"I can, so I teach with AI": Modelling the interplay between self-efficacy, mathematics-related beliefs and TPACK-M

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This study investigated, through structural equation modelling, the relationships among pre-service elementary teachers' beliefs about mathematics teaching and learning, their self-efficacy regarding artificial intelligence (AI) usage and their mathematics-specific technological pedagogical content knowledge (TPACK-M). The participants comprised pre-service elementary teachers selected from three public universities in Türkiye. Data were collected using the Mathematics-Related Beliefs Scale, AI Self-Efficacy Scale and Mathematics Technological Pedagogical Content Knowledge Scale. The findings revealed that AI self-efficacy has a direct positive effect on TPACK-M. Constructivist beliefs positively influence TPACK-M development through both direct and indirect pathways. While traditional mathematics beliefs had no significant direct effect, they negatively influenced TPACK-M indirectly through AI self-efficacy. Consequently, the proposed model indicates that AI self-efficacy serves as an essential mediating variable in developing TPACK-M, constructivist beliefs significantly enhance this development, whereas traditional beliefs exhibit a restrictive role.

Implications for practice or policy:

- Teacher education programme designers should ground mathematics lessons in constructivist pedagogy because constructivist beliefs directly strengthen TPACK-M.
- Primary education faculty should design low-risk AI tasks because AI self-efficacy is the strongest direct predictor of TPACK-M.
- Policymakers in Türkiye's Council of Higher Education and Ministry of National Education should align primary teacher education standards with constructivist principles because traditional beliefs lower AI self-efficacy, which in turn constrains TPACK-M development.

Keywords: TPACK, AI self-efficacy, mathematical beliefs, structural equation model, pre-service elementary school teachers

Introduction

As technology advances exponentially and the volume of available information grows at a quick rate, the processes of storing and disseminating knowledge have advanced significantly, driven by technologies such as the Internet, cloud computing and artificial intelligence (AI) (Ardıç, 2021). Their rapid growth, accelerated by the COVID-19 pandemic, reshaped education (Drachsler et al., 2021; Max et al., 2022). Teacher education now prioritises information and communications technology (ICT) integration and digital competence (Redecker, 2017; Valtonen et al., 2019), and many countries have introduced national strategies (Australian Curriculum and Assessment Authority, 2023; Finnish National Board of Education, 2016; Ministry of National Education, 2024).

Teachers play a decisive role in integrating technology into curricula (Drijvers, 2015). In this context, competencies in technological pedagogical content knowledge (TPACK) have become essential for effective practice (Hava & Babayiğit, 2025). As a model, TPACK defines teachers' knowledge of meaningful ICT use in education (Koehler & Mishra, 2009) and emphasises linking pedagogy with real-world contexts

(Angeli et al., 2016; Santos & Castro, 2021). It enables instruction tailored to student needs (Suharwoto & Lee, 2005) and supports learning by making technology a powerful tool for achievement (Chauhan, 2017; Moyer-Packenham & Suh, 2012).

Technology integration has long been central to mathematics education, fostering conceptual understanding (National Council of Teachers of Mathematics, 2014). Advances in ICT have enabled innovative methods that improve teaching quality (Kuznetsova et al., 2022). Yet, integrating technology in mathematics is more complex than daily use, requiring additional skills and knowledge (Polly & Rock, 2016). Developing pre-service teachers' TPACK is therefore vital, particularly in elementary years when students form positive attitudes and mathematical thinking. Alongside knowledge, teachers' pedagogical beliefs are critical for technology integration (Drumm, 2019). Since, instructional decisions are strongly shaped by teachers' beliefs (Cross, 2009; Shahvarani & Savizi, 2007), teacher education should foster both subject knowledge and beliefs consistent with programme goals (Liljedahl, 2008). Specifically, in mathematics teaching, beliefs regarding mathematics education and instruction have emerged as influential factors in the effective use of technology.

Furthermore, AI integration has become a major innovation in mathematics education (Wardat et al., 2023), enriching learning and teaching experiences (Öcal-Dörterler et al., 2024). Pre-service teachers' AI self-efficacy is a key factor shaping TPACK. Self-efficacy, widely studied in ICT adoption (Huffman et al., 2013; Hwang et al., 2016), is central to this study, which modelled pre-service teachers' mathematics-related beliefs, AI self-efficacy and mathematics-specific TPACK (TPACK-M).

Background

Self-efficacy towards AI

After the pandemic, digital technologies gained importance in education, with AI expected to drive major advancements (Hofer et al., 2021; Slimi & Villarejo, 2023). AI, defined as systems emulating human abilities such as reasoning, inference and learning (Gondal, 2018), provides adaptive, human-like interactions (Xu et al., 2023). To use these effectively, teachers need competencies in AI integration (Chiu, 2024; Wang et al., 2023), especially in K-12 contexts, where guidance is essential (Chiu et al., 2024). However, in this study, AI was addressed as a broad concept encompassing various AI-supported technologies and applications that can be used in educational contexts. Therefore, the scope was not limited specifically to generative AI tools such as ChatGPT. Although generative AI constitutes an increasingly prominent category of educational AI, the construct of AI self-efficacy examined in this study refers more broadly to pre-service teachers' perceived capability to use AI-based technologies.

Technology integration depends on both external resources and internal factors such as knowledge, skills and attitudes (Njiku et al., 2019). Among these, self-efficacy plays a central role (Ertmer et al., 2012). Bandura (1994) defined it as belief in one's ability to achieve goals, a core element of social cognitive theory (Mozahem et al., 2021). In mathematics education, where AI use is growing (Mohamed et al., 2022), AI self-efficacy refers to confidence in applying AI tools to solve problems, adapt and innovate (Morales-García et al., 2024). Accordingly, teachers who believe that they can use AI effectively may be more willing to explore unfamiliar AI tools, invest effort in learning their functions and persist when facing technical or pedagogical challenges. Evidence from the broader technology integration literature supports this mechanism: teachers' technology-related self-efficacy has been associated with their technology integration behaviours and their use of ICT in teaching practices (Dikmen & Demirer, 2022; Hatlevik & Hatlevik, 2018). Furthermore, ICT self-efficacy has been shown to mediate the effects of institutional support on pre-service teachers' TPACK, indicating that confidence may help transform available knowledge and support into integrated technological and pedagogical competence (Wang & Zhao, 2021). More directly in the AI context, Ismaniati et al. (2025) found that teachers' AI self-efficacy significantly predicted their intention to adopt AI and mediated the relationship between TPACK and AI adoption intention. These findings indicate that AI self-efficacy can function as a psychological bridge between what teachers know about technology integration and their readiness to apply that knowledge. It may therefore

be particularly important for TPACK-M, as pre-service classroom teachers must feel capable of evaluating and adapting AI tools in ways that align with mathematical content, instructional objectives and appropriate pedagogical strategies.

AI is likely to reshape educators' roles (Felix, 2020), requiring reassessment of technology, pedagogy and content (Ning et al., 2024). In mathematics, the TPACK framework is critical for guiding such integration (Koh, 2018; Van-Vaerenbergh & Pérez-Suay, 2022). Li (2024) confirmed that teachers' attitudes towards AI correlate with their TPACK, but research explicitly linking AI self-efficacy to TPACK remains limited. Recent empirical studies have also linked AI self-efficacy to teachers' AI-TPACK, AI adoption intentions and the quality of AI-supported instruction (Du et al., 2026; Erol et al., 2025; Ismaniati et al., 2025; Xu et al., 2025). However, its role in pre-service teachers' discipline-specific TPACK remains under-explored. The present study addresses this gap by examining how AI self-efficacy contributes to pre-service classroom teachers' TPACK-M. Based on the theoretical and empirical evidence reviewed above, the following hypothesis was formulated:

- H1: AI self-efficacy has a positive effect on TPACK.

Beliefs about mathematics

Beliefs are defined as individuals' psychologically held understandings or propositions regarded as true (Philipp, 2007). From a cognitive perspective, they are mental constructs shaped by experience (Schoenfeld, 2013). In mathematics, beliefs concern approaches to tasks and are often grouped into beliefs about the nature of mathematics, its learning and its teaching (Raymond, 1997). Learning beliefs centre on active versus passive construction, while teaching beliefs align with teacher-centred (traditional) or student-centred (constructivist) approach (Thompson, 1992). The traditional approach assigns the teacher the role of transmitting mathematical knowledge to students, while students are expected to follow the instructions provided during this transmission process. In contrast, the constructivist approach assigns teachers the responsibility of creating learning environments that support students in actively constructing their own knowledge (Čuka & Cindrić, 2025).

Although some have argued the link between beliefs and teaching practice is weak (Safrudiannur & Rott, 2020), most studies have confirmed beliefs strongly influence mathematics instruction (Buehl & Beck, 2014; Eichler et al., 2023; Hughes et al., 2019; Jacobson & Kilpatrick, 2015). Effective mathematics teaching today relies on TPACK, which integrates technology, pedagogy and content (Bonafini & Lee, 2021; Kartal & Çınar, 2018). New technologies are also reshaping the nature of mathematics and classroom knowledge, influencing teachers' perspectives and beliefs (Leung, 2013). Such changes in beliefs, in turn, shape their techno-pedagogical knowledge.

Given that an individual's capability to perform effectively and maintain motivation in significant life events heavily relies on their self-efficacy beliefs (Bandura, 1997), it follows that beliefs also influence self-efficacy perceptions. Research has shown reciprocal links between the two (Bates et al., 2011; Chrysostomou & Philippou, 2010). In mathematics education, teaching self-efficacy is frequently examined with beliefs, and studies have consistently reported positive relationships (Gagnier et al., 2021; Lau, 2022). Since teaching self-efficacy is associated with effective instructional strategies (Woolfolk Hoy & Burke-Spero, 2005), it is reasonable to expect connections between mathematics beliefs and AI self-efficacy, which is increasingly significant in contemporary mathematics education. In line with this reasoning, the following hypotheses were formulated:

- H2: Constructivist beliefs about mathematics teaching and learning positively affect TPACK.
- H3: Traditional beliefs about mathematics teaching and learning positively affect TPACK.
- H4: Constructivist beliefs about mathematics teaching and learning positively affect AI self-efficacy.
- H5: Traditional beliefs about mathematics teaching and learning positively affect AI self-efficacy.

TPACK

The TPACK framework, introduced by Mishra and Koehler (2006), is widely used to explain teachers' knowledge of integrating digital technologies into instruction (Harris et al., 2017; Hughes et al., 2020; Schmid et al., 2020). It builds on Shulman's (1986) concept of pedagogical content knowledge (PCK), which described teachers' unique understanding of subject matter and pedagogy.

Expanding PCK, TPACK combines three domains – technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK) – and their intersections: technological pedagogical knowledge (TPK), PCK and technological content knowledge (TCK) (Thompson & Mishra, 2007). TPK involves choosing technologies aligned with pedagogy, PCK focuses on purposeful integration of content and pedagogy (Schmidt et al., 2009) and TCK addresses how technology can be embedded into subject instruction (Margerum-Leys & Marx, 2002). Together, these domains form a comprehensive model describing the interplay of technology, pedagogy and content (Angeli et al., 2016).

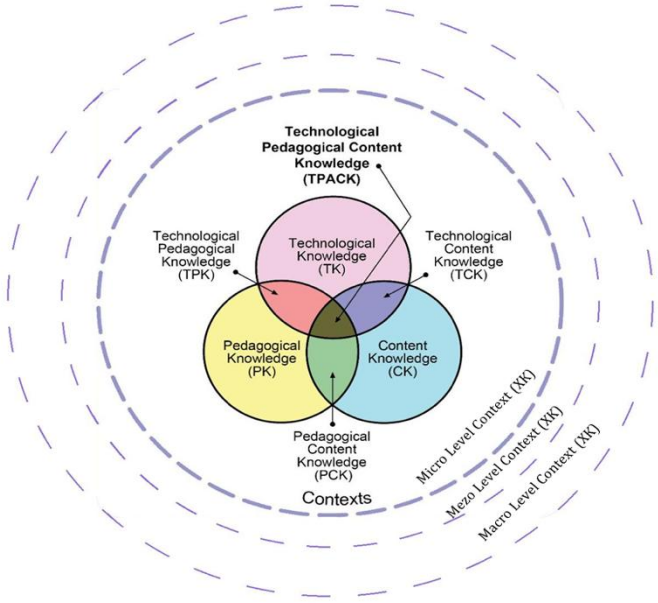


Figure 1. Revised TPACK model (Mishra, 2019, p. 77)

To expand the TPACK framework, Porras-Hernández and Salinas-Amescua (2013) added contextual knowledge (XK), distinguishing micro (classroom), mezo (school and community) and macro (national and international) levels. Mishra (2019) later revised the model to explicitly include XK, stressing that teaching and learning always occur in context, shaped by curriculum, policies, socio-political factors, teacher beliefs and student knowledge (Ali & Hawk, 2024). Thus, contextual levels interact with TPACK components and significantly affect technology integration decisions.

Despite its popularity in research (Ning et al., 2022), TPACK has faced debate. Critics call for clearer distinctions between domains such as PCK, TCK, and TPK (Angeli & Valanides, 2009; Archambault & Barnett, 2010; Graham, 2011). Two views dominate: the integrative view, which sees the domains as interrelated (Graham, 2011; Koehler & Mishra, 2009; Macrides & Angeli, 2018) and the transformative view, which considers them unique knowledge structures (Angeli & Valanides, 2009). Doering et al. (2009) also argue the three core domains are not equally weighted but part of a dynamic construct. In spite of these critiques, TPACK remains a valuable framework for understanding the complex skills needed for effective technology integration (Voogt et al., 2013). However, gaps remain, particularly in exploring how affective dimensions, such as beliefs and attitudes, shape TPACK development. Accordingly, the following hypotheses examining the mediating role of AI self-efficacy in the relationship between mathematics beliefs and TPACK were formulated:

- H6: AI self-efficacy mediates the relationship between constructivist beliefs about mathematics teaching and learning and TPACK.
- H7: AI self-efficacy mediates the relationship between traditional beliefs about mathematics teaching and learning and TPACK.

The current study

The TPACK framework has been widely used to assess teachers' digital technology integration (Schmid et al., 2020). Although teachers' affective factors such as beliefs and attitudes strongly shape classroom practice (Bai et al., 2024; Yildiz & Arpaci, 2024), TPACK does not explicitly address them (Bowman et al., 2022). To address this gap, McLay and Reyes (2024) argued that supporting affective dimensions in teacher education could strengthen technology-focused courses. Examining mathematics beliefs and AI self-efficacy in relation to TPACK may thus extend the framework. Given the importance of pedagogical principles in elementary education (Ertmer & Ottenbreit-Leftwich, 2010) and the sensitive nature of technology integration at this level (Higgins et al., 2007), this study focused on pre-service elementary teachers.

Method

In this study, the relationships among beliefs about mathematics teaching and learning, AI self-efficacy and TPACK were examined using structural equation modelling (SEM). SEM is a multivariate technique used to define causality and relationships between observable and latent variables within a theoretical model (AlAli & Al-Bakarat, 2022). SEM enables simultaneous testing of complex models involving multiple dependent variables and mediator variables (Byrne, 2013), as it is a robust statistical method recognised for its capability to analyse complex interactions among multiple variables simultaneously (Li & Li, 2024). Accordingly, the hypothetical SEM model of the study is presented in Figure 2.

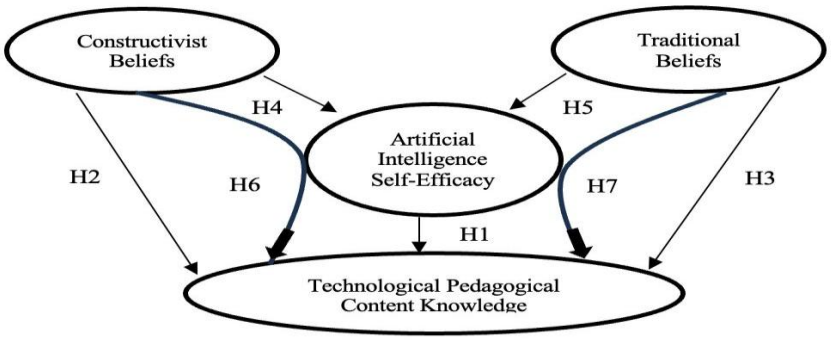


Figure 2. The hypothesised model of the study

Participants

Although no universally accepted rule exists for determining sample size in SEM studies, various methods have been suggested depending on the target population and the nature of the research (Kline, 2005). In this study, convenience sampling was employed. The participants comprised 352 pre-service elementary teachers enrolled in the elementary education undergraduate programmes at three public universities in Türkiye during the 2024–2025 academic year, who were selected via convenience sampling and volunteered to participate in the study. Detailed participant characteristics are presented in Table 1.

Table 1
Demographic characteristics of the participants (N = 352)

Variables	Frequency (*f*)	Percentage (%)
Gender		
Female	285	80.97
Male	67	19.03
Year of study		
First year	90	25.5
Second year	89	25.2
Third year	83	23.5
Fourth year	90	25.5
Total	352	100

Table 1 summarises some demographic characteristics of the sample. A total of 352 pre-service teachers participated in the study, of whom 285 (80.97%) were female and 67 (19.03%) were male. Therefore, the sample is predominantly female. This is consistent with the gender distribution typically observed in primary school teacher training programmes in Türkiye and should be considered when generalising the findings to male pre-service teachers. The sample also shows a balanced distribution in terms of year of study. First- and fourth-year students constitute the largest groups (*n* = 90, 25.5%), followed by second-year (*n* = 89, 25.2%) and third-year (*n* = 83, 23.5%) students. With comparable representation across all four levels (23.5% –25.5%), the sample has the power to include pre-service teachers at different stages of their professional preparation. This supports the comparability of responses across grade levels and reduces the likelihood of results being attributed to a single grade level.

Instruments

In order to collect data for the variables of focus in this study, three instruments were used.

Mathematics Related Belief Scale: This scale was developed by Kayan (2011); It is in Turkish and consists of 32 items and two sub-dimensions: traditional beliefs (TB) and constructivist beliefs (CB). The scale is structured on a 5-point Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The Cronbach's alpha coefficients for the original scale were as follows: TB: 0.734; CB: .835. Bartlett's test of sphericity was significant at the 0.05 level, and Kaiser–Meyer–Olkin (KMO) was calculated as 0.917. In this study, the Cronbach's alpha values were recalculated ($\alpha_TB = .696$, $\alpha_CB = .751$).

Self-Efficacy in Artificial Intelligence Scale: Developed by Wang et al. (2023), it was adapted into Turkish by Uyan and Gültekin (2024). The adapted scale consists of 21 items and includes four sub-dimensions: assistance, anthropomorphic interaction, comfort and technological competence. The scale is a 5-point Likert-type ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The Cronbach's alpha coefficients of the sub-dimensions in the adapted version are as follows: As: .708; Ae: .739; Kr: .782; Ty: .74. The composite reliability (CR) of the scale was calculated as .782, Bartlett's test of sphericity was significant at the 0.05 level and KMO was calculated as .884. In this study, the overall Cronbach's alpha value was recalculated ($\alpha = .847$).

Mathematical Technological Pedagogical Content Knowledge Scale: This scale was developed by Önal (2016). The scale is in Turkish and consists of 59 items and nine sub-dimensions (technological knowledge, pedagogical knowledge, content knowledge, technological pedagogical knowledge – online, technological pedagogical knowledge – offline, technological content knowledge, pedagogical content knowledge, technological pedagogical content knowledge, contextual knowledge). The scale is based on a 5-point Likert-type structure ranging from 1 (*inadequate*) to 5 (*fully adequate*). The Cronbach's alpha of the scale was originally reported as 0.97. Bartlett's test of sphericity was significant at the 0.01 level and KMO was calculated as 0.60. In this study, the Cronbach's alpha was recalculated ($\alpha = .973$).

Data collection

The data for this study were collected face-to-face from pre-service elementary teachers enrolled at three public universities. The data collection process took place between 15 December and 15 January 2025. Out of 370 distributed questionnaires, 352 were returned (response rate: 95.1%). Initially, participants were selected from among volunteer pre-service elementary teachers who were easily accessible at the three universities. Participants were informed about the importance of the study, and confidentiality commitments were clearly communicated. Following the initial round of questionnaire administration, to increase the response rate, follow-up communication was made with participants who had not submitted the questionnaire within 15 days and with those who had not yet participated, encouraging their involvement. Once the required number of responses had been reached – and even exceeded (Venkatesh & Bala, 2008) – the data collection process was finalised.

Data analysis

All data analyses were conducted using two widely recognised statistical software programmes: SPSS (version 21) and AMOS (version 19). SPSS was used to calculate frequency, percentage, standard deviation, mean, correlation, normality and Cronbach's alpha values. Using AMOS, standardised (beta) path coefficients, *p* values and confidence intervals were reported to assess path coefficients and hypothesis testing (Hair et al., 2022). The following model fit criteria were used: chi square to degrees of freedom ratio ($\chi 2$ / df < 5), root-mean-square error of approximation (RMSEA < 0.08), standardised root-mean-square residual (SRMR < 0.08), normed fit index (NFI > 0.90), goodness of fit index (GFI > 0.90), comparative fit index (CFI > 0.90), Tucker-Lewis index (TLI > 0.90) (Harlow, 2023, Chapter 9; Isiaka et al., 2021). In SEM, parcelling is recommended to reduce measurement errors and achieve more robust results (Little et al., 2013; Rocha & Chelladurai, 2012). Since the beliefs about mathematics teaching and learning did not include sub-dimensions, a three-parcel model was created to minimise measurement error. In line with the suggestions by Williams et al. (2009), items were randomly assigned to each parcel based on their order in the scale, ensuring a balanced number of items in each parcel.

To interpret the correlation coefficients, Cohen's (1988) criteria were utilised (small .10 ≤ r < .30, medium .30 ≤ r < .50 and large r ≥ .50). Regarding path coefficients, Cohen's (1988) guidelines were standardised, where values of .10 – .29 represent small, .30 – .49 medium and .50 or higher indicate large effect sizes.

Ethical procedures

Strict measures were implemented to safeguard participants' anonymity and autonomy, fully consistent with Bryman's (2016) ethical research guidelines. In accordance with these principles, ethical approval was obtained (ethics committee approval date: 18.12.2024, decision/document no:E.900379), informed consent with detailed explanation was provided, participation was entirely voluntary, participants were identified by codes instead of names and data were securely stored in a private Google Drive folder accessible only to us, retained for 5 years post-study, and shall then be permanently deleted.

Results

Descriptive statistics, reliability estimates and correlations

The recalculated reliability estimates for the instruments used in this study are reported under the relevant section (Instruments). These results indicate that the scales provide reliable measurements. Table 2 presents several descriptive statistical values for each of the scales used.

Table 2
Descriptive statistics of the scales

Variables	*M*	*SD*	Min.	Max.
Traditional beliefs	2.813	.510	1.11	4.78
Constructivist beliefs	4.070	.293	3.00	4.78
AI self-efficacy	3.247	.497	2.10	4.67
Assistance	4.322	.495	2.17	5.00
Technological competence	2.767	.723	1.00	5.00
Anthropomorphic interaction	2.366	.918	1.00	5.00
Comfort	3.225	.801	1.00	5.00
TPACK	3.607	.529	1.97	4.97
TK	3.121	.668	1.00	5.00
PK	3.736	.597	1.55	5.00
CK	3.743	.653	1.67	5.00
TPK	3.519	.678	1.50	5.00
TCK	3.610	.683	1.40	5.00
PCK	3.683	.667	1.00	5.00
TPACK	3.530	.663	1.67	5.00
XK	3.889	.699	1.20	5.00

Note. TPACK refers to the overall scale score, whereas "technological pedagogical content knowledge" refers to the corresponding sub-dimension of the mathematical technological pedagogical content knowledge scale.

When examining the standard deviation values presented in Table 2, it is possible to observe the degree of homogeneity or heterogeneity in participants' responses to certain variables. Notably, the variable constructivist beliefs yielded a standard deviation of 0.293, indicating that participants' views on this construct were highly similar and demonstrated a high level of homogeneity. In contrast, the variable anthropomorphic interaction produced the highest standard deviation value at 0.918, revealing a broader diversity of opinions among participants and thus a high degree of heterogeneity. For the remaining variables, standard deviation values generally ranged between 0.5 and 0.8, reflecting a moderate tendency towards response homogeneity. These findings suggest that while some concepts were evaluated with clear consensus among participants, others revealed considerable variation in perspectives.

Measurement model

The analysis was conducted in two stages, beginning with the measurement model and followed by the structural model. Mathematics teaching and learning beliefs were modelled with three parcels, TPACK with eight sub-dimensions, and AI self-efficacy with four sub-dimensions. Confirmatory factor analysis indicated acceptable model fit (χ^2/df = 2.551, CFI = .926, incremental fit index = .927, TLI = .910, GFI = .904, adjusted goodness of fit index = .868, SRMR = .071, RMSEA = .066). Standardised regression coefficients ranged from .418 to .913, with all paths statistically significant (p < .01), confirming that the indicators adequately represented the latent constructs.

Structural model

A structural model was specified to examine the mediating role of AI self-efficacy in the relationships between pre-service teachers' beliefs about mathematics teaching and learning (constructivist and traditional) and their TPACK. The results indicated that AI self-efficacy exerted a positive, large and significant direct effect on TPACK (ß = .325, p < .01). Similarly, constructivist beliefs had a positive, small-to-medium significant direct effect on TPACK (ß = .263, p < .01). Conversely, the direct path from traditional beliefs to TPACK was positive and small but non-significant (ß = .136, p = .064). Regarding the predictors of AI self-efficacy, constructivist beliefs exerted a positive, small significant direct effect (ß = .240, p < .01), whereas traditional beliefs showed a negative, medium significant direct effect (ß = -.350, p < .01). In terms of indirect paths, constructivist beliefs had a small, positive, and significant indirect effect on TPACK via AI self-efficacy (ß = .078, p = .007). In contrast, traditional beliefs exerted a small, negative,

and significant indirect effect via AI self-efficacy (ß = -.114, p = .001). These findings demonstrate that AI self-efficacy mediates the relationships between both types of teaching and learning beliefs and TPACK. The structural model yielded an acceptable fit to the data: X^2/df = 2.578, CFI = .924, GFI = .904, NFI = .925, TLI = .900, SRMR = .074 and RMSEA = .067 (see Figure 3).

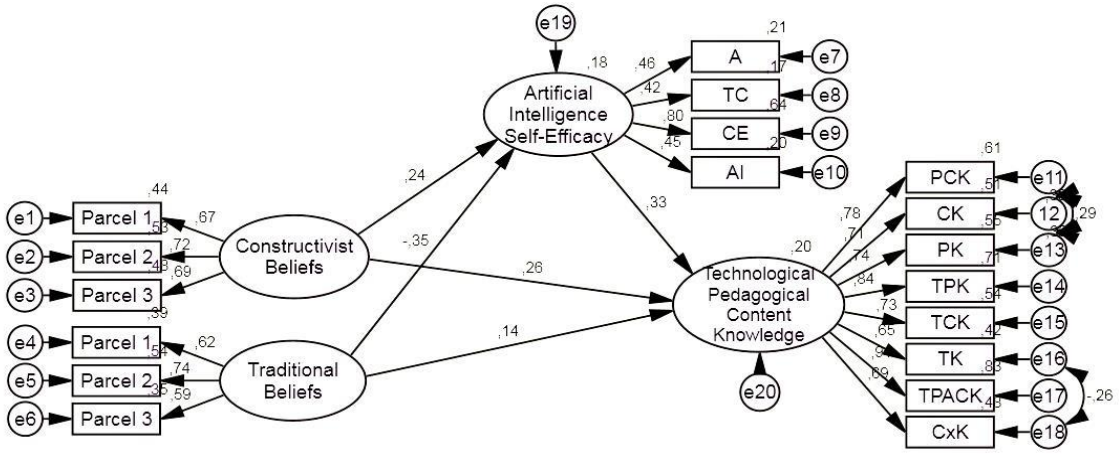


Figure 3. Structural model explaining the relationships among AI self-efficacy, constructivist and traditional beliefs about mathematics teaching and learning and TPACK

As a result, the squared multiple correlation value (R^2) indicated that the predictor variables explained 20.3% of the variance in TPACK scores. The bootstrapping method was applied to evaluate the significance of direct and indirect effects within the structural model. This procedure was carried out with 5,000 resamples at the 95% confidence interval (see Table 4).

The Pearson product-moment correlation results revealed statistically significant and positive relationships between certain variables. A positive, small and statistically significant correlation was found between AI self-efficacy and TPACK (r = .277, p < .01). A positive, moderate and significant correlation was observed between constructivist beliefs about mathematics teaching and learning and TPACK (r = .308, p < .01). Furthermore, a positive, small-effect-size and statistically significant correlation was identified between constructivist beliefs and AI self-efficacy (r = .185, p < .01). In contrast, negative and statistically significant correlations were found between certain variables. For instance, a negative, small-effect-size, and statistically significant relationship was found between traditional beliefs about mathematics teaching and learning and AI self-efficacy (r = –.299, p < .01). Although some other variables also showed negative correlations, these relationships were not statistically significant. For example, the correlation between traditional beliefs and TPACK was negative with a small effect size, but was not statistically significant (r = –.023, p > .01, p > .05) (see Table 3).

Table 3

Correlations among scale scores for the study variables

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. TB	-															
2. CB	.138**	-														
3. AI self-efficacy	-.299**	.185**	-													
4. Assistance	-.131*	.408**	.542**	-												
5. Technological competence	-.134*	-.017	.550**	.055	-											
6. Anthropomorphic interaction	-.283**	-.030	.708**	.157**	.198**	-										
7. Comfort	-.219**	.188**	.831**	.378**	.370**	.368**	-									
8. TPACK	-.023	.308**	.277**	.290**	.173**	.094	.229**	-								
9. TK	.007	.124*	.287**	.188**	.323**	.082	.235**	.673**	-							
10. PK	-.030	.334**	.220**	.277**	.115*	.057	.183**	.847**	.465**	-						
11. CK	-.052	.270**	.197**	.217**	.090	.092	.152**	.823**	.434**	.707**	-					
12. TPK	-.047	.248**	.268**	.266**	.179**	.077	.237**	.832**	.528**	.636**	.608**	-				
13. TCK	.059	.230**	.179**	.225**	.127*	-.002	.176**	.724**	.497**	.480**	.493**	.649**	-			
14. PCK	-.004	.265**	.164**	.203**	.064	.086	.110*	.847**	.459**	.700**	.699**	.622**	.530**	-		
15. TPACK	-.036	.205**	.271**	.250**	.148**	.125*	.226**	.893**	.612**	.652**	.646**	.775**	.679**	.729**	-	
16. Contextual knowledge	-.007	.289**	.174**	.220**	.071	.052	.150**	.720**	.304**	.612**	.529**	.554**	.469**	.636**	.601**	-

Note. Effect sizes for correlation coefficients were interpreted based on Cohen's (1988) criteria: small (.10 ≤ r < .30), medium (.30 ≤ r < .50) and large (r ≥. 50).
*p < .05.**p < .01.

Table 4
Structural model for hypothesis testing results

Hypothesis	Path Direct effect	Standardised factor loading	%95 CI		Estimate	SE	CR	*p*	Result
H1	AI self-efficacy → TPACK	.325	.147	.507	.746	.194	3.856	.000*	Accepted
H2	CB → TPACK	.263	.092	.406	.530	.138	3.829	.000*	Accepted
H3	TB → TPACK	.136	-.019	.292	.169	.092	1.849	.064	Rejected
H4	CB → AI self-efficacy	.240	.059	.501	.210	.077	2.730	.006*	Accepted
H5	TB → AI self-efficacy Indirect effect	-.350	-.521	-.164	-.190	.051	-3.690	.000*	Accepted
H6	CB → TPACK (indirect via AI self-efficacy)	.078	.019	.234				.007*	Accepted
H7	TB → TPACK (indirect via AI self-efficacy)	-.114	-.237	-.035				.001*	Accepted

Note. Effect sizes were interpreted based on Cohen's (1988) guidelines: small (.10–.29), medium (.30–.49) and large (.50 or higher).
*$p < .01$.

Discussion and conclusion

This study aimed to develop a model to reveal the relationship between pre-service primary school teachers' TPACK towards mathematics, their beliefs about mathematics teaching and learning (constructivist and traditional beliefs) and their self-efficacy towards AI. Our model demonstrates acceptable goodness of fit and, considering the contributions of the variables, explains approximately 20% of the variance in TPACK-M scores. This represents meaningful but modest explanatory power, considering the multidimensional and context-dependent nature of TPACK-M. Although the result demonstrates that beliefs and AI self-efficacy are relevant psychological contributors to pre-service teachers' TPACK-M, the remaining variance indicates that its development is also shaped by factors outside the present model. These may include prior technology and AI experience, mathematical and pedagogical knowledge, technology integration training, teaching practice, access to technological resources and institutional support. The unexplained variance may additionally reflect measurement error, individual heterogeneity and unmodelled interactions. Thus, the model provides a focused rather than comprehensive explanation of TPACK-M.

The first result indicates that AI self-efficacy significantly and positively predicts pre-service elementary teachers' TPACK-M, supporting H1. This finding suggests that pre-service teachers who feel more capable of understanding and using AI also perceive themselves as better able to integrate technology, pedagogy

and mathematical content. Previous meta-analyses have highlighted self-efficacy as a central factor in technology integration (Joshi, 2023; Zeng et al., 2022), while empirical studies have shown that computer- and technology-related self-efficacy is associated with TPACK development (Dong et al., 2020; Masry-Herzallah, 2025; Prasetiyo et al., 2022; Schubatzky et al., 2025). More recent AI-focused evidence strengthens this interpretation. Erol et al. (2025) identified a positive relationship between teachers' AI self-efficacy and AI-TPACK, whereas Ismaniati et al. (2025) found that AI self-efficacy predicted teachers' intention to adopt AI and mediated the relationship between TPACK and AI adoption intention. Du et al. (2026) further demonstrated that self-efficacy in using AI to actively engage learners contributed to the quality of AI-supported instruction and mediated the relationship between AI-TPACK and instructional quality. However, its effect varied by instructional purpose, as self-efficacy in using AI to promote differentiation did not significantly predict instructional quality. The present study extends these findings by demonstrating that AI self-efficacy is also relevant to a discipline-specific form of professional knowledge – TPACK-M – among pre-service classroom teachers. Collectively, the findings indicate that preparing future classroom teachers for AI-supported mathematics instruction requires not only technological knowledge but also confidence in selecting and pedagogically adapting AI tools to mathematical content and learning objectives.

The model shows that constructivist beliefs significantly enhance pre-service teachers' TPACK (H2), while traditional beliefs has no direct effect (H3) but a negative indirect impact (H7). Thus, student-centred views support stronger digital pedagogical knowledge, whereas traditional approaches limit its development. Research confirms these patterns: Yang and Leung (2015) found constructivist beliefs promote viewing technology as transformative, while traditional beliefs reduce it to a passive tool. Thurm and Barzel (2022) reported that constructivist beliefs and self-efficacy strengthen TPACK, and Misfeldt et al. (2016) showed teachers viewing mathematics as inquiry use technology more flexibly. Hidayat et al. (2024) linked TPACK sub-components to constructivist beliefs, and Güner et al. (2025) emphasised their complex, multilayered influence. Together, these findings underscore that constructivist beliefs foster meaningful and creative technology integration, while traditional beliefs constrain TPACK development and marginalise technology in instruction.

The study found that constructivist beliefs significantly enhance pre-service teachers' AI self-efficacy (H4), while traditional beliefs reduce it (H5). Teachers who view learning as discovery feel more competent with AI, whereas teacher-centred beliefs lower trust in AI. This suggests pedagogical belief systems shape perceived competence with emerging technologies. Research supports this link: constructivist beliefs improve mathematics and teaching self-efficacy, while traditional beliefs constrain them (Lau, 2022; Zuya et al., 2016). Beliefs also shape AI-related self-efficacy, which depends on pedagogical flexibility. For example, Gagnier et al. (2021) showed science, technology, engineering and mathematics teachers' self-efficacy was influenced by technology-based beliefs, while Scherer and Bertram (2024) found beliefs and self-efficacy co-develop in inclusive mathematics contexts. Usta et al. (2019) similarly reported that constructivist beliefs build confidence in technology, while traditional beliefs promote its exclusion. Strengthening constructivist instructional beliefs is therefore key to enhancing teachers' AI self-efficacy.

Finally, AI self-efficacy mediates the relationships between pre-service classroom teachers' mathematics-related beliefs and TPACK-M, supporting H6 and H7. Constructivist beliefs were associated with TPACK-M both directly and indirectly through increased AI self-efficacy, whereas traditional beliefs had no significant direct effect but showed a negative indirect effect through reduced AI self-efficacy. These contrasting pathways indicate that mathematics-related beliefs may contribute to TPACK-M partly by shaping pre-service teachers' confidence in using AI. Research has similarly identified self-efficacy as an important mechanism connecting teachers' technological competence, TPACK and technology-related outcomes (Bai et al., 2024; Birisci & Kul, 2019; Dong et al., 2020; Wang & Zhao, 2021). Recent AI-focused studies further support this mediating role. Ismaniati et al. (2025) found that AI self-efficacy mediated the relationship between TPACK and AI adoption intention, while Du et al. (2026) showed that self-efficacy in using AI to engage learners mediated the relationship between AI-TPACK and instructional quality. Erol et al. (2025) also demonstrated significant interrelationships among teachers' AI attitudes, AI self-efficacy and AI-TPACK. Extending this literature, the present study shows that AI self-efficacy also functions as a

mechanism through which constructivist and traditional mathematics beliefs are differently associated with TPACK-M. Thus, developing AI-related confidence may help translate constructivist beliefs into stronger mathematics-specific technology integration, whereas traditional beliefs may restrict this development by weakening AI self-efficacy.

Limitations and recommendations

The findings are limited to pre-service elementary teachers from three public universities, suggesting replication with larger and more diverse samples. The study relied solely on quantitative data, without qualitative methods to explore beliefs, self-efficacy and techno-pedagogical knowledge. Future studies should employ mixed methods (e.g., semi-structured interviews) to capture reflective thinking. Because responses relied on self-perceptions, social desirability bias may have influenced results.

This study examined constructivist and traditional mathematics beliefs and AI self-efficacy as predictors of mathematics-related TPACK. Because mathematics-related beliefs and AI self-efficacy explained 20% of the variance in TPACK-M, future research should test more comprehensive models incorporating mathematical content knowledge, pedagogical competence, prior AI experience, technology integration training, institutional support, access to technological resources and opportunities for authentic teaching practice. Longitudinal or experimental studies may also clarify how these factors interact in the development of TPACK-M over time.

Because the study conceptualised AI broadly, the findings should not be interpreted as reflecting self-efficacy specifically related to generative AI. Future studies may distinguish between general AI self-efficacy and generative AI self-efficacy and examine whether these constructs have different relationships with TPACK-M.

Author contributions

Zeynep Bahar Erşen: Conceptualisation, Investigation, Formal analysis, Writing – original draft, Writing – review and editing; **Ebru Ergül:** Data curation, Investigation, Formal analysis, Methodology, Writing – original draft, Writing – review and editing; Visualisation.

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Please cite as: Erşen, Z. B., & Ergül, E. (2026). "I can, so I teach with AI": Modelling the interplay between self-efficacy, mathematics-related beliefs and TPACK-M. *Australasian Journal of Educational Technology*, *42*(5), 59–79. https://doi.org/10.14742/ajet.10806