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Technological, pedagogical, and content knowledge among mathematics teachers: Difference of teaching experience and certification status

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Abstract

Background: Teachers continue to face challenges in applying Technological, Pedagogical, and Content Knowledge (TPACK) in classroom settings. Many mathematics teachers, in particular, lack adequate preparation and mastery of the three core components of TPACK.
Aim: This study aims to investigate and analyze differences in TPACK proficiency among mathematics teachers based on their teaching experience and certification status.
Method: Adopting a mixed-method approach with a sequential explanatory design, the study involved 65 Islamic Junior and Senior High School mathematics teachers in Palu City, selected through proportionate stratified random sampling. Additionally, four teachers were interviewed to gain deeper insights. The instruments used included TPACK questionnaires and structured interview guidelines.
Results: The findings revealed no significant differences in TPACK proficiency between certified and non-certified mathematics teachers. While teachers demonstrated a solid understanding of content and appropriate teaching methods, they seldom incorporated technology into their instruction. Furthermore, teaching experience showed no substantial impact on TPACK proficiency. Junior teachers were observed to have better familiarity with technology, while senior teachers exhibited greater adaptability in managing diverse classroom situations.
Conclusion: Certification status and teaching experience do not significantly influence TPACK proficiency among mathematics teachers. The primary barrier to integrating technology lies in limited access to adequate facilities. Continued professional development initiatives are essential to enhance teachers' technological competencies and their integration into classroom practices.

INTRODUCTION

The rapid advancement of science and technology has profoundly influenced the competencies required of teachers. Integrating technology into teaching practices has become indispensable, particularly in learning activities (Helsa et al., 2023). Teachers are no longer required to only master teaching methods and subject matter but must also acquire the ability to integrate technology effectively into their teaching practices (Hadi & Kurniawati, 2022; Vu, 2018). This requires a seamless combination of technological proficiency, pedagogical expertise, and content knowledge (Galanti et al., 2021; Khoza & Biyela, 2020). In today's educational and societal landscape, the European Space for Higher Education highlights the urgent need to reevaluate digital pedagogy to enhance

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the quality of education. Mishra and Koehler emphasize that high-quality 21st-century education relies on a deep understanding of the interconnectedness between technology, content, and pedagogy. This understanding is essential for developing digital competencies and leveraging them effectively in teaching (Caena & Redecker, 2019; Meroño et al., 2021). These interconnections form the foundation of Technological Pedagogical Content Knowledge (TPACK), a framework that encapsulates the integration of technology, pedagogy, and content in education.

Knowledge about the effective use of technology based on knowledge of teaching materials and how to teach them is called Technological Pedagogical Content Knowledge (TPACK) (Mishra, 2019). The concept of TPACK was initially introduced by Shulman, emphasizing the integration of pedagogical knowledge and content knowledge in education (Salas-Rueda, 2019). Mishra and Koehler (Alrwaished et al., 2017) expanded this model by incorporating technological knowledge, creating a comprehensive framework for integrating technology into pedagogy and content. TPACK represents an understanding of how technology can be used in teaching and its transformative impact on instructional practices (Farikah & Al Firdaus, 2020). It focuses not only on the application of technology but also on its purposeful utilization to enhance the learning process. The core components of TPACK include Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK). These are further integrated into four interconnected components: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical and Content Knowledge (TPACK) (Mishra, 2019). The relationship between these components is presented in the following figure.

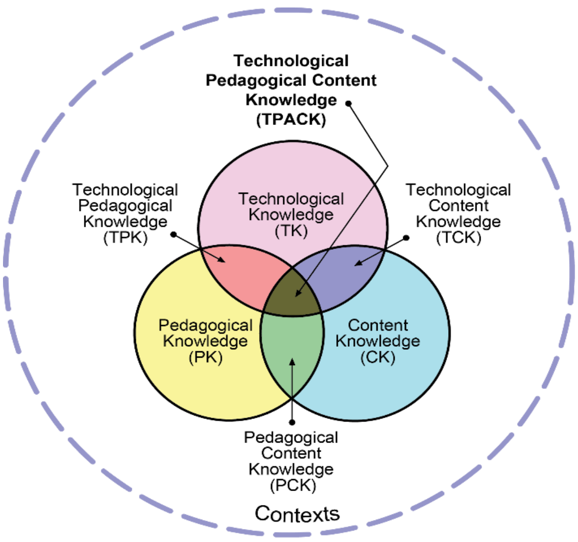

Figure 1. TPACK Component (Mishra, 2019)

TPACK has been applied across various scientific disciplines, including mathematics education (Akkoc & Alan, 2020). Several studies highlight that a teacher's competence can be assessed through their TPACK abilities (Bower et al., 2017; Tanak, 2020). The effective implementation of the TPACK framework in mathematics learning relies on teachers' adequate understanding of its practical application in classroom settings (Akkoc & Alan, 2020). As a critical component of teacher professionalism, TPACK emphasizes the importance of integrating technology seamlessly into the learning process (Mailizar et al., 2021). However, numerous challenges persist in applying TPACK in education (Mailizar et al., 2021; Nursiah et al., 2021; Wahyuni, 2019). These challenges include insufficient technological infrastructure, limited resources, and teachers' lack of confidence, skills, and mental preparedness, which significantly hinder the integration of technology in schools (Schmid et al., 2024). Specifically in mathematics education, many teachers struggle to integrate technology effectively because they lack mastery of the core components of TPACK (Bowers & Stephens, 2011). Furthermore, data from the Ministry of Education and Culture and the Ministry of Religious Affairs reveal consistently low teacher competence levels nationwide (Ichsan et al., 2023; Mardhatillah & Surjanti, 2023). These challenges emphasize the need for targeted interventions to strengthen teachers' confidence and skills in using technology effectively in mathematics education.

Recognizing these challenges, professional development and teaching experience play a crucial role in improving teacher competence and addressing the gaps in TPACK proficiency. In the theory of teacher professional development, Guskey proposes a model of teacher change, emphasizing that improvements in teacher competence often begin with professional development initiatives (Sims et al., 2023). Teachers' professional status is validated through certifications aligned with relevant legislation, reflecting their adherence to professional standards. Beyond certification, teaching experience plays a significant role in shaping teacher competence. The Refined Consensus Model (RCM) identifies personal Pedagogical Content Knowledge (pPCK) as a critical component of PCK, representing professional knowledge gained through reflective experiences in education (Carlson et al., 2019). Various factors, including teaching experience, interact to enhance teacher competence (Hume et al., 2019). Furthermore, teaching experience influences the teaching styles of novice and experienced teachers, often leading to different instructional approaches (Muthmainnah & Marsigit, 2018). It also affects teachers' ability to adapt to online learning environments, highlighting its role in modern educational contexts (Santosa & Sarwanta, 2021). Thus, fostering continuous professional development and leveraging teaching experience are essential to overcoming TPACK-related challenges and enhancing the overall quality of education.

Several studies have examined the concept of TPACK, including analyzing and exploring the components of teachers' TPACK (Akhwani & Rahayu, 2021; Alrwaished et al., 2017; Yurinda & Widyasari, 2022), prospective teachers (Nursiah et al., 2021) and integrating the Technology, Pedagogy, and Content Knowledge (TPACK) framework in mathematics learning (Rafi & Sabrina, 2019). Other studies examined the influence of Self-Efficacy, Teaching Experience, and Teacher Age on Computer Mastery (Santosa & Sarwanta, 2021), the impact of TPACK on Online Teacher Professional Development (Mailizar et al., 2021) and readiness to become a professional teacher (Zulhazlinda et al., 2023). Previous research focused on analysing teachers' TPACK skills descriptively and their impact on teacher professional development. This study differs from prior research in using a comprehensive quantitative and qualitative analysis of TPACK skills based on teaching experience and profesionalism. This allows the authors to understand the dynamics and contexts that influence the implementation of TPACK in the classroom. By linking theoretical frameworks with practical teaching experiences, this study helps bridge the gap between academic studies and classroom realities, ensuring the relevance and applicability of TPACK in mathematics education. Therefore, this study aims to describe and examine the differences in TPACK among mathematics teachers based on experience and certification status.

METHODS

Design

This study employed a mixed-methods approach to provide a comprehensive understanding of mathematics teachers' TPACK (Technological Pedagogical Content Knowledge) in relation to their teaching experience and professionalism. A sequential explanatory design was used, beginning with a quantitative phase followed by a qualitative phase. In the quantitative phase, comparative and regression analyses were conducted using inferential statistics to test hypotheses regarding the impact of professionalism and teaching experience on teachers' TPACK abilities. After obtaining quantitative results, a qualitative phase was conducted using a case study approach. This phase involved in-depth interviews to explore how teachers apply their TPACK skills in everyday teaching practices.

Participants

The population in this study consisted of all mathematics teachers who taught at Islamic Senior and Junior Highschool (MA and MTs) in Palu. Sampling was conducted using probability sampling technique, namely proportionate stratified random sampling. The researcher chose this technique because the sample was grouped first into groups of teachers who already had teaching certificates and those who did not. Furthermore, calculations were carried out using sampling rules based on the Slovin formula to obtain the number of samples. Based on this formula, the number of samples to be studied was 65 teachers. Furthermore, of the 65 teachers, the proportion of the number of samples from each group of teachers who already have teaching certificates and who do not is as follows

Certified Teacher $= \frac{43}{77} \times 65 = 36{,}3 \approx 36$

Uncertified Teacher $= \frac{34}{77} \times 65 = 28{,}7 \approx 29$

Instruments

The research instruments included primary and supporting tools. The primary instrument was the researcher, while the supporting instruments consisted of a TPACK questionnaire and interview guidelines. The TPACK questionnaire underwent expert validation by specialists in mathematics education and learning technology, achieving a validity index score of V = 0.82, indicating its suitability for use. The questionnaire was distributed both online and offline via Google Forms at the link bit.ly/KuesionerTPACK_Guru. It comprised two sections: demographic data (school, teaching experience, and certification status) and TPACK components. The TPACK section covered seven aspects—Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical and Content Knowledge (TPACK)—using a Likert scale.

Data Analysis

Quantitative data were first converted from nominal to interval scale using the method of successive intervals (MSI) and then analyzed descriptively. Hypotheses were tested using inferential statistics, including a t-test to compare the TPACK abilities of certified and uncertified teachers and regression analysis to evaluate the effect of teaching experience on TPACK skills. Prerequisite tests, such as normality and homogeneity tests, were conducted before hypothesis testing. Normality was assessed using the Shapiro-Wilk test, while homogeneity was tested with the Levene test at a 5% significance level (Badjeber & Wicaksono, 2020). For regression analysis, additional tests for normality and linearity were performed, with the linearity test conducted using an F test at the same significance level.

In the qualitative phase, research subjects were selected based on TPACK questionnaire results. One certified and one uncertified teacher with scores closest to the average for their respective groups were chosen. Additionally, a teacher with the longest teaching experience and one with the shortest experience were included to provide diverse perspectives.

RESULTS AND DISCUSSION

Result

The description of TPACK scores was obtained by initially transforming the ordinal data from the questionnaire responses into interval data using the Method of Successive Intervals (MSI). The findings indicate that the average TPACK ability score of mathematics teachers at MTs and MA in Palu City is 109.45, equivalent to 68.33%. The average scores for each TPACK aspect are illustrated in Figure 2 below.

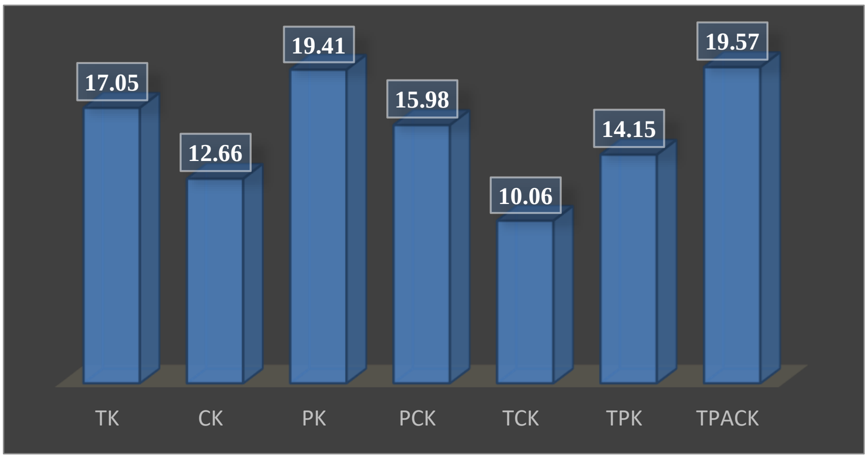

Figure 2. Distribution of the TPACK score of Each Component

The average trend of TPACK skills of teachers with less than 15 years of service is better than those with more than 15 years of service. This can be seen in the following figure 3.

Figure 3. Distribution of TPACK score by working period

In more detail, it was found that neither junior nor senior teachers excelled in mastering all three core components of TPACK. For the TK (Technological Knowledge) component, teachers with less than 10 years of teaching experience achieved relatively higher average scores. Conversely, in the PK (Pedagogical Knowledge) component, teachers with the longest tenure of 31 to 35 years recorded the second highest average. Meanwhile, the average scores for the CK (Content Knowledge) component were nearly identical across all groups. These findings are summarized in Table 1 below.

Table 1. Score Description of Each Component of TPACK of Mathematics Teachers Based on Teaching Experience

Teaching Experience	TK	CK	PK	PCK	TCK	TPK	TPACK
0-5 years	19,67	12,15	19,08	15,71	9,81	13,59	17,79
6-10 years	18,54	14,03	19,47	15,42	11,28	15,99	21,56
11-15 years	20,17	13,37	23,47	18,49	10,88	16,53	21,91
16-20 years	16,64	12,72	19,08	16,14	9,74	13,30	17,57
21-25 years	15,13	13,51	17,96	15,78	9,74	13,68	19,67
26-30 years	15,39	10,78	16,14	15,21	9,37	12,44	20,02
31-35 years	13,84	12,07	20,69	15,10	9,59	13,54	18,47

This study also examines the variable of teacher professionalism, measured through certification status. The findings indicate that certified teachers have a slightly higher average TPACK ability score (109.8) compared to non-certified teachers (108.9). Among certified teachers, those certified between 2021 and 2023 achieved the highest average TPACK score, with 130.13 or 81.24%. Conversely, the lowest average score was recorded by teachers certified between 2012 and 2014. The study further analyzed the average scores for each TPACK component based on certification status. The results reveal that certified teachers outperform their non-certified counterparts in six components: Pedagogical Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical and Content Knowledge (TPACK). However, non-certified teachers demonstrated stronger abilities in the

Technological Knowledge (TK) component. These details are further illustrated in the following figure.

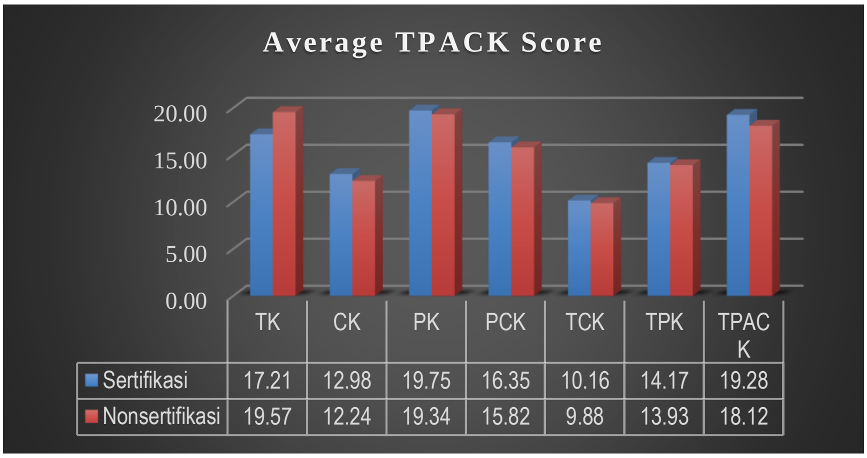

Figure 4. Average Score of each Component of TPACK

After confirming that the TPACK score data met the classical assumptions, a hypothesis test was conducted to compare the means using a t-test. The results of the t-test for the mean difference in TPACK scores between certified and non-certified mathematics teachers indicated a significance value of 0.844, which exceeds the threshold of 0.05. Therefore, the null hypothesis (H_0) is accepted, meaning that the average TPACK ability of certified mathematics teachers in Palu City is not significantly better than that of non-certified teachers. Additionally, a simple linear regression analysis was performed to assess the potential effect of the independent variable (X), teaching experience, on the dependent variable (Y), TPACK ability, under the assumption of a linear relationship. The regression analysis yielded a significance value of 0.547, which is also greater than 0.05. As a result, the null hypothesis is accepted, indicating that there is no significant effect of teaching experience on the TPACK ability of mathematics teachers in Palu City. A simple linear regression equation was derived from the data analysis.

$$Y = 111{,}512 - 0{,}172X$$

In the regression equation above, the regression coefficient value is -0.172. The regression coefficient is negative. This means that for every 1% increase in the work experience variable, the TPACK ability variable decreases by 0.172.

The study results revealed a diverse range of teaching tenures among the participants, spanning from 1 year to 32 years, highlighting significant variations in experience levels. This variation provided a valuable opportunity to explore how different lengths of teaching experience influence the understanding and application of TPACK. For the qualitative phase, two participants were deliberately selected to represent these extremes in teaching tenure. The teacher with the shortest tenure of 1 year, coded as "S1," offered insights into the challenges and perspectives of novice educators, particularly their approach to integrating technology into teaching. Conversely, the teacher with the longest tenure of 32 years, coded as "S2," provided a contrasting viewpoint, showcasing the adaptability and accumulated wisdom of veteran educators in navigating technological and pedagogical changes over time. These interviews provided nuanced perspectives that are visually summarized and presented in Table 2.

Table 2. Description of mathematics teachers' TPACK based on teaching experience

TPACK Aspect	Subject S1	Subject S2
TK	Subject S1 can install specialized software to support learning, such as GeoGebra, and has participated in training activities for the preparation of teaching materials based on IT media and lesson study training in the digital era online through the MOOC Pintar platform (https://pintar.kemenag.go.id).	Subject S2 has never installed specific software to support learning or participated in training activities related to the use of IT. S2 also answered that she could not learn technology quickly.
CK	Subject S1 stated that he experienced no difficulties understanding or teaching mathematics material. S1 has also participated in training activities to prepare media-based teaching materials online through the MOOC Pintar platform.	Subject S2 had an easy understanding of the mathematics material taught and also participated in training activities for making learning media, even though it has been quite a while
PK	S1 commonly uses direct learning strategies and group discussions depending on the material being taught. Subject S1 has attended lesson study training in the digital era online through the MOOC Pintar platform.	S2 also uses direct learning strategies and group discussions. Subject S2 has attended training related to innovative learning methods.
PCK	Subject S1 first looks at the lesson plan (RPP), then compiles teaching material slides and LKPD based on the material database that has been owned. S1 only makes minor updates every year, especially in the practice questions given	Subject S2 makes LKPD or searches for material summaries via Google
TCK	Subjects S1 had yet to deliver the material taught using technology. Inadequate facilities constrain subject S1	Subjects S2 also had yet to deliver the material taught using technology because they were constrained by the ability to utilize technology.
TPK	Subject S1 ever used Google Forms to conduct a quiz to determine students' initial knowledge at the beginning of learning. Subjects S1 agreed that students would be happier if they learned using technology-based media, but they rarely use it in class.	Subject S2 has used the Moodle application prepared by the Ministry of Religious Affairs to conduct daily tests. but subjects S2 also rarely use technology in class.
TPACK	Subjects S1 have never used media and technology to deliver material during classroom learning	Subjects S2 also have never used media and technology to deliver material during classroom learning

This study not only explores the qualitative aspects of teaching experience but also investigates teacher professionalism. One participant was selected from each category of certified and non-certified teachers. The selection was based on the TPACK questionnaire scores, ensuring the chosen subjects had scores close to the average for their respective groups. The non-certified teacher participant was assigned the code "S3," while the certified teacher participant was coded as "S4." The findings from these interviews are presented in Table 3 below.

Table 3. Description of mathematics teachers' TPACK based on certification status

TPACK Aspect	Subject S3	Subject S4
TK	Subject S3 stated that he had only ever installed math software during his lectures but never to support learning. However, subject S3 has never participated in training activities on the use of technology in learning	The same thing also happened to subject S4. However, S4 has participated in activities related to using ICT through intelligent platforms.
CK	Subject S3 stated she had no difficulties understanding or teaching mathematics materials. When teaching, she used personal books, e-books, and additional material obtained through Google. Regarding training related to the development of teaching materials, subject S3 has never attended any training.	Subject S4 also had the same statement as S3, but S4 had attended training in making interactive teaching materials.
PK	Subjek S3 sering menggunakan strategi pembelajaran langsung dan diskusi kelompok. Namun, Subyek S3 belum pernah mengikuti pelatihan.	Subjects S4 also often use direct learning strategies and group discussions. Subject S4 has attended training on learning innovation.
PCK	Subjects S3 prepare the material to be taught by referring to various references such as books or Google.	Subjects S4 also prepare the material to be taught by referring to various references such as books or Google.
TCK	Subject S3 said they had never delivered material using technology. S3 has an excellent ability to use technology but needs more facilities	Limited facilities are an obstacle, so subject S4 has never taught using technology.
TPK	Subject S3 never used any technology to conduct evaluations	Subject S4 used the Moodle application the Ministry of Religious Affairs prepared to conduct daily tests
TPACK	Subjects S3 have never used media and technology to deliver material during classroom learning.	Subjects S4 also have never used media and technology to deliver material during classroom learning.

Discussion

Based on the data analysis of the research findings, it was determined that there was no significant difference in the TPACK abilities of mathematics teachers in Palu City who were certified and those who were not. This result deviates from the initial research hypothesis but is consistent with findings from previous studies (Devitha et al., 2021; Nuruzzakiah et al., 2022; Sukmara & Nurhikmahyanti, 2015). The difference in TPACK abilities between certified and non-certified teachers is only evident in the TK (Technological Knowledge) component. For the remaining six components—CK (Content Knowledge), PK (Pedagogical Knowledge), TPK (Technological Pedagogical Knowledge), PCK (Pedagogical Content Knowledge), TCK (Technological Content Knowledge), and TPACK—no significant differences were observed (Busnawir et al., 2023). These findings suggest that there are minimal differences across most TPACK components.

In general, both certified and non-certified teachers need to learn how to use media and technology effectively to deliver materials during classroom instruction.

Despite having adequate skills in utilizing technology, both groups face challenges due to limited facilities. Certified teachers often participate in training sessions related to teaching materials, innovative learning methods, and the use of technological media. However, the application of these skills in the classroom is not always optimal. Certified teachers have yet to demonstrate significant improvements in the quality of classroom learning. This is evidenced by their limited ability to explain materials effectively, minimal use of learning technology, and insufficient attention to individual student needs (Sukmara & Nurhikmahyanti, 2015). The teacher certification process aims to enhance the quality of teachers and, consequently, the learning process. Teacher professionalism can be assessed through various aspects of their competencies (Pradana et al., 2019). Therefore, continuous evaluation of the teacher certification program is necessary to ensure the sustained quality of educators (Helsa et al., 2023). The government, particularly the Ministry of Religious Affairs, has made ongoing efforts to improve this process. According to KMA Number 745 of 2020 regarding Guidelines for Implementing Professional Teacher Education (PPG) in Position, one of the learning outcomes for PPG students is the ability to design lessons by integrating knowledge of teaching materials, pedagogy, and information and communication technology (TPACK), as well as other relevant approaches. Since 2021, the PPG curriculum has included the development of TPACK for prospective certified teachers. This integration has led to teachers certified between 2021 and 2023 achieving the highest average TPACK scores, reflecting the effectiveness of the updated curriculum. To ensure continued improvement in the quality of teaching, efforts to enhance TPACK competencies among teachers must be sustained, as TPACK plays a crucial role in the success of the learning process (Helsa et al., 2023). Ultimately, improving TPACK competencies through structured certification programs and continuous professional development will strengthen the overall quality of education and better prepare teachers to meet the demands of 21st-century learning.

The following finding is that teaching experience has no significant effect on the TPACK ability of mathematics teachers in Palu City, which contradicts the proposed hypothesis. However, this aligns with several previous findings (Bakar et al., 2020; Lin et al., 2013; Paidi et al., 2020; Restiana & Pujiastuti, 2019). Teaching experience has a limited impact on improving teacher competence. Still, other factors, such as learning media training and continuing professional development, maybe more decisive in developing teacher competence (Nazari et al., 2019). Another study also suggested that training focused on technology integration and teaching methodology should be conducted to create TPACK effectively (Zheng et al., 2023). In addition, senior and junior teachers tend to use relatively similar teaching styles (Paidi et al., 2020). A teacher constantly faces various conditions that support and hinder the learning process.

In situated learning theory, Lave and Wenger emphasize that knowledge and learning must be situational, both in the physical and social contexts, to achieve learning goals (Gonen et al., 2016). Learning and competency development occur through active participation in actual practice rather than through passive accumulation of work experience. In the context of TPACK, teaching experience does not automatically improve teacher competence. Learning in contexts rich with technology use or through intensive professional collaboration is more likely to improve TPACK.

Implication

The absence of significant differences in the TPACK skills of mathematics teachers based on professionalism underscores the critical need to strengthen the integration of TPACK within teacher professional education curricula. This integration should not only focus on theoretical understanding but also emphasize practical applications that align with the demands of modern classrooms. Educational institutions must also play a proactive role in facilitating continuous professional development programs, enabling teachers to update their skills in technology integration regularly. Additionally, ensuring the availability of adequate technological resources and infrastructure is vital to support the effective application of TPACK in teaching practices. Without such support, even well-trained teachers may struggle to implement technology-driven pedagogical strategies.

Moreover, the lack of significant differences in TPACK competencies among mathematics teachers based on teaching experience highlights the opportunity to foster meaningful collaboration between senior and junior teachers. Senior teachers, with their wealth of classroom experience, can provide valuable insights into pedagogical practices, while junior teachers, often more adept at using emerging technologies, can share innovative approaches to integrating these tools into the learning process. Such collaborative efforts can create a dynamic professional learning community where teachers of varying experience levels work together to enhance their competencies and address challenges in technology integration.

To achieve these objectives, policymakers and school administrators must ensure that professional development programs are designed to address the specific needs of both experienced and novice teachers. These programs should include opportunities for collaborative learning, hands-on training in technological tools, and strategies for aligning technology use with curriculum objectives. Ultimately, by fostering an environment that supports continuous learning and collaboration, the education system can better equip teachers to meet the demands of 21st-century education and improve student learning outcomes.

Limitation and Suggestion for Further Research

This study has some limitations and weaknesses. This study only used questionnaires and interviews to measure TPACK ability. Although this method provides qualitative and quantitative data, the results may only partially reflect fundamental skills as there are no hands-on practical tests or classroom observations. In addition, this study focused more on teacher certification and teaching experience. Other dimensions of professionalism, such as social and personality competencies, should have been explored in depth. Limited facilities were cited as one of the main obstacles. Therefore, future studies could examine the influence of other variables, such as the availability of technology infrastructure, school environment, institutional support, or additional training, which may affect teachers' TPACK skills.

CONCLUSIONS

Based on the research findings and discussions, it can be concluded that the average TPACK ability of mathematics teachers in Palu City who possess teaching certificates is not significantly better than those without certification. Both certified and non-certified teachers demonstrate good knowledge of technology use but rarely implement it in classroom learning due to limited access to technological facilities. Despite these challenges, both groups exhibit a strong understanding of the material they teach and employ similar teaching strategies, such as group discussions or hands-on learning. However, non-certified teachers are less active in self-development activities, such as training on teaching materials, innovative teaching methods, and technology-based learning media, compared to their certified counterparts. Additionally, teaching experience does not significantly influence the TPACK ability of mathematics teachers in Palu City. Teachers with minimal teaching experience often have a better understanding of technology use in learning but rarely utilize it in practice. In contrast, teachers with extensive teaching experience demonstrate greater flexibility in adapting to various classroom situations and conditions but do not exhibit substantial differences in their ability to comprehend or deliver content effectively. Regardless of certification status or teaching experience, teachers actively participate in self-development activities related to TPACK through training on teaching materials, innovative teaching strategies, and technology-based learning media. However, the effective use of media and technology in classroom instruction remains limited, even among certified teachers.

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AUTHOR CONTRIBUTIONS STATEMENT

This research was conducted in MA and MTs in Palu City. RB compiled the research instruments, conducted interviews with research subjects, and analyzed the data qualitatively. At the same time, YL assisted in preparing research instruments and conducted quantitative data calculation and analysis. MJ and WN acted as data collectors through questionnaires and recapitulated quantitative data.

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