Acta Psychologica 249 (2024) 104432

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

The relationship between technological pedagogical content knowledge and belief among preservice mathematics teachers

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ARTICLE INFO

Keywords:
Educational technology
Pedagogy
Teachers' belief
Teacher training
Technology integration

ABSTRACT

The increasing interest in exploring beliefs about teaching mathematics with technology has led educators to employ belief systems as a framework for understanding the impact of technology on math instruction. However, the complex nature of pre-service teachers' beliefs in teaching mathematics with technology involves various dimensions. This study aims to investigate the predictive relationship between Technological Pedagogical Content Knowledge (TPACK) sub-components and beliefs in teaching mathematics with technology, revealing a statistically significant direct impact. Utilizing a correlational research approach, we collected data from a cohort of 159 Malaysian pre-service teachers with a focus on mathematics education. Structural Equation Modelling (SEM) was employed to analyze the proposed model. The measurement model exhibited a satisfactory fit with the collected data. Notably, technological knowledge (25 %), technological pedagogical content knowledge (69 %), and technological content knowledge (39 %) significantly influence discovery learning, while technological knowledge (24 %), technological pedagogical content knowledge (74 %), and technological content knowledge (30 %) significantly influence multiple representations. This underscores the critical role of TPACK in shaping educators' perspectives and practices, providing a crucial avenue for enhancing technology integration in teaching mathematics.

1. Introduction

In recent years, there has been a growing interest in integrating technology into educational settings, recognizing its potential to complement traditional teaching methods and enrich the overall learning experience in the classroom (Bingimlas, 2009). However, the effective incorporation of information and communications technology (ICT) in education requires careful consideration of various key factors. A crucial determinant of success in technology-based teaching and learning is ensuring that teachers are thoroughly prepared with the necessary ICT tools and resources (Ghavifekr & Rosdy, 2015; Hidayat et al., 2023). Educators should be open to integrating technology into their teaching methods, viewing it to advance and innovate their instructional approaches (Bacatan, 2022; Hidayat & Wardat, 2023). Having a fundamental belief in the integration of technology in the classroom is imperative for teachers, as it forms the basis for the successful implementation and utilization of technological tools in education. For example, the use of technology by mathematics teachers is significantly affected by their beliefs and attitudes toward the role of technological tools in teaching and learning (Belbase et al., 2020). The relationship between pre-service teachers' beliefs about mathematics, mathematics teaching, and the use of technology has been studied extensively, with findings indicating that pre-service teachers' dynamic beliefs about the nature of mathematics, constructivist beliefs about mathematics learning and teaching, and positive attitudes toward ICT are correlated with their constructivist beliefs about ICT use (Yang & Leung, 2015). Furthermore, the results of the research emphasize the importance of considering one's beliefs about the epistemology of mathematics and mathematics teaching and learning when constructing beliefs regarding mathematics assessment (Tamba & Cendana, 2021).

Nonetheless, the current issue of belief in teaching mathematics with technology among pre-service teachers is a multifaceted topic that encompasses various dimensions. Studies have shown that pre-service teachers' beliefs about mathematics, mathematics teaching, and the use of technology are interconnected (Yang & Leung, 2015). At the same time, teachers also encounter various obstacles and difficulties when

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https://doi.org/10.1016/j.actpsy.2024.104432
Received 29 June 2024; Received in revised form 18 July 2024; Accepted 23 July 2024
Available online 10 August 2024

integrating technology into their classrooms. These challenges include a lack of training in integrating technology with teaching and learning processes (Farooq & Soormro, 2018), limited competence in information and communication technology (Chiatoh & Chia, 2020), and inadequate access to technology tools and facilities (Bingimlas, 2009). For instance, research carried out by Abdelfatah (2010) suggested that certain types of technology remain underutilized. Even teachers with a solid foundation in technological pedagogy may face difficulties when incorporating technological content knowledge into their teaching and learning practices (Shilenge & Ramaila, 2020).

In the evolving landscape of education, the focus on teacher educators has been substantial, with scholars delving into the intricacies of their roles and practices (Safrudiannur et al., 2021; Thurm & Barzel, 2021). Abbitt (2011) indicates specific areas of knowledge within the TPACK framework that have an impact on the beliefs of preservice teachers regarding the integration of technology in their teaching practices. Self-confidence contributes to shaping the ability of preservice teachers to effectively incorporate technology into their teaching methods (Jeong, 2019). Few studies have explored the factors influencing teachers' beliefs about teaching mathematics with technology, such as self-efficacy, perceptions of math abilities, math anxiety, emotional responses to math-related information, and the support available in the learning environment (Bursal & Paznokas, 2006; Burte et al., 2020). However, there is limited research investigating the role of TPACK in shaping these beliefs. To our knowledge, the impact of TPACK on teachers' beliefs about teaching mathematics with technology has not yet been examined. This gap in the literature underscores the necessity for additional research in this crucial area, which could yield important insights for teacher education programs and professional development initiatives designed to improve technology integration in mathematics education.

However, a noticeable gap exists in our understanding when it comes to the specific attributes of preservice teachers and their significance in the integration of technology within the educational process. The correlation between TPACK and preservice teachers' beliefs about teaching, especially when it comes to integrating technology into mathematics instruction, is an underexplored area of research. Mathematics teacher training institutions must acknowledge and leverage the crucial role played by preservice teachers. These individuals serve as guardians, entrusted with the responsibility of preparing the next generations of educators for the complex and technology-driven educational scenarios of the twenty-first century (Tondeur et al., 2019). The nuanced and evolving nature of the belief system associated with teaching mathematics using technology among preservice teachers presents a multifaceted area of research. This complexity extends to interconnected aspects, notably technological pedagogical content knowledge. Moreover, the unexplored terrain lies in understanding the relationship between technological pedagogical content knowledge and the belief in teaching mathematics with technology, adding further depth to the current body of research. Hence, the present study investigates the correlation between technological pedagogical content knowledge and the belief in teaching mathematics with technology. Additionally, we delve into the sub-components of TPACK, which include technological knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge, in relation to the sub-components of the belief in teaching mathematics with technology, specifically focusing on discovery learning and multiple representations. This fresh investigation promises to reveal novel discoveries and yield substantial implications for both practical applications and theoretical frameworks.

Therefore, the primary objective of this research is to examine the predictive relationship between the sub-components of TPACK and the belief in teaching mathematics with technology. The research addresses the following questions: (a) Can TPACK be a predictor for the belief in teaching mathematics with technology? (b) Can the sub-components of TPACK, namely technological knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge, serve as predictors for the sub-components of the belief in teaching mathematics with technology, specifically concerning discovery learning and multiple representations?

2. Theoretical perspective

This study draws inspiration from the Technological Pedagogical Content Knowledge (TPACK) framework, which elucidates the interplay between technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) to optimize teaching and learning endeavours (Graham, 2011). This framework underscores the crucial role of educators in understanding how to seamlessly integrate technology into educational practices. TPACK offers a holistic lens through which to explore the nuanced interactions among these three domains—technological, pedagogical, and content knowledge—within pedagogical contexts, with a specific focus on the integration of technology into instructional strategies. By embracing the TPACK framework, educators are better equipped to navigate the complexities of modern teaching environments and effectively leverage technology to enhance student learning outcomes.

In their pioneering work, Mishra and Koehler (2006) posit that effective technology-based instruction involves more than just incorporating technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK); it requires the dynamic interweaving and negotiation of these domains based on the specific context (Mishra & Koehler, 2006). This framework recognizes the fluid nature of teaching, underscoring the importance of educators skilfully navigating the intricate relationships among technology, pedagogy, and content. The relevance of the Technological Pedagogical Content Knowledge (TPACK) framework in educational research across all subjects or topics in teaching and learning has gained widespread recognition. Scholars have widely embraced it as a guiding framework for investigating the impact of technology on instructional practices (Voogt et al., 2013). The framework has proven invaluable in comprehending how educators incorporate technology into their instructional strategies and the subsequent effects on student learning outcomes (Koehler & Mishra, 2016).

Furthermore, TPACK has been acknowledged for its value as a framework in the training of pre-service teachers (Koh et al., 2010). The framework recognizes the evolving and progressive development of educators' expertise as they engage with technology in diverse educational settings. Consequently, TPACK aligns with the idea that teacher education programs should encompass the acquisition of technological skills as well as pedagogical and content aspects to facilitate the effective integration of technology (Koehler & Mishra, 2016). In this study, the TPACK framework serves as a conceptual structure to examine the intricate interplay between the technological, pedagogical, and content knowledge of pre-service teachers and their perspectives on integrating technology into mathematics instruction. When exploring the relationship between TPACK and teacher beliefs about technology integration, it becomes clear that TPACK serves as a comprehensive framework for grasping the critical knowledge areas required for successful technology use in education (Naz et al., 2021; Wijaya et al., 2022). Furthermore, this extensive framework aligns with other theories that address teacher beliefs and technology integration, such as the Theory of Planned Behavior (TPB). TPB is particularly valuable for examining teachers' beliefs and intentions regarding classroom technology use (Laksani et al., 2020). This theory posits that attitudes toward technology, subjective norms, and perceived behavioral control play a significant role in shaping teachers' intentions and behaviors concerning technology integration. Combining TPACK with TPB can provide a more profound understanding of the factors that motivate teachers to adopt and effectively utilize technology in their teaching, thereby enhancing the overall educational experience. This research aims to contribute to scholarly discussions on technology integration in education and provide guidance to teacher preparation programs on how to better equip instructors for the challenges presented in twenty-first-century classrooms, utilizing TPACK as its theoretical foundation.

2.1. The belief in teaching mathematics with technology

Educators' perspectives on integrating technology into mathematics instruction significantly shape their lesson preparation and instructional strategies. By employing belief systems as a conceptual framework, teachers can delve into and grasp the ways in which technology influences the teaching and learning processes in mathematics. The adoption of technological tools in education is guided by a multitude of beliefs, values, and attitudes (Ertmer et al., 2012; Saadati et al., 2015). Therefore, it is imperative to delve into and understand these concepts thoroughly to ensure the successful and meaningful integration of technology in mathematics classrooms. Exploring teachers' beliefs regarding technology in math instruction provides valuable insights into their motivations, preferences, and potential challenges, ultimately facilitating more effective teaching practices and enhancing students' learning experiences in mathematics.

Research indicates that teachers' beliefs significantly influence their willingness to incorporate modern technology into the classroom (Luehmann, 2008). This includes considerations about how technology can effectively support student learning in math and its compatibility with contemporary teaching methods (Borba & Villarreal, 2005). Moreover, the way teachers approach the core concepts of math can impact their perception of how technology aids in exploring and understanding mathematical ideas (Pierce & Ball, 2009). The Technology Acceptance Model (TAM), proposed by Davis in 1989, offers insights into the factors affecting teachers' attitudes toward using technology. TAM emphasizes that teachers are more likely to adopt technology in math instruction if they perceive it as valuable and easy to use (Teo et al., 2008).

Goos (2013) argues sociocultural factors, institutional support, and opportunities for professional development influence educators' views on the effectiveness of technology in math instruction. The connection between positive teacher attitudes and substantial support from educational institutions is evident (Ertmer et al., 2012). This literature emphasizes the complexity of the relationship between teachers' beliefs and their integration of technology in mathematics teaching. It underscores the importance of a deep understanding of these beliefs as the foundation for incorporating technology in teaching and learning.

2.2. The connection between TPACK and the belief in teaching mathematics with technology among pre-service teachers

There exists a profound connection between Technological Pedagogical Content Knowledge (TPACK) and the considerations that prospective mathematics teachers should bear in mind when integrating technology into their teaching practices. This underscores the multifaceted nature of teacher training. According to Koehler and Mishra (2009), the elements of TPACK are not isolated entities but interconnected components that influence teachers' decision-making processes. Pre-service teachers with strong Technological Pedagogical Knowledge (TPK) are likely to have a heightened conviction about how technology can revolutionize instructional methods, aligning with the principles of discovery learning (Kim, 2018). Moreover, TPACK has implications for subject knowledge perceptions. For example, pre-service teachers with a deeper understanding of technology are more inclined to embrace the use of multiple representations in teaching mathematics (Koehler & Mishra, 2016). This intricate interplay underscores the importance of preparing educators in a manner that encompasses technological understanding, pedagogical skills, and content knowledge.

Educators aiming to prepare future teachers for the challenges of modern classrooms must thoroughly grasp this interconnectedness. According to Herring et al. (2016), educational institutions tasked with equipping teachers should not only impart technological skills but also emphasize how to effectively integrate technology into the classroom to enhance teaching and learning. Engaging students in real-life instructional scenarios using TPACK principles can help shape positive perceptions of how technology can be seamlessly incorporated into mathematics education. This nuanced perspective on the relationship between TPACK and beliefs contributes to the development of practical teacher training courses, aligning with the broader discourse on how to effectively employ technology in the classroom through a comprehensive approach that prepares teachers for the demands of the twenty-first-century classroom.

3. Method

3.1. Design and participants

We employed a quantitative approach, specifically a correlational research design (Creswell, 2012; Hidayat et al., 2022), to investigate predictive relationships between sub-components of TPACK and belief in teaching mathematics with technology among pre-service teachers. Correlational research, as outlined by Ary et al. (2013), provides a comprehensive perspective on the interrelations among multiple variables. This research design involves gathering data to uncover the existing connections between different variables (Fraenkel et al., 2012; Shanmugam & Hidayat, 2022). By employing correlational research, the aim is to reveal patterns and associations among the variables under investigation. This approach enables researchers to gain insights into the complex relationships that exist within a particular phenomenon or context, thereby contributing to a deeper understanding of the underlying dynamics at play. Correlational design is selected based on concerns about establishing a relationship between two or more variables in the identical population (Curtis et al., 2015). Adopting a simple random sampling method for its accessibility to the whole population (Elfil & Negida, 2017), we selected 159 undergraduate students from mathematics education field in Malaysia as our participants. They consisted of male (24.5 % or 39 students) and female (75.5 % or 120 students) students at the respective universities. Selecting undergraduate students enables us to focus on individuals in a pivotal phase of their education and preparation to become prospective mathematics educators. Gaining insight into their viewpoints and encounters can offer valuable guidance for enhancing mathematics education initiatives. We explained the research objectives and participants' rights as voluntary contributors. Upon their agreement, we obtained their consent digitally, adhering to ethical procedures. This study was conducted digitally, face-to-face, or in a hybrid format via an online survey platform. All collected data are treated confidentially, with strict privacy safeguards. Consequently, the researcher does not require any personal information from respondents, such as names or phone numbers. Maintaining participants' anonymity enhances trust and encourages honest responses, thereby preserving the research process's integrity. Participants can be assured that their confidentiality is protected throughout the study, fostering a secure environment for their participation.

3.2. Instruments

We adopted instruments from Schmid et al. (2020) to measure Technological Pedagogical Content Knowledge (TPACK). We measured two main constructs: TPACK and belief in teaching mathematics with technology. In the original measurement by Schmid et al. (2020), seven sub-components were developed. However, our study specifically concentrates on technological knowledge, technological pedagogical knowledge, technological content knowledge, and technology pedagogical content knowledge. The primary rationale for selecting these components is their incorporation of technological elements. Our research is centred on examining beliefs regarding the integration of technology in mathematics education. The four sub-constructs of TPACK with the items consist of technological knowledge (four items), technological pedagogical knowledge (four items), technological content knowledge (four items), and technology pedagogical content knowledge (four items). An instance of an item assessing technological knowledge is 'I stay updated on significant advancements in technology'. An example of an item gauging technological content knowledge is 'I am aware of how technological advancements have impacted the subject area I teach'. A sample item measuring technological pedagogical knowledge is 'I am capable of selecting technologies that improve instructional methods for a lesson'. An example of an item evaluating technology pedagogical content knowledge is 'I can select technologies that enhance the content delivery for a lesson'. Altogether, our study incorporates a set of 16 items designed to assess Technological Pedagogical Content Knowledge (TPACK). All items were assessed using a 5-point Likert scale, ranging from 'strongly disagree' to 'strongly agree'.

We employed an assessment instrument created by Thurm (2017) to evaluate beliefs toward teaching with technology. This tool consists of six components: discovery learning, multiple representations, time commitment, skill retention, skill loss, and previous mastery of mathematics without technology. However, our study focused specifically on the subcategories of discovery learning and multiple representations, as the other components predominantly pertain to the drawbacks associated with teaching using technology. We chose to focus solely on these two components because they reflect the positive impact of incorporating technology into mathematics education. There are two sub-constructs of belief in teaching mathematics – discovery learning (five items), and multiple representations (four items). An example of an item used to assess the sub-component of discovery learning involves 'leveraging technology to generate numerous instances, enabling students to discern relationships and structures, such as the symmetries of a graph depicting a function'. Conversely, an example of measuring the sub-component of multiple representations entails 'utilizing technology to facilitate connections between various types of representations, such as graphs, tables, and algebraic expressions'. Overall, our research includes a total of nine items designed to assess beliefs regarding the integration of technology into teaching practices. All items were assessed using a 5-point Likert scale, ranging from 'strongly disagree' to 'strongly agree'.

3.3. Data analysis

The first analysis involved descriptive statistics addressing mean, standard deviation, kurtosis, and standard deviation. Then, we employed structural equation modelling (SEM) to test the hypothesized predictive relationship using IBM SPSS Amos version 18. We computed the classical test theory Confirmatory Factor Analysis (CFA) to evaluate our instrument. We also applied Composite Reliability (CR) and Average Variance Extracted (AVE) for convergent and discriminant validity. We employed Structural Equation Modelling (SEM) using AMOS version 18.0 to evaluate the hypothesized model. Initially, we conducted Confirmatory Factor Analyses (CFA) for each variable in a measurement model to confirm the dimension structures of the instruments for our sample. Sequential models were assessed for digital skills, emotional intelligence, and employability skills sub-constructs. Following this, we established the hypothesized model to test the mediating effect of emotional intelligence between digital skills and employability skills using the Bootstrapping method. Model fit was assessed based on various criteria, including chi-square values ($p > 0.05$), the comparative fit index (CFI) (> 0.950), Tucker-Lewis's index (TLI) (> 0.950), root mean square error of approximation (RMSEA) (< 0.080), and Goodness of Fit Index (> 0.900). The chi-square test evaluates the disparity between observed sample data and fitted covariance matrices. CFI and TLI compare model fit with null or independent models. Finally, for discriminant validity, reliability, and convergent validity, we utilized composite reliability (CR) (> 0.60), Cronbach's alpha values (> 0.70), and average variance extracted (AVE) (> 0.50).

4. Results

4.1. Descriptive outputs

Table 1 presents the descriptive findings for TPACK sub-constructs (namely technological pedagogical content knowledge, technological knowledge, technology pedagogy knowledge, and technology content knowledge) in relation to sub-constructs of belief in teaching mathematics with technology (discovery learning and multiple representations). In this present study, the descriptive analysis encompassed mean values, standard deviation, skewness, and kurtosis.

As shown in Table 1, the students demonstrated moderate to high levels of TPCK, TK, TPK, and TCK, with mean values of 3.976, 4.020, 4.077, and 3.833, respectively. The skewness scores fell within the range of −0.447 to −0.135 (within ±2.0), while kurtosis values ranged from −0.839 to −0.442 (within ±2.0). Importantly, none of the scores exceeded the threshold for all four sub-constructs, indicating a normal distribution (Tabachnick & Fidell, 2013). Similarly, the students exhibited high levels of belief in teaching mathematics with technology (including discovery learning and multiple representations), with mean values of 4.393 and 4.276, respectively. Skewness scores ranged from −1.134 to −0.500 (within ±2.0), and kurtosis scores varied from −0.215 to 1.788 (within ±2.0). Like the cognitive aspects, none of the scores surpassed the cutoff for both sub-constructs, suggesting a normal distribution (Tabachnick & Fidell, 2013).

4.2. Discriminant, convergent validity, and reliability index

The examination of measurement data reliability in our study involved a thorough analysis utilizing both Cronbach's alpha and composite reliability (CR), as outlined in Table 2. The internal consistency ratings were found to be robust across various dimensions, with TPCK registering at 0.892, TK at 0.899, TPK at 0.881, TCK at 0.865, discovery learning at 0.904, and multiple representations at 0.882. Notably, all surveys displayed Cronbach's and CR values surpassing the 0.7 threshold, affirming their high reliability. The sub-constructs of TPACK exhibited composite reliability ranging from 0.862 to 0.909, and for the belief in teaching mathematics with technology, it ranged from 0.881 to 0.906. Overall, the composite reliability surpassed the 0.7 threshold, indicating not only an acceptable level of reliability but also strong internal consistency, which is in line with previous research (Hair et al., 2010). Additionally, validity assessments were conducted to ensure the accurate representation of latent constructs. The AVE metrics, employed for assessing convergent validity, yielded robust values ranging from 0.610 to 0.715 for TPACK and 0.649 to 0.660 for the belief in teaching mathematics with technology. These results not only supported the validity of convergence (Hair et al., 2010) but also confirmed

Table 1
Descriptive results.

Constructs	Sub-constructs	Skewness	Kurtosis	Mean	Standard deviation
TPACK	TPCK	−0.171	−0.839	3.976	0.699
	TK	−0.447	−0.443	4.020	0.759
	TPK	−0.234	−0.442	4.077	0.641
	TCK	−0.135	−0.528	3.833	0.751
Belief in teaching mathematics with technology	Discovery learning	−1.134	1.788	4.393	0.611
	Multiple representations	−0.500	−0.215	4.276	0.634

Note: TPCK: technological pedagogical content knowledge; TK: technological knowledge; TPK: technology pedagogy knowledge; TCK: technology content knowledge.

Table 2
Reliability and validity output.

Constructs	Sub-constructs	Alpha	CR	AVE
TPACK	TPCK	0.892	0.891	0.672
	TK	0.899	0.909	0.715
	TPK	0.881	0.898	0.688
	TCK	0.865	0.862	0.610
Belief in teaching mathematics with technology	Discovery learning	0.904	0.906	0.660
	Multiple representations	0.882	0.881	0.649

Note: TPCK: technological pedagogical content knowledge; TK: technological knowledge; TPK: technology pedagogy knowledge; TCK: technology content knowledge.

the validity (Fornell & Larcker, 1981). Importantly, all sub-constructs exceeded the 0.5 threshold, indicating adequacy for Structural Equation Modelling (SEM) analysis in this investigation (Fornell & Larcker, 1981; Hair et al., 2010).

4.3. Model fit statistics

In the initial phase of our analysis, we scrutinized the measurement model pertaining to the TPACK construct and the belief in teaching mathematics with technology. The outcomes obtained through maximum likelihood estimation unveiled that the measurement model for TPACK, encompassing its four sub-constructs, demonstrated a satisfactory fit with the data: $\chi2 = 215.813$, $\chi2/df = 2.202$, RMSEA = 0.087, CFI = 0.942, TLI = 0.929. Additionally, the measurement model associated with the belief in teaching mathematics with technology indicated that two sub-constructs exhibited a commendable alignment with the observed data: $\chi2 = 84.754$, $\chi2/df = 3.260$, RMSEA = 0.090, CFI = 0.943, TLI = 0.921. Although the chi-square result holds significance, an in-depth examination of χ^2/df, RMSEA, CFI, and TLI collectively suggests that the a priori model maintains an appropriate factor structure. This underscores the robustness and reliability of the chosen model despite the statistical significance of the chi-square test, reinforcing confidence in the validity of our measurement framework.

Table 3 displays the factor loading and coefficient of CFA. All factor loadings derived from the sub-constructs of discovery learning ranged from approximately 0.732 to 0.845. For multiple representations, they varied from 0.660 to 0.703, for technological pedagogical content knowledge, they were between 0.765 and 0.858, for technological knowledge, they spanned from approximately 0.810 to 0.895, for technology pedagogy knowledge they ranged from 0.759 to 0.867, and for technology content knowledge, they ranged from 0.696 to 0.821 – all of which were statistically significant. Significantly, each item within every sub-construct demonstrated statistically significant factor loadings ($p < 0.001$), confirming the correlation among items for each respective sub-construct. The standardized estimates for factor loading indicated that all items exceeded the threshold of 0.50, surpassing the recommended criteria as per Hair et al. (2010).

Table 3
Factor loadings of construct.

Construct	Sub-construct	Item	Loading factor	p
The belief in teaching mathematics with technology	Discovery learning	DL5	0.832	***
		DL4	0.826	***
		DL3	0.845	***
		DL2	0.822	***
		DL1	0.732	***
	Multiple representations	MR4	0.735	***
		MR3	0.824	***
		MR2	0.826	***
		MR1	0.834	***
TPACK	Technological pedagogical content knowledge	TPCK4	0.765	***
		TPCK3	0.819	***
		TPCK2	0.858	***
		TPCK1	0.833	***
	Technological knowledge	TK4	0.810	***
		TK3	0.895	***
		TK2	0.863	***
		TK1	0.812	***
	Technology pedagogy knowledge	TPK4	0.759	***
		TPK3	0.822	***
		TPK2	0.866	***
		TPK1	0.867	***
	Technology content knowledge	TCK4	0.813	***
		TCK3	0.821	***
		TCK2	0.789	***
		TCK1	0.696	***

*** = Significant.

Much like the scrutiny applied to the measurement model, specific cut-off scores were employed for each measurement to assess the proposed model. The Structural Equation Modelling (SEM) results unveiled a notably favorable fit to the data, with $\chi2 = 570.868$, $\chi2/df = 2.130$, RMSEA = 0.084, CFI = 0.906, and TLI = 0.900, as illustrated in Fig. 1. The depicted model in Fig. 1 emerged as the ultimate structural model, delineating the associations between the sub-construct of belief in teaching mathematics with technology and Technological Pedagogical Content Knowledge (TPACK). Each parameter estimate along the structural paths in the proposed model reached statistical significance. Specifically, the direct impact of TPACK on the belief in teaching mathematics with technology was statistically significant [$\beta = 0.70$, $p < 0.01$, $t = 6.265$]. Consequently, the findings derived from SEM underscore that TPACK accounts for as much as 70 % of the variability in the belief in teaching mathematics with technology. Therefore, H0, which states that preservice teachers' TPACK is one of the factors contributing to preservice teachers' belief in teaching mathematics with technology, was not fully supported. Therefore, it is concluded that preservice teachers with high TPACK harbour favorable attitudes toward integrating teaching mathematics with technology.

Nevertheless, the connection between the sub-construct of Technological Pedagogical Content Knowledge (TPACK) and the belief in teaching mathematics with technology remains uncertain. We investigated this association among preservice teachers by examining the link between the sub-construct of TPACK and the belief in teaching mathematics with technology. The structural model depicted in Fig. 2 delineates the relationships between technological pedagogical content knowledge, technological knowledge, technology pedagogy knowledge, and technology content knowledge concerning the belief in teaching mathematics with technology among preservice teachers. This scrutiny promises to contribute fresh perspectives to the existing body of knowledge. The SEM results revealed a notably favorable fit to the data, with $\chi2 = 571.105$, $\chi2/df = 2.188$, RMSEA = 0.086, CFI = 0.904, and TLI = 0.900, as depicted in Fig. 2.

As indicated in Table 4, the direct path coefficients demonstrated significance in the following relationships: (a) technological knowledge → discovery learning [$\beta = 0.25$, $p < 0.05$, $t = 2.511$], (b) technological pedagogical content knowledge → discovery learning [$\beta = 0.69$, $p < 0.05$, $t = 3.216$], (c) technological content knowledge → discovery learning [$\beta = 0.39$, $p < 0.05$, $t = 2.644$], (d) technological knowledge → multiple representations [$\beta = 0.24$, $p < 0.05$, $t = 2.239$], (e) technological pedagogical content knowledge → multiple representations [$\beta = 0.74$, $p < 0.05$, $t = 3.378$], and (f) technological content knowledge → multiple representations [$\beta = 0.30$, $p < 0.05$, $t = 32.016$]. Consequently, the hypothesis was fully supported. Conversely, the direct path coefficients were not deemed significant in the cases of (a) technological pedagogical knowledge → discovery learning [$\beta = 0.11$, $p > 0.05$, $t = 0.884$], and (b) technological pedagogical knowledge → multiple representations [$\beta = 0.08$, $p > 0.05$, $t = 0.605$]. In summary, technological knowledge (25 %), technological pedagogical content knowledge (69 %), and technological content knowledge (39 %) collectively explained the variance in discovery learning. Simultaneously, technological knowledge (24 %), technological pedagogical content knowledge (74

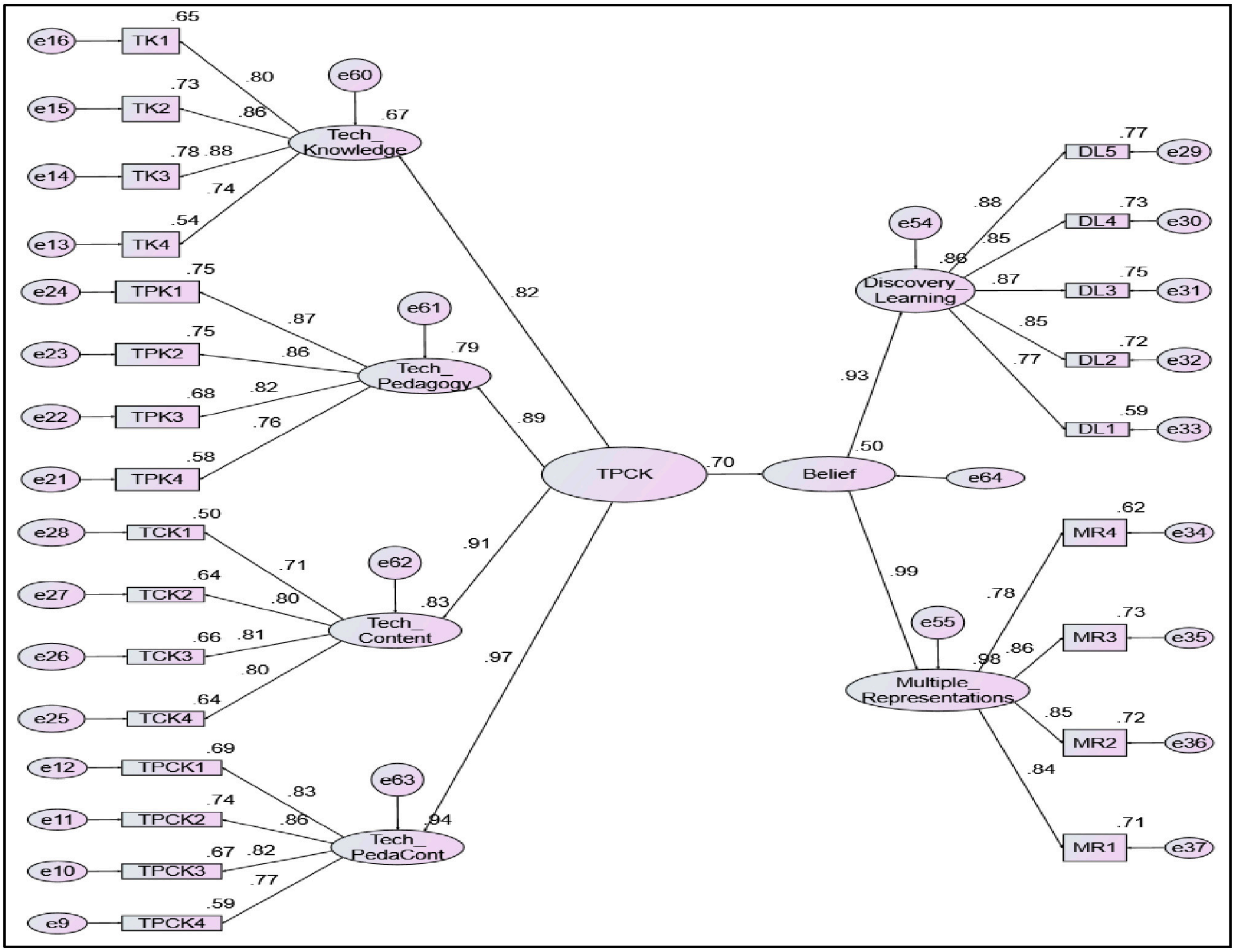

Fig. 1. Initial model of TPACK-belief.

%), and technological content knowledge (30 %) accounted for the variance in multiple representations.

5. Discussion

Our research revealed a significant and positive correlation between technological pedagogical content knowledge (TPACK) and the belief in teaching mathematics with technology among pre-service teachers. This connection is grounded in the understanding that a robust TPACK foundation equips pre-service teachers with the necessary knowledge and skills to seamlessly integrate technology into their teaching methods. When pre-service teachers possess a profound comprehension of how to effectively employ technology alongside pedagogical and content knowledge, it fosters a positive shift in their beliefs regarding the advantages and effectiveness of incorporating technology in mathematics education. This finding aligns with existing research highlighting the interconnected nature of pre-service teachers' beliefs about technology integration and their TPACK self-efficacy (Bwalya & Rutegwa, 2023; Kazu & Erten, 2014). The TPACK framework has proven instrumental in evaluating teachers' professional development efforts related to technology, underscoring its relevance in shaping teachers' beliefs and practices in utilizing technology for teaching mathematics (Tanucan et al., 2021). Furthermore, the TPACK framework has been linked to enhancements in lesson planning and teaching demonstration skills, providing additional evidence of its influence on teachers' beliefs and instructional approaches. However, it is important to note that the growth in TPACK among pre-service teachers may not always be significant (Rakes et al., 2022). This suggests that while TPACK is influential, there may be factors that impact its development and application among pre-service teachers.

We have identified a significant and positive correlation between the technological knowledge of pre-service teachers and their beliefs in teaching mathematics with technology, particularly concerning the dimension of discovery learning. This finding aligns with prior research findings in this domain (Ertmer et al., 2012). One possible explanation for this association is linked to independent exploration. Technological knowledge of teachers plays a vital role in enabling the use of technology for students' exploration of open problems within the framework of discovery learning. In the context of mathematics instruction, technological knowledge encompasses educators' comprehension and proficiency in employing various technological tools and resources. When applied to the context of discovery learning, technological knowledge empowers teachers to integrate specific technologies that support independent inquiry and problem-solving among students. Educators with a robust foundation in technological knowledge can introduce digital platforms, interactive software, or online resources that facilitate students' autonomous exploration of open problems. For example, they may implement collaborative online platforms where students can work together on problem-solving tasks, share insights, and collectively explore diverse approaches to open mathematical problems. The strategic use of technology, guided by technological knowledge, equips students with the means to participate in self-directed learning experiences. It enables them to investigate open problems, apply mathematical concepts, and cultivate independent problem-solving skills.

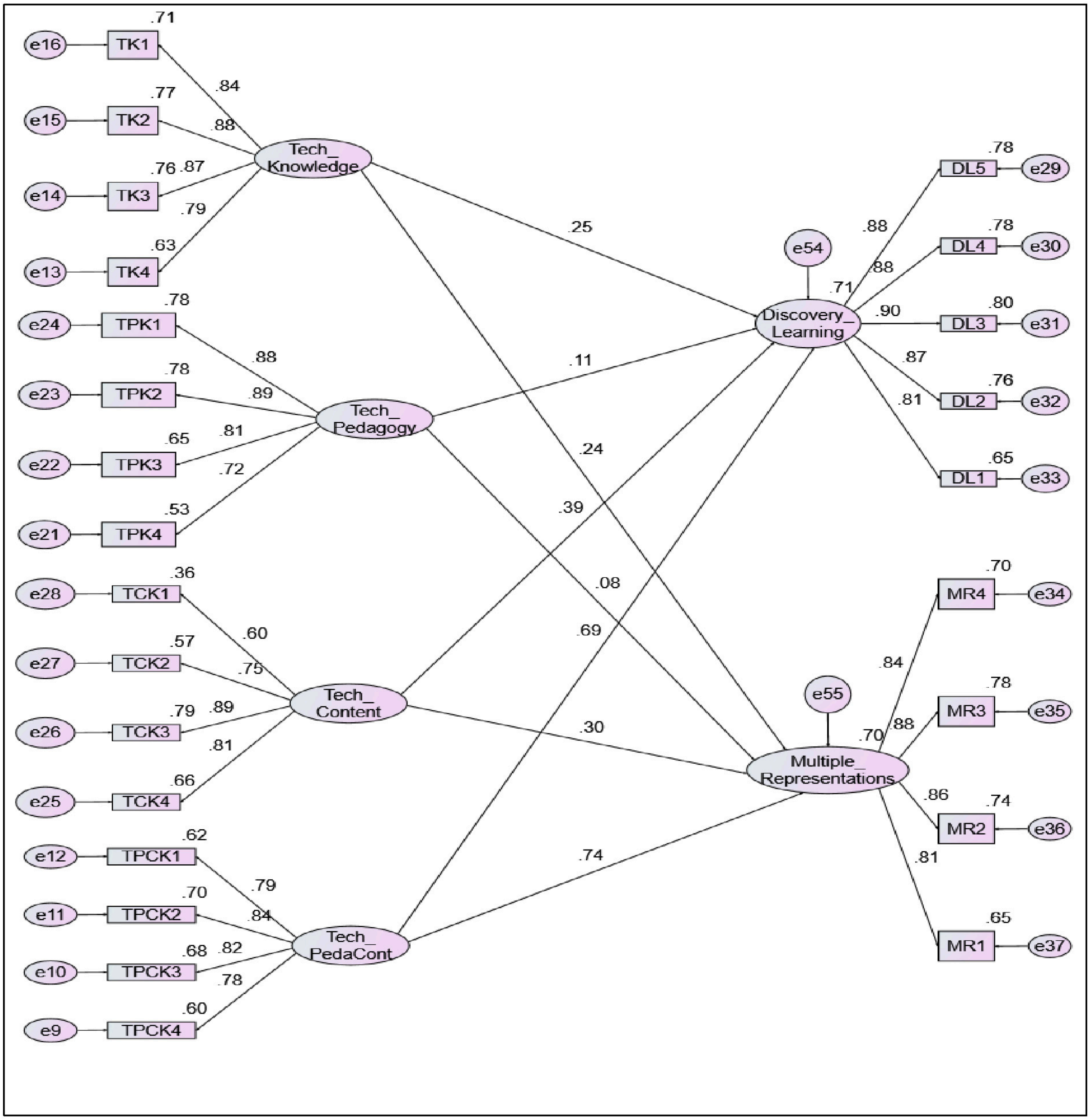

Fig. 2. Final model of TPACK-belief.

Table 4
Path analysis.

Dependent construct		Independent construct	Estimate	S.E.	C.R.	P
Belief of teaching mathematics with technology	←	TPACK	0.701	0.088	6.265	***
Discovery learning	←	Technological knowledge	0.255	0.110	2.511	0.012
Discovery learning	←	Technological pedagogical knowledge	0.115	0.175	0.884	0.377
Discovery learning	←	Technological pedagogical content knowledge	0.695	0.261	3.216	0.001
Discovery learning	←	Technological content knowledge	0.388	0.152	2.644	0.008
Multiple representations	←	Technological pedagogical knowledge	0.082	0.165	0.605	0.545
Multiple representations	←	Technological knowledge	0.237	0.104	2.239	0.025
Multiple representations	←	Technological pedagogical content knowledge	0.739	0.237	3.378	***
Multiple representations	←	Technological content knowledge	0.302	0.139	2.016	0.044

*** = Significant.

Consequently, technological knowledge emerges as a crucial factor in creating a student-centered learning environment where technology serves as a tool for inquiry and exploration in the field of mathematics.

We have not identified any statistically significant or positive relationship between the technological pedagogical knowledge of pre-service teachers and their beliefs about using technology in teaching math, specifically in terms of discovery-based learning. Research suggests that pre-service teachers might encounter difficulties in combining technological understanding with field-specific knowledge and pedagogical expertise throughout their training, potentially affecting their capacity to facilitate discovery-oriented learning (Çelik, 2020). This notion gains further validation from the discoveries of another study, which demonstrate that pre-service geography educators demonstrate comparatively diminished levels of Pedagogical Content Knowledge and Technological Pedagogical Knowledge (Mensah, 2023). Possible explanations for this lack of correlation could stem from various factors. Firstly, pre-service teachers may not have received sufficient training or exposure to effective methods for integrating technology into their pedagogy. Secondly, differences in educational philosophies or personal preferences among pre-service teachers may influence their attitudes toward technology use in math teaching. Thirdly, there might be a limited understanding among pre-service teachers of the potential benefits that technology can offer in fostering discovery-based learning in mathematics. Furthermore, a lack of confidence or comfort with technology in the context of math education could also be a contributing factor. Moreover, individual variances in experiences, backgrounds, and personal beliefs could further compound this discrepancy between their technological pedagogical knowledge and their beliefs regarding the use of technology in math instruction. These differences may influence how pre-service teachers perceive the role of technology in the classroom and shape their attitudes toward its integration into teaching practices. Therefore, addressing these multifaceted factors is essential in bridging the gap between technological pedagogical knowledge and beliefs about technology use in math education.

Nonetheless, we have observed a significant and positive association between the technological pedagogical content knowledge and technological content knowledge of pre-service teachers and their convictions regarding teaching mathematics with technology, specifically focusing on the aspect of discovery-based learning. The primary reason for these noteworthy and meaningful findings lies in the connection between two specific components related to content. Discovery-based learning is inherently intertwined with the mathematical content itself, which serves as a key factor contributing to the observed positive correlation. It is worth highlighting the crucial role of technology in enhancing the quality of learning and problem-solving skills, both of which are foundational elements of discovery-based learning (Irdalisa et al., 2020). Moreover, recent research has shown that the development of technological pedagogical content knowledge and technological content knowledge through activities like lesson study can have a positive impact on teachers' pedagogical, content, and technological proficiency, all of which are vital for effectively implementing discovery-based learning (Rochintaniawati et al., 2019). Additionally, it is important to underscore the significance of teachers' ability to seamlessly integrate technology into classroom instruction, a core aspect of TPACK, which greatly influences their pedagogical and professional competence essential for fostering discovery-based learning environments (Safriana et al., 2023). These findings resonate with previous studies that emphasize the critical role of teachers' mastery of technology, pedagogy, and subject matter knowledge as outlined within the TPACK framework (Malik et al., 2019). This highlights the interconnectedness of technology integration, pedagogical skills, and subject expertise in facilitating effective discovery-based learning experiences in educational settings.

Regarding the dimension of multiple representations, there exists a significant and positive relationship between technological knowledge, technological pedagogical content knowledge, technological content knowledge, and beliefs about teaching mathematics with technology, particularly focusing on multiple representations. Notably, the strongest correlation is observed between technological pedagogical content knowledge and multiple representations. This correlation underscores the crucial role of integrating technology to enrich teaching and learning experiences in mathematics education. This finding is consistent with previous research in this field (Baumert et al., 2010). This integration is particularly crucial for fostering deeper conceptual understanding and problem-solving skills among students. Multiple representations are foundational in mathematics education as they provide learners with various perspectives and approaches to comprehend mathematical concepts. Educators with robust technological pedagogical content knowledge can effectively utilize technology to create and employ multiple representations, catering to the diverse learning needs of students. Furthermore, the research emphasizes the importance of mathematics teachers employing technology and active teaching methods to present different representations of mathematical concepts, thereby enhancing students' understanding and engagement in mathematics (Özüdoğru, 2021). Additionally, studies highlight that teachers can enhance students' mathematical understanding by offering multiple representations and explanations, emphasizing the significance of diverse representations in promoting student learning (Baumert et al., 2010; Hossain et al., 2012). However, we have not observed any notable or affirmative correlation between the technological pedagogical knowledge possessed by pre-service teachers and their convictions regarding the utilization of technology in math instruction, particularly concerning multiple representations. This highlights the intricate nature of the connection between technological expertise and pedagogical convictions within the realm of math education. One plausible explanation lies in pedagogical methodologies. The efficacy of incorporating technology into math teaching, especially through multiple representations, is contingent not solely upon technical adeptness but also on instructional strategies. It is plausible that pre-service teachers lack exposure to or instruction in pedagogical methodologies that effectively utilize technology to teach mathematical concepts through various representations, thereby attenuating the association between technological pedagogical knowledge and beliefs.

6. Conclusion and implication

The incorporation of technology into mathematics instruction has garnered considerable attention in recent times. Studies have indicated that technology can have a positive impact on mathematics education by augmenting student learning, engagement, and academic performance. Moreover, its use in this context can challenge conventional teaching methods and foster a deeper conceptual grasp of mathematical principles. This is particularly pertinent in the 21st century, where fields such as science, mathematics, technology, and engineering are paramount, underscoring the imperative for educators to deliver effective instruction in these domains. The primary aim of this study is to explore the predictive relationship between the various components of TPACK and the inclination to teach mathematics with the aid of technology. Our findings reveal that technological knowledge, technological pedagogical content knowledge, and technological content knowledge significantly impact discovery learning, while they also significantly influence the utilization of multiple representations. This underscores the pivotal role of TPACK in shaping educators' attitudes and methodologies, offering a crucial avenue for enhancing the integration of technology in mathematics instruction.

The findings of this study indicate significant theoretical implications for technology integration in educational settings. TK, TPACK and TCK are essential for facilitating discovery learning and multiple representations. Theoretical frameworks in education should incorporate the pivotal role of TK, TPACK, and TCK in enhancing both discovery learning and the use of multiple representations, thereby guiding future research and practice in educational technology integration. These results highlight the importance of equipping educators with comprehensive technological competencies that go beyond basic technological skills to include the integration of these skills with pedagogical strategies and content knowledge. Such training enables educators to create more dynamic and interactive learning environments, fostering student engagement and deeper understanding. This underscores the necessity for teacher education programs to prioritize extensive technological training, ensuring educators are well-prepared to effectively utilize technology in diverse instructional contexts.

The findings hold significant implications for the field of mathematics education, emphasizing the critical role of educators' proficiency in integrating technology effectively into teaching practices through TPACK. This underscores the importance of prioritizing TPACK development in both pre-service and in-service teacher training programs. Moreover, the varying degrees of influence exhibited by different TPACK components highlight the complex nature of technology integration in mathematics instruction, necessitating educators and policymakers to acknowledge the nuanced interplay between technological knowledge, pedagogical strategies, and content expertise. As such, efforts in designing professional development initiatives and curriculum frameworks should consider these multifaceted dynamics to enhance technology integration in mathematics education. Ultimately, these findings stress the significance of cultivating a comprehensive understanding of TPACK to maximize the benefits of technology use and facilitate meaningful learning experiences for students in mathematics classrooms.

6.1. Limitation and future direction

While our research offers valuable insights, it is crucial to recognize its limitations. The primary limitation is the relatively small sample size, consisting of only 159 prospective mathematics teachers. This limited sample may affect the generalizability of our findings to a broader population. Additionally, our study focused specifically on prospective mathematics teachers, rather than a wider range of educators within the STEM field. Consequently, the results may not fully reflect the perspectives and experiences of educators in other STEM disciplines, potentially limiting the applicability of our findings beyond mathematics education. This narrow focus could affect the transferability of the results to practicing teachers and may not entirely capture the complexities of technology integration in real classroom settings. Concentrating solely on pre-service teachers may introduce bias, as their experience and exposure to technology integration differ from those of in-service educators (Kannadass et al., 2023). Future research should aim to address these limitations by using larger and more diverse samples, including a broader array of STEM educators, to provide a more comprehensive understanding of the relationship between technological pedagogical content knowledge and beliefs about technology use in STEM teaching contexts.

Our study exclusively focuses on prospective mathematics teachers, a group with limited experience in school settings. However, it is noteworthy that our sample consists of final-year students who have completed all coursework encompassing content, pedagogical knowledge, and technology, preparing them for practical teaching sessions. While our findings provide valuable insights into this specific cohort, future research endeavours are encouraged to include experienced teachers to enhance the generalizability of results. It is essential to consider that experienced teachers likely possess a robust level of Technological Pedagogical Content Knowledge (TPACK), which can significantly influence their beliefs regarding teaching mathematics with technology. By incorporating experienced educators into research studies, a more comprehensive understanding of the relationship between TPACK and teaching beliefs can be achieved, thus contributing to the advancement of effective technology integration practices in mathematics education.

In our study, we utilized a measurement tool developed by Thurm (2017) to gauge beliefs about teaching with technology. This tool comprises six components: discovery learning, multiple representations, time requirement, skill loss, skill loss, and prior mastery of mathematics by hand. However, our study specifically concentrated on the subcomponents of discovery learning and multiple representations, as the remaining components primarily address the negative aspects of teaching with technology. It is crucial for future research endeavours to encompass all components of measuring beliefs about teaching with technology to achieve a more comprehensive understanding of educators' perspectives and attitudes toward technology integration in teaching practices. By considering a broader range of components, future studies can effectively capture the multifaceted nature of beliefs about teaching with technology and offer valuable insights for improving technology integration in educational settings.

A mixed-methods approach could yield richer insights into teacher beliefs and practices. Considering that TK, TPACK, and TCK significantly influence both discovery learning and multiple representations, utilizing both quantitative and qualitative methods can provide a more thorough understanding of these dynamics. Quantitative data can determine the extent and significance of these influences, while qualitative data can reveal the underlying reasons, contexts, and experiences shaping these beliefs and practices. This approach enables researchers to capture the complexity of technology integration in education, offering valuable perspectives that can inform more effective strategies for supporting teachers in their use of technology. Finally, to comprehensively understand teacher belief toward technology, it is crucial to consider a wider range of belief components. This broader approach would offer a more holistic perspective on the factors influencing technology integration, providing deeper insights into supporting and enhancing teachers' use of technology in the classroom. Future research should incorporate these additional belief components to develop a fuller picture of teacher attitudes and to improve strategies for effective technology integration in education.

CRediT authorship contribution statement

Riyan Hidayat: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Formal analysis, Conceptualization. **Zamzami Zainuddin:** Supervision, Software, Data curation. **Nurul Hijja Mazlan:** Methodology, Investigation.

Declaration of competing interest

The authors have stated that there are no conflicts of interest regarding the subject matter of this paper.

Data availability

The corresponding author can provide the datasets upon request.

Acknowledgment

This work did not receive a dedicated grant from any official funding entity, private sector, or non-profit organization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2024.104432.

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