tavakol and Dennick (2011), alpha values above 0.7 indicate acceptable reliability, while values exceeding 0.9 represent excellent reliability. In this study, the overall reliability ($\alpha = 0.976$) has high alpha values, which means that the instrument is reliable for measuring these different types of knowledge.

3.5 Data Collection Procedure

A Google Form questionnaire was prepared to obtain data for this study. This approach was selected because it significantly reduces the time researchers spend on data collection compared to traditional paper-based questionnaires (Nayak & Narayan, 2019). Within one week, the Google Form link was distributed via Telegram and WhatsApp to the selected teachers in the Semporna district.

3.6 Data Analysis

Two primary methods were employed for analyzing the collected data and information: descriptive analysis and inferential analysis. Descriptive analysis was used to summarize and describe the basic features of the data to provide simple summaries of the sample and the measures. This included the use of measures of central tendency such as mean and median, as well as measures of variability such as standard deviation and range to answer the first research question: *i) What is the level of teachers' TPACK in utilizing the use of AI technology in teaching and learning?* On the other hand, inferential analysis was used to conclude the data that are subject to random variation. Thus, an independent t-test and

ANOVA were used to answer the second and third research questions: *ii) Are there any significant differences between teachers' TPACK knowledge regarding their gender? iii) Are there significant differences between teachers' TPACK knowledge and age?* This included hypothesis testing to examine relationships between variables and to make predictions. The interpretation of mean scores is based on the scale used by Nunally (1978).

During the data analysis process, five outliers were removed from the dataset based on boxplots to prevent distortion in the results. This left a final sample size of 105 valid responses. This step ensured that the dataset met the assumptions required for inferential statistical tests, such as normality and homogeneity of variance. The statistical analysis was conducted using IBM SPSS Statistics 29 software. After completing the data analysis, the data was significantly analyzed based on demographics, TPACK domain, independent t-test analysis of teachers' TPACK differences according to gender, and ANOVA analysis of teachers' TPACK differences according to age.

4. Results

4.1. Level of Teachers' TPACK in Practising the use of AI Technology in Teaching and Learning

The first research question investigates teachers' TPACK level in practising AI in their teaching and learning. Table 3 shows overall findings for the level of TPACK sub-dimensions. The investigation used descriptive statistical tests, including the mean and standard deviation. Among all domains of TPACK, the highest mean value was obtained by the PK, i.e., 4.33 (S.D = 0.57), while the TPACK domain obtained the lowest value of mean 3.62 (S.D = 0.67). TK, TCK, TPK, and TPACK were moderately high according to the weighted mean values. In contrast, CK, PK, and PCK were found to be at high levels. All variables were checked and normally distributed.

Table 3: Descriptive Analysis of Teachers' TPACK

Dimension	M	S. D	Level
Content Knowledge (CK)	4.21	0.57	High
Pedagogical Knowledge (PK)	4.33	0.57	High
Technological Knowledge (TK)	3.71	0.62	Moderately high
Pedagogical Content Knowledge (PCK)	4.12	0.60	High
Technological Content Knowledge (TCK)	3.65	0.65	Moderately high
Technological Pedagogical Knowledge (TPK)	3.63	0.70	Moderately high
TPACK	3.62	0.67	Moderately high

4.2. Differences between Teachers' TPACK Knowledge regarding their Gender
The assumption was performed in line with the second research question, and an independent sample t-test was conducted to determine whether all TPACK domains differed by gender. The results of the analysis are presented in Table 4.

Table 4: Independent T-Test Analysis of Teachers' TPACK based on their Gender

	Male		*Female*		*t*	*df*	*p*
	M	*SD*	*M*	*SD*			
CK	4.14	0.54	4.28	0.60	-1.22		0.23
PK	4.32	0.53	4.35	0.63	-0.30		0.77
TK	3.69	0.64	3.74	0.60	-0.44		0.66
PCK	4.08	0.58	4.17	0.64	-0.73	103	0.47
TCK	3.64	0.65	3.67	0.64	-0.24		0.81
TPK	3.56	0.75	3.72	0.65	-1.19		0.24
TPACK	3.61	0.71	3.65	0.63	-0.30		0.76

An independent sample t-test was conducted to compare the TPACK of male and female teachers. The analysis revealed that female teachers scored slightly higher than their male counterparts across all domains of the TPACK framework: CK, PL, TK, PCK, TCK, TPK, and TPACK, although not statistically significantly. The p-values reported indicate no statistically significant differences in TPACK scores by gender. Therefore, there is no significant difference in TPACK scores between male and female teachers. We fail to reject the null hypothesis, indicating no significant difference between teachers' TPACK for their gender.

4.3. Differences between Teachers' TPACK knowledge regarding their Gender
The assumption was performed in line with the third research question. A one-way ANOVA was conducted to compare the teachers' TPACK knowledge according to age (below 30 years, 31-40 years, 41-50 years, and 51- 60 years). The results of the test are presented in Table 5:

Table 5: ANOVA Analysis of Teachers' TPACK according to their Age
ANOVA

		SS	*df*	*MS*	*F*	*p*
CK	Between Groups	2.822	3	.941	3.045	.032
	Within Groups	31.194	101	.309		
	Total	34.015	104			
PK	Between Groups	3.268	3	1.089	3.525	.018
	Within Groups	31.211	101	.309		
	Total	34.479	104			
TK	Between Groups	.337	3	.112	.289	.833
	Within Groups	39.234	101	.388		
	Total	39.570	104			
PCK	Between Groups	3.174	3	1.058	3.067	.031
	Within Groups	34.840	101	.345		
	Total	38.015	104			

TCK	Between Groups	.684	3	.228	.539	.657
	Within Groups	42.734	101	.423		
	Total	43.418	104			
TPK	Between Groups	.456	3	.152	.300	.826
	Within Groups	51.216	101	.507		
	Total	51.672	104			
TPACK	Between Groups	.100	3	.033	.072	.975
	Within Groups	46.546	101	.461		
	Total	46.645	104			

As shown in Table 5, some TPACK components showed a statistically significant difference in teachers' age groups. One-way ANOVA for CK, PK, and PCK demonstrated significant differences in TPACK scores among different age groups. Therefore, the null hypothesis for domains CK, PK, and PCK is rejected. Other domains, such as TK, TCK, TPK, and TPACK, do not show significant variations with age.

The post hoc Tukey analysis was carried out to ascertain the source of the difference in the identified dimensions of the TPACK scale. The test revealed significant CK and PK (p<0.05). Teachers aged 41-50 years have significantly higher CK and PK than the age group of 51 - 60 years. Meanwhile, there was no statistically significant difference between age groups in PCK.

5. Discussion

5.1 Level of Teachers' TPACK in utilizing AI Technology in Teaching and Learning

This study explored teachers' TPACK in utilizing generative AI in the teaching and learning process. According to the descriptive results of this study, the average score across the seven sub-dimensions of TPACK suggests that teachers generally have moderately high levels of TPACK. The results indicate that the PK obtained the highest competence of teachers among all other domains, which shows that the teachers seem more confident in pedagogical knowledge than different elements of expertise. This finding is consistent with findings by Bingimlas (2018) and Koh et al. (2010), highlighting the prominence of teachers' pedagogical knowledge. PK is the knowledge about understanding teaching methods, managing classrooms effectively, and planning lessons and assessments, focusing on how students learn and instruction is delivered (Koehler & Mishra, 2009). This high PK is particularly valuable for integrating AI into teaching as it enables teachers to adapt AI tools to align with effective classroom management and student-centred instruction.

Teachers' abilities in CK and TK ranked second and third highest. This indicates a solid foundational understanding of their subject matter, teaching strategies, and integrating both. The dimensions integrated with AI technology, such as TK, TCK, TPK, and TPACK, scored moderately high. While teachers are skilled in utilizing AI technology, these scores indicate room for improvement in their pedagogical and content knowledge. The lowest scores in the AI technology-integrated dimensions (TK, TCK, TPK, TPACK) compared to core teaching skills

(CK, PK, PCK) highlight a need for targeted professional development in technology use. It is essential to encourage teachers to utilize AI technology (Kim et al., 2022). Enhancing teachers' TK can help them use AI more creatively in the classroom, integrating traditional teaching with modern technology (Pazin et al. 2022). Professional development focused on AI tools can build teachers' confidence and skills, making it easier to use these tools to improve learning in different subjects.

5.2 Teachers' TPACK Differences according to Gender

According to the results on the teachers' TPACK differences according to gender in every TPACK domain, female teachers performed slightly better than male teachers. This indicates no statistically significant differences in TPACK scores by gender. This result aligns with the findings of Castéra et al. (2020) and Zhakiyanova et al. (2023), who found no gender differences in TPACK among teachers. It is, however, in contrast to a study by Ortega-Sánchez and Gómez-Trigueros (2019) that found higher TCK among female teachers while Akram et al. (2021) and Scherer et al. (2017) who reported higher TPACK capabilities among male teachers. These varied results show that gender is not a significant independent variable regarding the dimensions of TPACK (Tuncer & Dikmen, 2018). This suggests that TPACK professional development can be designed to include all teachers. It can focus on building these competencies broadly without needing to tailor programmes specifically by gender. This approach aligns with findings in studies that showed no significant gender differences in TPACK, emphasizing the framework's general applicability across demographic groups.

5.3 Teachers' TPACK Differences according to Age

The findings from this study align with and expand upon prior research on TPACK, particularly in the context of age differences among teachers. The significant differences between CK, PK, and PCK across different age groups resonate with several earlier studies. Aligned with studies by Anzari et al. (2021) and Saikkonen and Kaarakainen (2021), this study revealed that younger teachers generally exhibit higher levels of proficiency in digital and technological teaching. Notably, significant differences in CK, PK, and PCK were observed among age groups, with teachers aged 41-50 outperforming those aged 51-60. This suggests that younger and middle-aged teachers are more effective at integrating technology into their teaching practices. This is likely owing to their greater exposure to and familiarity with digital tools, as indicated by Jiménez-Hernández et al. (2020).

On the other hand, Cetin-Berber and Erdem (2015) found that age groups were not a significant factor in TPACK perceptions. Given the findings in this study, teachers aged 51-60 could benefit from targeted professional development across all TPACK domains, including initial and ongoing support to integrate AI technologies effectively into their pedagogy. Specifically, professional development programmes might focus on enhancing TK for older teachers to bridge potential technology-use gaps (Mahmud et al., 2020). Instead, training for younger teachers could emphasize PK to support a balanced TPACK skillset. Such targeted training could foster more effective AI integration in teaching, aligning TPACK competencies with the developmental needs of each age group.

6. Conclusion

This study investigated primary school teachers' TPACK in using generative AI in teaching. The findings revealed that teachers have a moderately high level of TPACK overall, with PK being the most substantial domain. Gender differences in TPACK were insignificant, indicating that male and female teachers perform similarly across all domains. However, significant age differences were found, with younger and middle-aged teachers (41-50 years) outperforming older teachers (51-60 years) in CK, PK, and PCK. This indicates that there may be a generational gap in technological skills, highlighting the necessity for focused professional development in AI technology, particularly for senior educators. Enhanced training programmes are crucial for effective AI integration in teaching practices, which can lead to improved learning outcomes.

6.1 Limitation and Future Research

This study focused solely on teachers in Semporna, Sabah. It is recommended that the survey scope be expanded to other zones in Sabah and other states in Malaysia. Comparing future study findings with the current results can help researchers identify factors that influence the study variables. Moreover, this study only analysed the differences between teachers' TPACK regarding their gender and age. The reliance on convenience sampling introduces a potential for response bias, as respondents may not fully represent the broader population. Future studies could address this limitation by implementing systematic follow-ups, offering incentives to improve participation, or extending the data collection period to enhance the response rate. Future research should also continue to investigate the impact of demographic factors such as teaching experience, ethnicity, or school location on TPACK and create strategies to support teachers' ongoing professional development in AI technology.

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