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Validating a context-specific TPACK scale for primary mathematics education in China

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ABSTRACT

This study presents the validation of a Technological Pedagogical Content Knowledge (TPACK) scale tailored explicitly for primary mathematics teachers in China. Recognizing the gap in context-specific TPACK assessment tools, the research aims to provide an instrument that aligns with the unique educational landscape of China. Utilizing established scales as prototypes, the study integrates the distinctive construct of contextual knowledge to encapsulate the interplay between technology, pedagogy, content, and the Chinese teaching context. A sample of 315 primary mathematics teachers from Chongqing, China, participated in this study. The scale's reliability and validity were rigorously tested using Cronbach's alpha and confirmatory factor analysis (CFA), ensuring its robustness and applicability. The findings show high internal consistency, with strong reliability indicated by Cronbach's alpha. CFA confirmed structural validity, with most fit indices meeting good fit criteria. Convergent and discriminant validity also demonstrated the scale's effectiveness in assessing the competencies needed for integrating technology into teaching. The study's main contribution is the development of a context-specific TPACK scale for Chinese primary mathematics education. This scale advances the theoretical understanding of TPACK in China and offers practical implications for teacher education, curriculum design, and technology policy, emphasizing the importance of context-sensitive assessment tools.

Keywords: TPACK, primary mathematics education, artificial intelligence, Chinese educational context

INTRODUCTION

In the contemporary era, the role of digital technology in education has undergone a significant transformation (Selwyn, 2021). The integration of digital technology has become prevalent in educational settings and has emerged as a catalyst for redefining teaching and learning experiences (Blannin, 2022). This transformation is particularly evident in the field of mathematics education (Psycharis & Kalogeria, 2017). Both research and practice have demonstrated that strategically integrating digital technology can greatly enhance the teaching and learning of mathematics. The effective integration of digital technology in mathematics education is a subtle endeavor that necessitates a synergistic amalgamation of technological proficiency, pedagogical expertise, and mastery of content knowledge (CK). This intricate interaction, frequently referred to as the Technological Pedagogical Content Knowledge (TPACK) framework, lies at the core of contemporary educational paradigms (Mishra & Koehler, 2006; Mishra et al., 2023; Niess & Gillow-Wiles, 2014). TPACK, an acronym for the three central components it encapsulates, constitutes a comprehensive framework that interweaves technological knowledge (TK), pedagogical knowledge (PK), and CK within the context of teaching and learning (Mishra & Koehler, 2006).

The significance of the TPACK framework lies in its capacity to bridge the traditional divide between the technological, pedagogical, and content aspects of education (Koehle et al., 2013; Mishra et al., 2023). This comprehensive framework equips educators with the necessary tools and insights to effectively integrate technology into the educational process, ensuring that it enhances, rather than detracts from, the core learning objectives (Niess, 2011). For primary mathematics education, TPACK assumes paramount importance, serving as a guiding light for teachers as they design engaging and meaningful learning experiences (Huang et al., 2024; Loong & Herbert, 2018). Moreover, in primary mathematics education, the TPACK framework is crucial in transforming classrooms into dynamic hubs of mathematical exploration and inquiry (Li et al., 2024). Primary mathematics teachers with strong TPACK can design learning activities that effectively foster students' mathematical thinking, problem-solving skills, and overall mathematical competence (Lyublinskaya & Kaplon-Schilis, 2022; Tsouccas & Meletiou-Mavrotheris, 2019). In this context, the framework serves as a compass guiding teachers towards effectively utilizing digital technology, which supports the development of foundational mathematical skills while nurturing a passion for learning (Li et al., 2024). This study focuses on the comprehension, refinement, and validation of a TPACK scale specifically designed for the unique context of primary mathematics education.

The education system in China is recognized for its consistent focus on developing fundamental skills, especially in mathematics, which holds a significant place in the overall educational framework (Norton & Zhang, 2016). Traditional teaching methods have historically served as the cornerstone of pedagogical practices in China, underpinning the development of mathematical proficiency in students (Sun, 2000). However, in the current era, marked by rapid technological advancements including artificial intelligence (AI) and global interconnectedness, China's educational paradigm has undergone a notable transformation (Wang et al., 2024; Zhou, 2023). There is an increasing recognition of the need to embrace digital technology and integrate it into primary education to equip students with the competencies required to thrive in the 21st century (Dockendorff & Zaccarelli, 2024; Dogan, 2012; Tay et al., 2021). This recognition is not merely a response to global trends but a proactive step in aligning the educational system with the evolving demands of the modern world.

The Chinese government has played a significant role in fostering this transformation by making significant investments in technology infrastructure and educational resources at the primary level. These investments reflect a national commitment to unlock the potential of technology in education. Initiatives such as the "Opinions on the implementation of the national primary and secondary school teachers' information technology application ability enhancement project 2.0" policy underscore this commitment (Ministry of Education the People's Republic of China [MoE], 2019). This policy aims to reinforce the integration of technology into teaching and learning practices, striving to provide students with a contemporary and future-oriented education. However, despite these efforts, a significant imperative remains unaddressed: the effective integration of technology, pedagogy, and CK in Chinese primary mathematics classrooms. This challenge arises from the need to align technological integration with traditional pedagogical practices' cherished principles and content mastery's imperatives. This study focuses on addressing a critical need in the field of primary mathematics education in China. By developing and validating a TPACK scale specifically designed for the unique context of Chinese primary schools, the objective of this study is to provide a powerful tool for enhancing the competencies of mathematics educators. This scale enables primary mathematics teachers' deeper understanding of integrating technology, pedagogy, and CK in the classroom, bridging the gap between traditional teaching methods and contemporary innovation. To achieve this goal, two research questions were formulated:

1. What is the reliability of the primary mathematics teachers' TPACK scale (PMTTS) in assessing the knowledge domains of the TPACK framework?
2. What is the validity of the PMTTS in measuring the knowledge domains of the TPACK framework?

LITERATURE REVIEW

TPACK Framework

This study is grounded in the TPACK framework, which has a rich history in educational research. Initially developed by Mishra and Koehler in 2006, TPACK was designed to understand the complex interactions between technology, pedagogy, and CK in education. Over the years, TPACK has evolved and been refined through empirical research, becoming a widely accepted and influential framework in educational studies (Kartal & Çınar, 2022; Kurt & Çakıroğlu, 2023; Zambak & Tyminski, 2019). The TPACK framework comprises three core elements: TK, PK, and CK. These elements interact and overlap to form four composite elements: technological content knowledge (TCK), technological pedagogical knowledge (TPK), pedagogical content knowledge (PCK), and, most importantly, TPACK (see **Figure 1**). The composite elements represent the integration of two or three core elements, emphasizing the interconnectedness and interdependence of technology, pedagogy, and content in educational practice (Koehle et al., 2013).

1. **CK**: This knowledge domain represents the depth of understanding of the subject matter taught, in this case, primary mathematics. CK encompasses the curriculum, standards, and fundamental mathematical concepts required for effective teaching.
2. **PK**: This knowledge focuses on the art and science of teaching. It encompasses instructional design, classroom management, assessment strategies, and the selection of teaching methods.
3. **TK**: This knowledge concerns the understanding of various technological tools and their application in educational settings. It involves proficiency in using technology and the ability to discern which tools are most suitable for specific educational objectives.
4. **TPK**: This knowledge represents the interplay between TK and PK. It explores how technology can be effectively integrated into teaching practices to enhance learning experiences.
5. **TCK**: This knowledge revolves around the connection between TK and CK. It delves into how technology can be employed to convey subject matter in a more comprehensible and engaging manner.
6. **PCK**: This knowledge emphasizes the synergy between PK and CK. It addresses how teaching strategies can be tailored to make content more accessible and engaging for students.
7. **TPACK**: This knowledge represents the fusion of all seven knowledge domains. It is the heart of the framework, showcasing the intricate interaction between technological, pedagogical, and CK. TPACK underscores the importance of this fusion in delivering effective, technology-enhanced education.

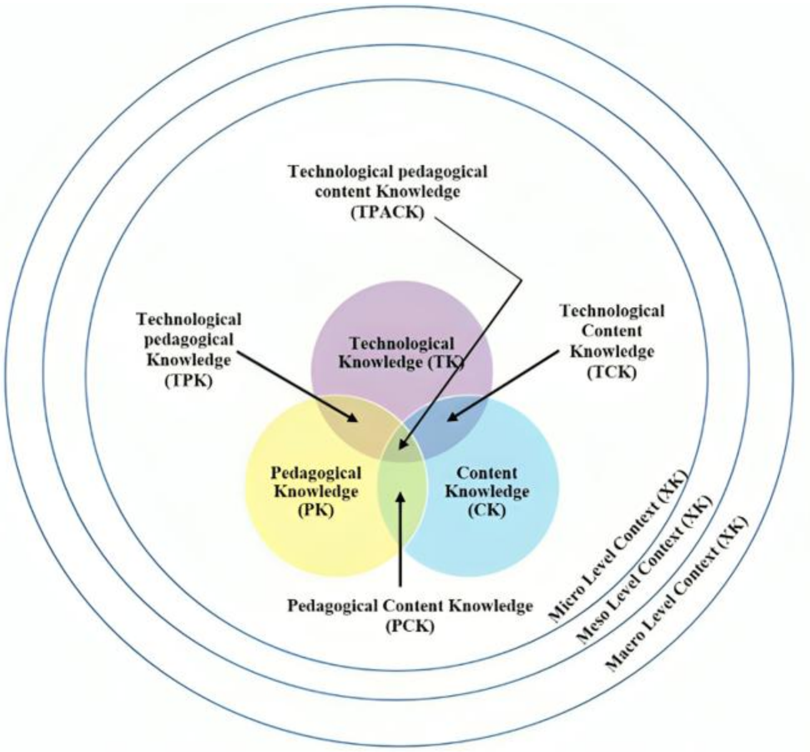

Figure 1. The TPACK framework (Mishra & Koehler, 2006; Porras-Hernández & Salinas-Amescua, 2013)

However, acknowledging the contextual nature of education, some scholars have advocated for the integration of XK within the TPACK framework (Mishra, 2019; Porras-Hernández & Salinas-Amescua, 2013). This integration highlights the importance of contextual factors, such as cultural, social, economic, and political influences that shape educational practices (Mishra, 2019). By incorporating XK, TPACK becomes more responsive to the distinct needs of various educational contexts, thereby enhancing its comprehensiveness and applicability. In this study, the expanded TPACK framework, which incorporates XK, serves as the theoretical lens guiding the research (see **Figure 1**). The objective is to develop and validate a context-specific TPACK scale that considers the micro, meso, and macro contextual factors (Porras-Hernández & Salinas-Amescua, 2013) relevant to Chinese primary mathematics education:

1. **Micro environment:** The immediate classroom context, comprising student demographics, available resources, and classroom dynamics, influences how teachers integrate technology in mathematics instruction.
2. **Meso environment:** Beyond individual classrooms, school-level factors, such as policies, administrative support, and professional development opportunities, affect the effective use of technology in primary mathematics education.
3. **Macro environment:** Broader societal, cultural, and policy contexts, including national policies, cultural norms, and global trends, shape the integration of digital technology in primary mathematics education.

Contextualizing TPACK: Literature Review and Gaps

The development and validation of TPACK scales have been a central focus in empirical studies aiming to measure and understand teachers' TK, PK, and CK (Scott, 2021). Schmidt et al. (2009) pioneered one of the earliest TPACK assessment tools, which comprised multiple subscales designed to capture the multifaceted dimensions of TPACK. Through rigorous testing and validation, their scale established a strong foundation for assessing teachers' TPACK levels reliably and validly. Following this groundbreaking work, different TPACK scales have emerged (Chai et al., 2019; Li, 2023; Liu, 2022; Ritzhaupt et al., 2015; Sahin, 2011), each tailored to specific educational contexts and focal points. For instance, Li et al. (2023) designed a TPACK scale focused on mathematics teachers' ability to integrate digital technology within the unique context of Chinese secondary schools. Such context-specific scales demonstrate a keen awareness of the nuanced ways in which TPACK intersects with local educational cultures and practices. The TPACK framework has been subject to continuous expansion and refinement by scholars seeking to enhance its applicability in diverse educational settings. One such example is the ICT-TPACK-Science scale, which was specifically designed to cater to the needs of pre-service science teachers (Kadıoğlu-Akbulut et al., 2020). This scale not only assesses but also facilitates the development of TPACK among science educators, thus serving as a powerful tool in measurable TPACK enhancement. By affording both pre-test and post-test assessments, it enables instructional courses to target areas requiring improvement and gauge the effectiveness of interventions (Kadıoğlu-Akbulut et al., 2020).

Moreover, many TPACK scales reflect the rich tapestry of international perspectives on technology integration in education. For instance, Niess and Gillow-Wiles (2014) conducted a study in the United States that emphasized the significance of TPACK in teacher preparation programs. They highlighted its potential to cultivate technological competencies among future educators, underscoring its importance in shaping the next generation of teachers. In a cross-cultural lesson study conducted by Huang et al. (2021) involving China and Australia, it was observed that the quality of online teaching hinged on two key factors: the TPACK of mathematics teachers and their proficiency in selecting appropriate online teaching digital technologies, encompassing equipment and online resources, to effectively engage and motivate students (Huang et al., 2021). It can be said that these studies underscore the crucial need for sustained research into TPACK scales and their application across various educational contexts. It is through continuous refinement and contextualization of these assessment tools that scholars and practitioners can gain a deeper understanding of TPACK's underlying constructs and enhance its utility in fostering meaningful technology integration in mathematics and beyond. Such efforts will undoubtedly contribute to the advancement of educational practices and help realize the full potential of digital technology in enhancing student learning experiences (Niess, 2016).

While the existing literature provides valuable insights into TPACK and its applications in mathematics education, several gaps remain unaddressed. One significant gap is the limited attention paid to the context-specificity of TPACK in primary schools (Scott, 2021). Context-specificity has been recognized as a crucial factor in technology integration in mathematics education (Akyuz, 2023; Li & Li, 2024). However, few studies have focused on understanding the unique contextual factors that shape TPACK in Chinese primary mathematics education. Existing TPACK scales have primarily been developed and validated in Western educational contexts (Scott, 2021), raising concerns about their applicability and relevance in Chinese schools, given the distinct cultural, educational, and technological landscapes (Dong et al., 2019; Li et al., 2023). In recent years, generative AI tools such as Ernie Bot (文心一言) and ChatGPT have been increasingly used in mathematics education (Cotič et al., 2024; Wardat et al., 2023). Considering the growing use of generative AI tools in mathematics education, it is essential to address these developments when designing a context-specific TPACK instrument, enabling mathematics teachers to better understand and enhance their capabilities in integrating digital technologies into classroom teaching.

To address these gaps, this study aims to design and validate a context-specific TPACK scale for assessing primary mathematics teachers' TPACK levels in China. By examining the unique contextual factors that influence TPACK development in this context, this study contributes to a more comprehensive understanding of TPACK and its applications in mathematics education. Furthermore, the proposed scale has the potential to support teachers' professional development and inform policy decisions aimed at enhancing technology integration and improving teaching and learning experiences in primary mathematics education.

METHODOLOGY

Research Design

The study employed a survey design, a methodology well-suited for collecting data from a large number of participants and conducive to quantitatively analysing their responses (Bryman, 2016). This approach was chosen for its effectiveness in capturing the diverse perspectives and experiences of primary mathematics teachers regarding their integration of technology, pedagogy, and CK in educational settings.

The primary objective of this study was to design and validate a contextually relevant TPACK instrument tailored specifically for primary mathematics teachers in the Chinese educational setting. To achieve the goal, the study initially identified two foundational instruments as prototypes for adaptation and refinement: one developed by Chai et al. (2013) and another by Li et al. (2023). These instruments were selected for their proven validity in previous studies and their relevance to the target demographic of primary mathematics teachers in China. The adaptation process involved a careful modification of these existing instruments, ensuring that they align closely with the unique requirements and teaching contexts of primary mathematics teachers in China. During this phase, special attention was given to cultural appropriateness, incorporating elements relevant to the Chinese educational environment. This process included integrating the unique construct of Contextual knowledge, which encapsulates the micro, meso, and macro environment in Chinese mathematics education. This integration was pivotal in creating a comprehensive tool capable of effectively assessing the TPACK of primary mathematics teachers within the specific nuances of the Chinese educational landscape. Utilizing these modified prototypes and the specialized XK construct, the research designed and validated the PMTTS.

Participants

This study randomly selected mathematics teachers from primary schools in Chongqing, China. Three hundred fifteen teachers (205 female and 110 male) participated in the study, covering all teaching grades from grade 1 to grade 6. The distribution of teachers across these grades was 14.92% teaching grade 1, 19.68% teaching grade 2, 23.17% teaching grade 3, 17.78% teaching grade 4, 15.87% teaching grade 5, and 8.57% teaching grade 6, which reflects the diverse teaching responsibilities of the participants (see **Table 1**). When considering teaching experience, the participants exhibited a broad spectrum of career lengths. Specifically, 18.41% had 0-5 years of experience, 26.67% had 6-10 years, 32.06% had 11-15 years, and 22.86% had over 15 years of experience. This extensive range of teaching experience offered a comprehensive insight into the application of technology in mathematics education throughout various stages of educators' careers.

The educational backgrounds of the participants were also diverse. A significant 67.30% held a bachelor's degree. Those with a junior college degree comprised 25.40% of the sample. Additionally, 7.30% of the participants held a master's degree. The gender distribution of the participants was skewed, with a majority being female teachers (65.08%). This reflects the common gender distribution trend in primary mathematics education in China, where female teachers typically outnumber their male counterparts. This diverse group of participants, with their varied educational backgrounds, teaching experiences, and grade-level involvements, provides a rich and comprehensive dataset for the study. Their contributions are significant in understanding technology integration in mathematics education and validating the TPACK scale in China's primary education context.

Table 1. Demographic information

Category	Female	Male	Total	Percentage of total population
Teaching grade				
Grade 1	41	6	47	14.92%
Grade 2	53	9	62	19.68%
Grade 3	43	30	73	23.18%
Grade 4	32	24	56	17.78%
Grade 5	25	25	50	15.87%
Grade 6	11	16	27	8.57%
Teaching experience				
0-5 years	47	11	58	18.41%
6-10 years	62	22	84	26.67%
11-15 years	52	49	101	32.06%
Above 15 years	44	28	72	22.86%
Educational background				
Junior college	65	15	80	25.40%
Bachelor's degree	128	84	212	67.30%
Master's degree	12	11	23	7.30%
Total	205	110	315	100%

Recruitment Process

The recruitment process for this study was conducted in collaboration with the Chongqing Teacher Education Training Center, aiming to ensure the participation of primary mathematics teachers from various schools in Chongqing. The researchers established a close working relationship with the center's administrator, which was instrumental in facilitating the recruitment process and ensuring the selection of a diverse and representative sample of primary mathematics teachers. Moreover, a questionnaire was developed using Qualtrics and disseminated via WeChat, a communication platform in China, to reach potential participants. This approach effectively elicited responses from a broad spectrum of mathematics teachers, contributing to the diversity of the sample.

Instrument

The instrument designed for this study was informed by the work of Chai et al. (2013) and Li et al. (2023), and it was tailored to address the technology integration in primary mathematics education in China. The instrument encompassed eight constructs: CK (4 items), PK (3 items), TK (3 items), PCK (3 items), TCK (4 items), TPK (3 items), TPACK (3 items), and XK (4 items). Including the XK construct is a novel feature of this instrument, reflecting the study's focus on the primary mathematics education context. Recognizing the evolving landscape of educational technology, the instrument included items specifically related to integrating AI tools in mathematics teaching. This addition was crucial in capturing the contemporary dynamics of technology-enhanced learning environments (Mishra et al., 2023; Moore et al., 2023). For instance, an item related to the use of AI in mathematics classes was phrased, as follows: "I can use AI tools (e.g., Ernie Bot and ChatGPT) in mathematics classes to improve student motivation." This item reflects the study's focus on understanding how emerging technologies like AI can be harnessed to enhance educational outcomes.

This study focused on Chinese primary mathematics education. Therefore, the instrument used mathematics-specific content instead of general content. This approach ensures the items are directly relevant to the participants' teaching field. For example, an item drawing inspiration from Chai et al. (2013) was enriched with a specific example: "I can design self-directed learning activities with educational resources (e.g., I can record online video courses and design mathematics assignments for students' self-learning at home)." This item captures the essence of TPACK and illustrates its practical application in the classroom. Additional examples were provided in **Appendix A** further to explain the clarity and applicability of the scale. These examples showcased a range of scenarios where technology, especially AI tools, could be effectively integrated into mathematics instruction.

Data Collection

The data collection for this study was executed by disseminating a web-based questionnaire specifically targeting primary mathematics teachers. This method ensured the teachers' ease of access and participation (Cohen et al., 2018). The questionnaire was structured into demographic information (e.g., genders, teaching grade, teaching experience, and educational background) and teachers' TPACK (27 items). Clear instructions accompanied each section to facilitate a comprehensive understanding and accurate responses. An ample response period was allocated, giving teachers sufficient time to reflect on and respond to the items thoughtfully. Prioritizing ethical research practices, the questionnaire was designed to collect data without gathering personal identifying information, thereby ensuring the anonymity and confidentiality of the participants. Robust data security measures were implemented to protect the collected information, restricting access exclusively to the research team.

An informative poster was created and circulated among the potential respondents to enhance participation and engagement. This poster concisely outlined the study's aims, the significance of participation, and instructions for accessing the questionnaire, including a QR code and a direct link. This approach informed the teachers about the study and underscored the value of their contribution, thereby encouraging a higher response rate (Bryman, 2016). The informed consent form and an explanatory statement were embedded within the web-based questionnaire. These documents clearly articulated the study's purpose, the voluntary nature of participation, and the ethical considerations in place, further strengthening the trust and transparency of the data collection process. The data collection phase lasted four weeks, allowing participants to engage with the questionnaire at their convenience. Periodic reminders were sent to the mathematics teachers to encourage comprehensive participation. Eventually, 315 of 459 mathematics teachers participated in the study, and the response rate was 68.6%. This high level of engagement underscores the representativeness of the sample (Cohen et al., 2018).

Data Analysis

This study analyzed the collected data using two software tools: SPSS (version 28) and AMOS (version 28). The aim was to thoroughly examine the reliability and validity of the developed scale designed to measure primary mathematics teachers' proficiency in various domains of the TPACK framework. To ensure the robustness and reliability of the findings, we selected a sample of 315 primary mathematics teachers for this study. This sample size is consistent with the recommended minimum for confirmatory factor analysis (CFA), which typically requires a sample of at least 200 to 300 respondents (Hair et al., 2010; Kline, 2023). Additionally, the sample size falls within the range suggested by previous research in educational contexts, and this ensures adequate statistical power for testing the model's fit and validating the constructs of the TPACK scale.

Reliability analysis

To assess the reliability of the scale, Cronbach's alpha coefficient and composite reliability (CR) were calculated for each TPACK dimension. This coefficient serves as a measure of internal consistency, with a higher value (typically ≥ 0.7) indicative of greater reliability and internal consistency of the scale, as suggested by Cohen et al. (2018). The application of this measure was critical in ensuring that each dimension of the TPACK framework was reliably represented in the scale.

Model fit analysis

In this research, the scale validation was exclusively undertaken using CFA, as implemented through AMOS software. This approach aligns with the established structure of the TPACK framework, which underpins the study and adheres to the precedents set by seminal works in the field, particularly those of Chai et al. (2013) and Li et al. (2023). The rationale for directly proceeding with CFA stems from the existing knowledge and well-defined constructs of the TPACK framework. Given that the factors of the scale have already been identified and supported by prior studies, the use of explatory factor analysis, which is typically employed to explore and identify potential latent factors in more exploratory or less-defined contexts, was deemed unnecessary (Cohen et al., 2018; Hair et al., 2018).

In essence, the constructs within the TPACK framework are theoretically established and empirically validated in prior research, providing a solid foundation for directly employing CFA. CFA was, therefore, utilized to rigorously test the hypothesized factor structure of the scale against the observed data. This method allows for a precise assessment of how well the proposed model fits with the collected data. An array of fit indices was utilized to assess the model's adequacy, including the Chi-square to degrees of freedom ratio (χ^2/df), root mean square error of approximation (RMSEA), goodness of fit index (GFI), adjusted goodness of fit index (AGFI), normed fit index (NFI), comparative fit index (CFI), incremental fit index (IFI), and Tucker-Lewis index (TLI) (Byrne, 2016). A well-fitting model, as indicated by these indices, would affirm that the scale effectively captures the intended dimensions of TPACK, thus reinforcing its validity.

Convergent and discriminant validity

This study rigorously evaluated convergent and discriminant validity. Convergent validity was determined by analyzing the factor loadings and the average variance extracted (AVE) for each construct, where higher values indicate a stronger association with the underlying construct (Byrne, 2016). For discriminant validity, the square root of the AVE for each construct was compared with the correlation coefficients between the constructs. This approach ensures that each construct is distinct from others within the model, with the square root of AVE for each construct exceeding its correlations with other constructs (Hair et al., 2018). Also, this comparison ensures that each construct is empirically distinct, capturing unique variance not accounted for by other constructs in the model.

FINDINGS

Face Validity

The initial phase of ensuring face validity for the TPACK scale involved an extensive literature review. This review identified two pivotal studies: Chai et al. (2013) and Li et al. (2023), which provided foundational insights and existing items relevant to the research context. The scale developed for this study was designed based on these existing scales, closely aligning with the TPACK framework. This approach ensured that the scale was grounded in the established theoretical and empirical literature, providing a solid foundation for its content and construct validity (DeVellis, 2017).

Additionally, to establish the face validity of the scale, a panel of three subject matter experts in mathematics education were consulted. These experts, possessing extensive knowledge of the TPACK framework and its application in educational settings, thoroughly evaluated the item pool. Their primary focus was to ascertain that each item was relevant and accurately representative of the intended constructs within the TPACK framework. This expert review helped refine the scale, ensuring theoretical soundness and construct relevance. Also, recognizing the importance of language in interpreting and understanding scale items, particularly in the context of Chinese mathematics teachers, we engaged two experienced Chinese teachers to review the scale's language. Their role was to scrutinize the wording of each item, ensuring that the expressions used were clear, correct, and authentically resonated with the cultural and educational nuances of Chinese mathematics education. This step was crucial in enhancing the scale's comprehensibility and relevance, bolstering its face validity for the target population (DeVellis, 2017).

Pilot Test

The pilot test of the TPACK scale was conducted among a group of 13 mathematics teachers randomly selected from the target population for the main study. This selection process was crucial to ensure the feedback was representative and pertinent. The participants' demographics accurately reflected the broader population of mathematics teachers in terms of their educational backgrounds, teaching experience, and the levels they taught, thus providing diverse and applicable insights into the usability of the scale (Cohen et al., 2018). The primary aim of the pilot test was to assess the clarity and comprehensiveness of the TPACK scale. Participants were asked to fill out the scale and offer feedback on the clarity and relevance of each item. This procedure was vital for identifying issues with item wording, scale structure, or concept representation that might not have been evident during the initial development phase (DeVellis, 2017). The feedback received from the pilot test participants was analyzed and resulted in slight yet significant adjustments to the wording of multiple items. These alterations aimed to improve the overall clarity of the scale and ensure that each item accurately captured the intended construct. The emphasis was on making the scale accessible and comprehensible to all potential respondents, especially given mathematics teachers' diverse teaching contexts and backgrounds.

Formal Questionnaire Reliability

After conducting the pilot test, the questionnaire was distributed to a more extensive sample of mathematics teachers. The results of this formal questionnaire are presented across four key dimensions: reliability, model fit, convergent validity, and discriminant validity.

The reliability of the TPACK scale was evaluated using Cronbach's alpha, a measure of internal consistency among the scale items across different constructs (Bryman, 2016). This reliability analysis encompassed the entire scale and its constructs, ensuring a thorough validation process (DeVellis, 2017). The results, presented in **Table 2**, align with widely recognized standards in psychometrics (Cohen et al., 2018). Notably, the TPACK scale demonstrates internal solid consistency across its various constructs, with an overall high reliability, as indicated by an alpha coefficient of 0.873 for all 27 items. Specifically, constructs such as CK, XK, and TCK exhibit outstanding reliability, with alpha values ranging from 0.804 to 0.837. These scores underscore the scale's effectiveness in precisely capturing these distinct dimensions of teachers' knowledge. On the other hand, constructs like PK, TK, PCK, TPK, and TPACK show adequate reliability, with alpha coefficients between 0.746 and 0.759. Although slightly lower, these values still suggest acceptable internal consistency, confirming the reliability of these constructs in measuring relevant aspects of teachers' technological and pedagogical expertise. Consequently, these reliability results corroborate the validity of the TPACK scale as a comprehensive and dependable tool for assessing the multifaceted nature of teachers' competencies in integrating technology within educational settings.

Table 2. The Cronbach's alpha test

Construct	Items	Cronbach's alpha	Level of Cronbach's alpha
Entire scale	27	0.873	Highly reliable
CK	4	0.824	Highly reliable
PK	3	0.746	Reliable
TK	3	0.746	Reliable
XK	4	0.837	Highly reliable
PCK	3	0.759	Reliable
TCK	4	0.804	Highly reliable
TPK	3	0.747	Reliable
TPACK	3	0.755	Reliable

Formal Questionnaire CFA Model

CFA was utilized to validate the measurement model in this study. The results obtained from the CFA analysis provided support for the postulated factor structure, which is consonant with the TPACK framework. Subsequently, the study's rigor is underscored by demonstrating the measurement model's validity through three key aspects: model fit, convergent validity, and discriminant validity.

Model fit

The model fit of the TPACK scale was assessed using multiple indices to ascertain the correspondence between the proposed model and the observed data. **Table 3** presents the fit indices employed in this evaluation, their respective observed values, and the thresholds for a good and acceptable fit, aligning with the guidelines Hair et al. (2018) recommended for robust structural equation modelling.

Table 3. The model fit of the PMTTS scale

Fit index	PMTTS scale fit value	Good fit threshold	Acceptable fit threshold
χ^2/df	1.888	0 < χ^2/df < 3	3 ≤ χ^2/df < 5
RMSEA	0.053	0 < RMSEA < 0.05	0.05 ≤ RMSEA < 0.10
GFI	0.892	0.95 ≤ GFI ≤ 1	0.90 ≤ GFI < 0.95
AGFI	0.861	0.90 ≤ AGFI ≤ 1	0.85 ≤ AGFI < 0.90
NFI	0.858	0.95 ≤ NFI ≤ 1	0.90 ≤ NFI < 0.95
CFI	0.927	0.95 ≤ CFI ≤ 1	0.90 ≤ CFI < 0.95
IFI	0.928	0.95 ≤ IFI ≤ 1	0.90 ≤ IFI < 0.95
TLI	0.912	0.95 ≤ TLI ≤ 1	0.90 ≤ TLI < 0.95

The Chi-square to degrees of freedom ratio (χ^2/df) yielded a value of 1.888, well below the threshold of 3, indicating a favourable model fit and a plausible model structure relative to the data. Additionally, RMSEA was 0.053, falling within the acceptable fit range and close to the good fit criterion of 0.05, suggesting that the model closely approximates the data with minimal error. Other indices, such as GFI, NFI and AGFI, recorded values of 0.892, 0.858 and 0.861, respectively. While AGFI meets the criteria for an acceptable fit (≥ 0.85), both NFI and GFI fall slightly below the acceptable threshold (≥ 0.90). Nevertheless, these values suggest that the model provides a reasonable representation of the observed relationships. Furthermore, CFI, IFI, and TLI exhibited fit values that suggest an acceptable to a good fit, reflecting the model's consistency with the theoretical structure. Therefore, these findings suggest that the TPACK scale demonstrates a reasonable fit with the collected data, supporting the scale's structural validity.

Convergent validity

The convergent validity of the scale was evaluated to ascertain whether different items theorized to measure the same construct relate to each other (Byrne, 2016). This was achieved by examining the factor loadings, AVE, and CR for each construct within the scale (see **Table 4**). In assessing convergent validity for the TPACK scale, the constructs exhibited strong internal consistencies and adequate representation (see **Figure 2**). CK demonstrated robust measurement, with factor loadings up to 0.83, an AVE of 0.549, and a CR of 0.828. Similarly, PK and TK exhibited substantial factor loadings, with PK peaking at 0.77 and TK at 0.81. Both constructs surpassed the convergent validity threshold, with AVEs of 0.505 for PK and 0.506 for TK and CRs of 0.753 and 0.752, respectively. XK showed impressive convergent validity, with factor loadings up to 0.88, an AVE of 0.559, and a CR of 0.829.

Table 4. Convergent validity

Construct	CR	AVE
CK	0.828	0.549
PK	0.753	0.505
TK	0.752	0.506
XK	0.829	0.559
PCK	0.766	0.525
TCK	0.828	0.547
TPK	0.757	0.510
TPACK	0.757	0.510

Additionally, the PCK and TCK constructs were confirmed as well-measured, evidenced by their AVE values of 0.525 and 0.547 and CRs of 0.766 and 0.828, respectively, indicating that these constructs are reliably captured by the scale. While TPK and TPACK had slightly lower factor loadings, they still satisfied the criteria for convergent validity, with AVEs of 0.51 and CRs of 0.757. These collective findings support the TPACK scale's efficacy in capturing the interconnected dimensions of educators' knowledge and skills in integrating technology within teaching practices.

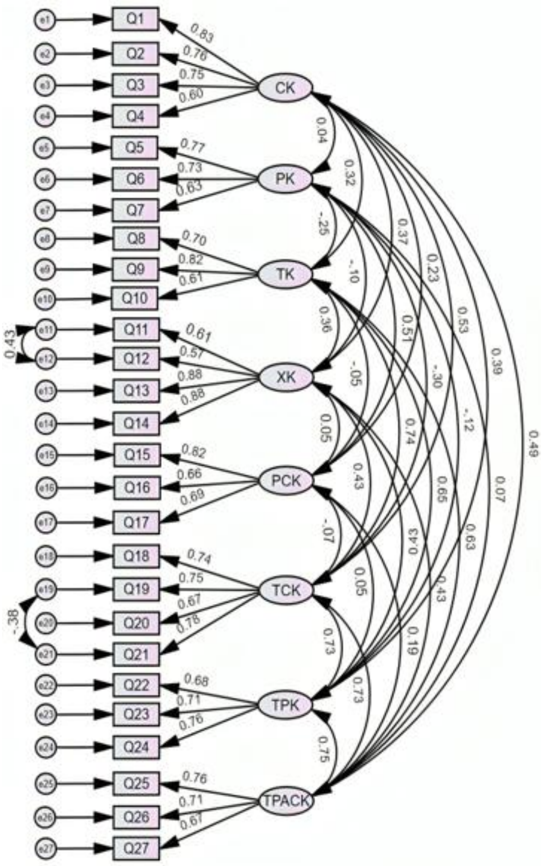

Figure 2. The CFA model developed in this study (Source: Authors' own elaboration)

Discriminant validity

The discriminant validity of the scale was assessed to ensure that each construct is distinct and not merely a reflection of another construct within the framework. This assessment is crucial for confirming that the scale measures multiple facets of the TPACK model without redundancy. According to Hair et al. (2018), for discriminant validity to be established, the square root of AVE for each construct should be greater than the correlations between that construct and any other construct in the model. Findings from **Table 5** illustrate that all constructs meet this criterion. For instance, CK, with a square root of AVE at 0.741, shows its highest correlation with another construct at 0.429 (with TCK), which is less than the square root of AVE value. Similar patterns are observed for PK, TK, XK, PCK, TCK, TPK, and TPACK, with each construct's square root of AVE exceeding any of its cross-construct correlations, thereby establishing strong discriminant validity. These results substantiate the scale's ability to distinctly measure each construct without substantial overlap, highlighting the scale's methodological rigor and its suitability for empirical research in educational technology. Such findings are essential for advancing the theoretical understanding of TPACK and contribute to the scale's credibility and utility in scholarly inquiry.

Table 5. Discriminant validity

Construct	$\sqrt{AVE}$	CK	PK	TK	XK	PCK	TCK	TPK	TPACK
CK	0.741	-							
PK	0.711	0.035	-						
TK	0.711	0.249	0.230	-					
XK	0.748	0.328	0.089	0.384	-				
PCK	0.725	0.197	0.402	0.014	0.044	-			
TCK	0.740	0.429	0.262	0.596	0.463	0.044	-		
TPK	0.714	0.316	0.110	0.497	0.428	0.055	0.596	-	
TPACK	0.714	0.391	0.022	0.489	0.427	0.160	0.595	0.577	-

The square root of AVE indicates the proportion of variance captured by the construct relative to the variance due to measurement error. Off-diagonal values represent the correlations between constructs. Discriminant validity is established when the square root of AVE for each construct is greater than its correlations with other constructs (Fornell & Larcker, 1981)

DISCUSSION

This study aimed to address a specific need in the field of educational technology by designing and validating a TPACK scale tailored for primary mathematics teachers in China. The findings indicate that this objective has been achieved, resulting in a contextually relevant tool that aligns with the unique aspects of Chinese primary education. While this represents a step forward in applying the TPACK framework in a specific educational context, it also acknowledges the broader ongoing efforts to integrate theoretical frameworks into diverse educational settings. The scale designed and validated through this research offers insights into the practical application of TPACK, contributing to a nuanced understanding of its role in primary mathematics education.

Developing a TPACK scale for primary mathematics education in China contributes to the field by addressing the gap in the literature concerning the need for context-specific TPACK assessment tools (Li et al., 2023; Scott, 2021). Unlike previous TPACK scales, which often adopted a more generalized approach to assessing technology integration across various subjects and educational contexts, this scale is meticulously designed to align with the specificities of primary mathematics education in the Chinese setting. In doing so, it extends the applicability of the TPACK framework, as originally conceptualized by scholars like Schmidt et al. (2009) and Chai et al. (2019), into a new cultural and educational context. This scale stands out by incorporating unique elements of the Chinese educational system and the specific challenges and opportunities that Chinese primary mathematics teachers face. Previous scales, such as those developed by Giannakos et al. (2014) and Kabakci Yurdakul et al. (2012), may not have fully captured these nuances, as they were often developed in and for different cultural and educational settings, primarily in Western contexts (Scott, 2021). The new scale, therefore, offers a more accurate and relevant tool for assessing the integration of technology in teaching by Chinese primary mathematics teachers.

Additionally, the significance of developing this scale lies in its potential to provide deeper insights into how primary mathematics teachers in China understand and apply the TPACK framework. It allows for a more precise evaluation of teachers' abilities to integrate technology effectively into their mathematics teaching, considering the cultural and educational particularities of the Chinese educational context. This is vital for informing teacher training programs, curriculum development, and educational policy decisions, ensuring they are tailored to the unique needs of the Chinese educational landscape. Moreover, the scale's development and validation contribute to the global discourse on TPACK by demonstrating the framework's flexibility and adaptability to different educational and cultural environments. It underscores the importance of contextual sensitivity in educational research and assessment tool design, potentially guiding future efforts to develop similar context-specific TPACK scales in other regions and subjects.

The inclusion and validation of the XK component in the TPACK scale marks a significant advancement in technology integration research, particularly within primary mathematics education. This enhancement of the TPACK framework addresses previously overlooked environmental factors, aligning with recent educational trends emphasizing the critical role of context in technology adoption (Li et al., 2023; Niess et al., 2014). By integrating XK, the scale provides a nuanced understanding of how primary mathematics teachers in China blend technology with pedagogy and CK. This is particularly relevant in modern educational settings, where traditional teaching methods are evolving rapidly due to the influence of digital technology (Blannin, 2022). By integrating XK, the scale's ability to capture the complex interplay between technology, pedagogy, content, and context offers educators a comprehensive tool for assessing and enhancing TPACK competencies.

Implication

The validation of the TPACK scale, tailored specifically to primary mathematics education in China, carries profound implications for various aspects of educational practice and policy. This alignment is consistent with the broader objectives of integrating technology into educational settings worldwide (Selwyn, 2021). In teacher education and professional development, this scale emerges as an invaluable tool for precisely evaluating and enhancing primary mathematics teachers' proficiency in technology integration. By identifying specific areas that require improvement, it paves the way for the creation of more focused and impactful professional development programs. These programs are crucial for equipping mathematics teachers with the necessary skills to navigate the increasingly digitized landscape of contemporary education. Moreover, this study's insight can potentially inform and guide curriculum designers and educational policymakers in the domain of curriculum design and pedagogical strategy. Through a comprehensive understanding of the multifaceted nature of TPACK, educators can devise innovative teaching strategies that effectively integrate technology, pedagogy, and CK. Such strategies are pivotal in enriching students' learning experiences and making mathematics education more interactive and engaging with modern technological advancements.

From a policy perspective, this study offers significant implications by providing a data-driven foundation for policymakers to formulate well-informed decisions on investments in educational technology and teacher training initiatives. Acknowledging the vital role of TPACK in enhancing the quality of primary mathematics education can lead to the formulation of policies that champion a more comprehensive and integrated approach to technology utilization in classrooms. Importantly, this research makes a notable contribution to the academic discourse within the field of educational technology. Introducing a validated TPACK scale specifically designed for primary mathematics education in China opens opportunities for further exploration into how diverse cultural and educational settings influence technology integration. This line of research is essential for fostering a more nuanced understanding of the global landscape of educational technology.

Limitations and Future Studies

While insightful, this study on TPACK in primary mathematics education within the Chinese context faces limitations that must be acknowledged. The specific sample size and the concentrated cultural and educational focus may impinge upon the broader applicability and generalizability of the findings. Moreover, the dependence on self-reported survey data could potentially introduce subjective biases, which must be carefully considered when interpreting the results and understanding their broader relevance (Creswell & Clark, 2018).

Several avenues for future exploration are recommended to extend the scope of this research and further enrich the comprehension of TPACK in diverse educational contexts. Expanding the study to incorporate a broader and more diverse sample, potentially including teachers from various regions within China or international contexts, would contribute significantly to the generalizability and comprehensiveness of the findings. Longitudinal studies could shed light on the evolution and development of TPACK competencies over time among primary mathematics teachers, offering more profound insights into the dynamics of TPACK proficiency throughout a teacher's career. Comparative studies that analyze TPACK competencies across different educational systems or cultures could yield valuable cross-cultural perspectives, enriching the understanding of how technological integration in teaching varies across diverse settings. Lastly, integrating qualitative research methods, such as interviews and classroom observations, could provide a more intricate and detailed portrayal of how TPACK is actualized in teaching practices. This multifaceted approach, blending quantitative and qualitative data, would allow for a more nuanced and thorough exploration of the complexities of implementing TPACK, informing future professional development initiatives and educational policies (Irwanto, 2021).

CONCLUSION

This study represents a meaningful step forward in educational technology research, particularly in creating and validating a TPACK scale tailored for primary mathematics education in China. By addressing a notable need identified in prior research, this study introduces a context-specific assessment tool that enhances the understanding of technology integration within primary mathematics education. The insight gained from this assessment scale could contribute thoughtfully to the existing body of knowledge regarding the TPACK framework, offering perspectives relevant to primary mathematics teacher education and policy considerations in educational technology. The study's introduction of the XK component within the TPACK scale marks a considerate advancement. It broadens the previous scales (Chai et al., 2013; Li et al., 2023) by integrating environmental factors that affect technology use in education, reflecting a response to digital technologies' dynamic and evolving nature in the educational sphere, especially in primary mathematics. The validation of this scale underscores its value as an instrument for assessing the complex competencies required by primary mathematics teachers in integrating technology, pedagogy, and CK. This development aligns well with the ongoing efforts to enhance educational practices and learning outcomes in primary mathematics settings (Hansen et al., 2016; Marban & Sintema, 2021).

Additionally, this research enriches the global conversation around TPACK, showcasing the adaptability of the framework in Chinese primary mathematics education. It underscores the importance of contextual sensitivity in educational research, highlighting the potential for future studies to develop TPACK scales that are attuned to the specific needs and characteristics of various regions and subjects. In summary, this research highlights the pivotal role of the TPACK framework in advancing the quality of primary mathematics education amidst the integration of digital technologies. The development of this tailored scale reflects a careful and thorough approach to examining the intricate relationship between technology, pedagogy, and content in education, setting a pathway for future explorations and advancements in the field of educational technology.

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Ethical statement: The authors stated that the study was approved by the Monash University Human Research Ethics Committee on 9 October 2020 with approval code 26687. Written informed consents were obtained from the participants.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: PRIMARY MATHEMATICS TEACHERS' TPACK SCALE

CK

1. I have sufficient understanding of mathematics (e.g., mathematical concepts, curriculum, methods, principles, knowledge of mathematical history, etc.).
2. I can use a mathematical way of thinking, to consider problems.
3. I have various ways to improve my mathematical literacy.
4. I am confident in my understanding of mathematics content, including number and algebra, figure and geometry, probability and statistics, as well as comprehensive practice.

PK

1. I can tailor my teaching methods to meet the needs of different students.
2. I can enhance students' mathematical thinking by creating challenging tasks for them.
3. I can use a wide range of teaching methods in a classroom setting (e.g., group cooperation, inquiry-based learning, project-based learning, flipped classroom, and lecture methods).

TK

1. I can easily learn digital technologies.
2. I frequently explore how to effectively use digital technologies (e.g., Interactive Whiteboard, AI tools, and mathematics software).
3. I have the technical skills I need to use digital technologies.

XK

1. I know digital technologies available in my school that can be utilized for teaching mathematics.
2. I understand students' ICT capability in my classroom.
3. I am familiar with educational policies aimed at improving the ICT capability of mathematics teachers.
4. I am familiar with the educational resources available for mathematics teaching and learning.

PCK

1. I can assist my students in learning mathematical concepts through various teaching methods without using digital technologies.
2. I can assist students in resolving challenges faced in learning mathematics without using digital technologies.
3. I can effectively facilitate student discussions on mathematical problems without using digital technologies.

TCK

1. I am familiar with digital technologies that can be applied in mathematics education (e.g., geometry software, Excel, and online mathematics resources).
2. I can use digital technologies to visualize mathematical concepts.
3. I can explore knowledge related to mathematics education by using educational resources.
4. I can use AI tools to explore mathematics knowledge.

TPK

1. I can use digital technologies to optimize my teaching methods for mathematics lessons.
2. I can use AI tools (e.g., Ernie Bot and ChatGPT) in mathematics classes to improve student motivation.
3. I can apply digital technologies to various mathematics teaching activities.

TPACK

1. I can teach lessons that appropriately combine mathematics content, digital technologies, and teaching approaches.
2. I can design self-directed learning activities with educational resources (e.g., I can record online video courses and design mathematics assignments for students' self-learning at home).
3. I can design a student-centered lesson that integrates mathematics content and technologies.