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Exploring Technological Pedagogical Readiness (TPR) in China's primary mathematics teachers: TPR scale validation

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Abstract
This study presents the Technological Pedagogical Readiness (TPR) scale, which aims to assess Chinese primary mathematics teachers' readiness to integrate technology in primary mathematics education in China. Based on the Technological Pedagogical Content Knowledge (TPACK) and the Technology Acceptance Model (TAM) frameworks, TPR scale incorporates factors such as contextual influences, professional development, and community involvement. Through an online survey involving 554 primary mathematics teachers, the study utilizes exploratory and confirmatory factor analyses to create TPR scale and establish the scale's validity and reliability, revealing strong factor loadings across its constructs. This analysis emphasizes the scale's effectiveness in capturing the complexities of technology integration in educational settings. The research underscores the importance of considering internal teacher factors like TPACK and external contextual factors like institutional support to achieve successful technology integration. Although the focus of the study is on scale development and validation, its application provides valuable insights for developing comprehensive strategies that address individual and broader educational system competencies. The study's findings suggest that TPR scale has wide-ranging applicability, making significant contributions to the global discourse on educational technology and serving as a valuable resource for future research, policy-making, and practice in enhancing technology integration across diverse educational contexts.

Keywords: technology integration, technological pedagogical readiness, TPACK, attitude, contextual factors, primary mathematics education

INTRODUCTION

In the wake of educational transformation characterized by digital innovation, technology integration in teaching and learning practices has emerged as a cornerstone for modern education (Blannin, 2022). This is particularly salient in mathematics education, where digital tools and platforms offer substantial opportunities to bolster conceptual understanding, enhance problem-solving skills, and increase student engagement (Drijvers et al., 2018). The ability and readiness of educators to integrate digital technology into their pedagogy are pivotal to harnessing these opportunities. Consequently, there is an exigent call for developing an assessment mechanism that captures the multifaceted aspects of teachers' attitudes and competencies regarding technology integration in their instructional practice.

Background

The COVID-19 pandemic has catalyzed an unprecedented digital shift in educational methods; the abrupt transition to remote and hybrid teaching models compelled educators to engage with digital platforms and tools in ways they had not anticipated (Johns & Mills, 2021). This digital pedagogical landscape unfolded unevenly across various educational contexts, revealing potential differences in teachers' capabilities to incorporate digital technology effectively. For example, DeCoito and Estaiteyeh (2022) mentioned that some educators seamlessly adapted to online teaching, integrating advanced digital tools to facilitate interactive

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Contribution to the literature

- This article introduces the Technological Pedagogical Readiness (TPR) scale, a novel instrument specifically designed to assess technology integration in primary mathematics education in China.
- By incorporating contextual factors, professional development, educational challenges, students technology literacy, and parental and community involvement, TPR scale extends beyond traditional frameworks like Technological Pedagogical Content Knowledge (TPACK) and Technology Acceptance Model (TAM). The comprehensive methodology, including rigorous exploratory and confirmatory factor analyses, ensures the scale's validity and reliability.
- This work not only fills a gap in the current literature by providing a tool tailored for primary mathematics teachers but also offers practical insights for enhancing educational strategies and policymaking in technology integration.

learning experiences, while others faced challenges in navigating beyond the basic use of digital platforms for direct instruction. This variation underscores teachers' diverse readiness and adaptability in embracing digital technologies to enhance educational delivery during the pandemic (DeCoito & Estaiteyeh, 2022). The disparate levels of technological fluency among educators highlighted a clear divide: educators who were previously inclined towards using technology in their teaching practices adapted more seamlessly than their less technologically inclined counterparts (Alabdulaziz, 2021). It can be said that this divide affected the continuity of instruction and the quality of student engagement and learning, particularly in subjects that require dynamic interaction, such as mathematics (Alabdulaziz, 2021).

The need for robust digital pedagogical competencies is particularly acute in primary mathematics education, where the pandemic has disrupted the traditional pathways of conceptual understanding and skill acquisition (Yao & Zhao, 2022). Foundational mathematical skills are crucial building blocks for future learning; hence, the transition to digital platforms could not simply be about transferring existing pedagogies online. It necessitated an innovative approach to teaching that leverages the interactive and collaborative features of digital tools to facilitate deeper understanding (Drijvers, 2015). The post-pandemic era ushers in a renewed vision for educational technology, where teachers' professional development must prioritize equipping educators with the technical skills to navigate digital tools and the pedagogical skills to transform their teaching practices (Li, 2023). Continuous professional development programs are now essential in addressing these gaps (Haleem et al., 2022). These programs should be tailored to advance technical skills and foster pedagogical innovation, ensuring that technology becomes an integral part of teaching and learning processes rather than a mere substitute for traditional methods (Cao et al., 2021). The journey towards digital proficiency in education is ongoing. The rapid adoption of technology underscored by the pandemic is not a transient phase but a transformative leap into a new educational paradigm that requires sustained support and development for teachers, particularly in primary mathematics education.

Problem Statement

This requirement fosters an urgent need to develop an effective instrument to measure multifaceted aspects of mathematics teachers' attitudes, competencies, and practices regarding technology integration in their instructional practice. This research is poised to fill the void above by proposing and substantiating a TPR scale tailored for primary mathematics teachers in Chongqing, China. The scale has been developed to encompass a comprehensive understanding of the knowledge, attitudes, perceptions, and contextual factors that profoundly impact teachers' readiness to incorporate digital technology into their mathematics instruction. By examining the reliability and validity of this scale, the research findings offer an indispensable instrument that promises to guide educational policy and enhance pedagogical methods within Chongqing, China, where study was conducted and potentially beyond the Chinese educational context. The validation of this scale will empower educational stakeholders to ascertain and enhance the readiness of mathematics teachers for such technological adoptions. In addition, the significance of this study is manifold. Primarily, it serves to refine the collective understanding of primary mathematics teachers' dispositions towards digital technology use, thereby enabling the design of professional development initiatives. Such programs are critical for empowering teachers to navigate and exploit the landscape of digital resources effectively, which can elevate teaching quality, augment student learning experiences, and democratize access to educational technologies.

Guided by the objective of fostering a comprehensive understanding of the multifaceted aspects of technology integration in mathematics education, the study is structured around two pivotal research questions:

1. What are the underlying dimensions of TPR scale as indicated by exploratory factor analysis?

2. How does confirmatory factor analysis reinforce structural integrity and reliability of TPR scale?

LITERATURE REVIEW

Enhancing Mathematical Understanding Through Digital Integration

Technology integration within mathematics education is a burgeoning field of study, delineating a shift from traditional pedagogies to innovative, digitally enriched learning environments. In primary mathematics education, the application of digital technology aims to augment the teaching experience and students' learning trajectories (Muir et al., 2016). Technology integration in mathematics education encompasses various tools and approaches, from simple calculators to sophisticated online learning environments and interactive software. The literature suggests that technology can provide dynamic representations of mathematical concepts and offer interactive experiences that are impossible with traditional chalk-and-talk methods (Doorman et al., 2012). For instance, Shi et al. (2021) advocate using educational software that provides visual and interactive representations of mathematical ideas, facilitating deeper conceptual understanding among students. Additionally, research has shown that digital technology can support differentiated instruction, allowing teachers to cater to various learning styles and abilities within the classroom (Ertmer & Ottenbreit-Leftwich, 2010). Sperling et al. (2022) highlight the versatility of digital technologies in providing differentiated learning pathways, adaptive learning systems, and real-time feedback, which are particularly beneficial in diverse classroom settings. Moreover, technology integration, such as artificial intelligence (AI), can enhance interactive learning through conversational agents or educational chatbots (Wardat et al., 2023). These AI-driven tools can provide immediate feedback and personalized learning experiences, which could be considered a formative assessment (Mishra et al., 2023). For example, a chatbot integrated into a mathematics education platform could analyze student responses to problems in real time, offering personalized tips and additional challenges based on the student's performance (Kuhail et al., 2022). This would enable teachers to monitor progress and adapt instruction to meet individual learning needs dynamically. This integration of AI and digital technologies signifies a pivotal evolution in educational practice, where the traditional role of the teacher expands to that of a facilitator who orchestrates a technology-rich learning environment, adeptly guiding students through a more personalized and responsive mathematics educational journey. However, the effective integration of technology in mathematics instruction is contingent upon multi-dimensional factors.

Facilitating Technology Adoption in Mathematics Education: Role of Teacher Attitudes & Technology Acceptance Model

Integrating digital technologies into education represents a complex endeavor shaped by many factors, including individual teacher characteristics and broader institutional contexts. Ertmer et al. (2012) highlight the critical role of teacher knowledge, beliefs, and attitudes toward technology in effectively implementing digital tools within the classroom. As Higgins et al. (2007) have demonstrated, teachers who are convinced of the transformative potential of technology are more inclined to integrate interactive whiteboards and online resources into their mathematics lessons, leading to enhanced student engagement and a more profound grasp of intricate concepts. This effect illustrates the potential for a teacher's optimistic perspective on technology to manifest in impactful educational practices. In addition to these personal attributes, aligning technological tools with curricular goals is essential, ensuring that digital enhancements, such as virtual reality simulations in mathematics classes, contribute substantively to learning rather than merely serving as novel distractions (Loong & Herbert, 2018). Within primary mathematics education, digital resources like virtual manipulatives (Jang & Tsai, 2012), problem-solving games (Polly, 2014), and AI-driven tools (Wardat et al., 2023) have been acknowledged as effective in increasing student engagement and deepening mathematical understanding. Teachers' beliefs and attitudes toward integrating technology predict their intentions to use digital technologies and online resources.

To further understand these attitudes and beliefs, TAM offers a theoretical lens through which researchers can examine the likelihood of technology integration by researchers (Eickelmann & Vennemann, 2017; Li, 2022; Teo et al., 2008). According to TAM (see **Figure 1**), an individual's intention to use technology is primarily determined by perceived usefulness and perceived ease of use (Davis, 1989). These factors are shaped by the individual's attitudes towards the technology (Teo et al., 2008). In mathematics education, if teachers perceive digital tools as beneficial to their teaching (e.g., enhancing student engagement, improving learning outcomes, or facilitating more efficient instruction), they are more likely to view them as useful (Teo et al., 2017). Similarly, if teachers find digital tools intuitive and easy to incorporate into their teaching practices, they are more likely to perceive them as easy to use (Eickelmann & Vennemann, 2017). Both of these positive perceptions can lead to increased adoption of digital tools in mathematics instruction, as highlighted by (Teo et al., 2008). Therefore, fostering positive attitudes and beliefs among teachers toward digital tools is crucial for successfully integrating technology into mathematics education (Eickelmann & Vennemann, 2017; Gurer,

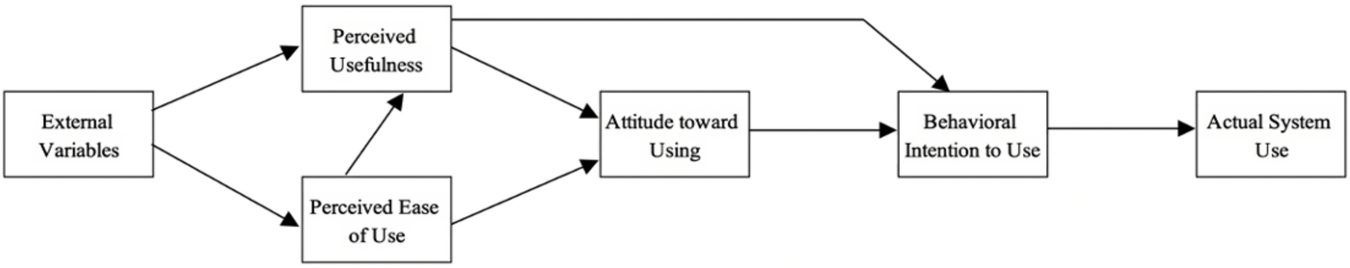

Figure 1. Self-created diagram based on TAM (Source: Authors' own elaboration)

2021). TAM emphasizes that these attitudes and beliefs are critical precursors to accepting and using technology in educational settings, making them essential considerations for educators and policymakers.

Role of TPACK in Technology Integration & Contextual Factors Affecting Technology Adaptation

TPACK framework is fundamental to understanding teacher preparedness for technology integration. Developed by Mishra and Koehler (2006), TPACK emphasizes the interconnectedness of technology, pedagogy, and content knowledge. Effective mathematics teachers can synthesize these domains to create engaging, pedagogically sound learning experiences that leverage the benefits of digital technology (Kartal & Cinar, 2022; Niess, 2016). For example, a mathematics teacher with strong TPACK skills might utilize interactive graphing tools like Desmos or GeoGebra to dynamically demonstrate the concept of slope, enriching students' understanding beyond static textbook representations (Rueda & Adán, 2019). However, the adoption of teacher technology is not solely determined by individual knowledge and skills. Contextual factors are crucial, including institutional support, access to resources, professional development opportunities, and the school's technological culture (Ertmer et al., 2012). Furthermore, external pressures such as educational policies mandating specific technologies or curricular standards requiring particular competencies also shape teachers' technology use (Porras-Hernández & Salinas-Amescua, 2013). These factors interact within the broader educational ecosystem, influencing teachers' decisions and practices regarding technology integration. Thus, a comprehensive understanding of teacher preparedness for technology integration must consider individual TPACK frameworks and the contextual factors that facilitate or hinder technology adoption (see **Figure 2**).

Teachers' attitudes towards technology, shaped by their TPACK and various contextual factors, profoundly impact the extent and manner of technology integration in classrooms. Research by Voogt et al. (2013) underscores that teachers are more likely to incorporate technology in their teaching when they perceive it as enhancing their ability to achieve curricular objectives. Indeed, this is particularly evident in primary

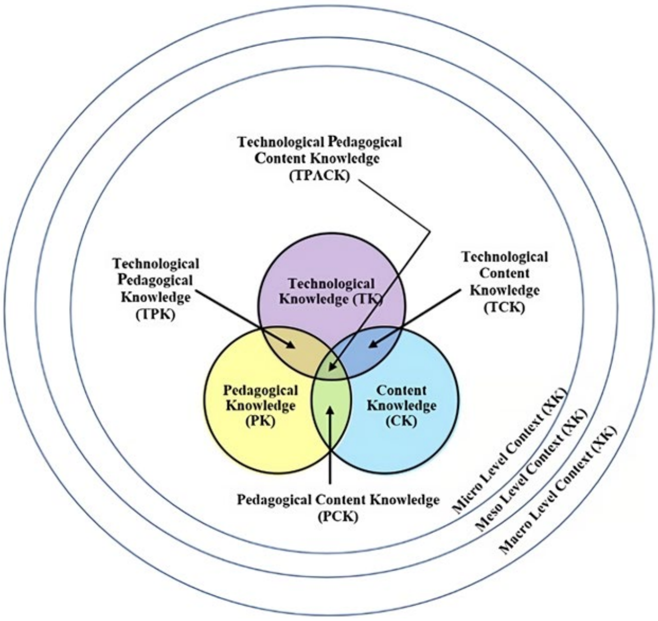

Figure 2. Self-created diagram based on TPACK framework (Adapted from Li et al., 2024)

mathematics education, where virtual manipulatives align with curricular goals related to number sense and arithmetic and constructivist pedagogical approaches that foster active learning. Furthermore, studies such as Chai et al. (2011) emphasize the role of teachers' self-efficacy in technology use, which is an integral component of TPACK, in promoting technology adoption. This highlights that beyond the mere availability of digital tools and institutional support, teachers' confidence in their ability to effectively utilize these tools is crucial (Chai et al., 2011). Ongoing professional development opportunities that address both the pedagogical and technical aspects of technology integration have been shown to facilitate sustained incorporation into teaching practices, especially in mathematics, where specific content demands may necessitate the use of specialized technological tools (Tondeur et al., 2017). Therefore, while individual teacher factors like TPACK are critical, the broader educational context, encompassing institutional policies, cultural norms, and resource availability, is pivotal in determining technology adoption in mathematics education. A comprehensive understanding of these interconnected factors is essential for effective technology integration in the classroom.

Contextual Factors: A Multilevel Perspective on Technology Integration

Building upon the foundational TPACK framework, the inclusion of contextual factors as conceptualized by Porras-Hernández and Salinas-Amescua (2013) and later integrated by Mishra (2019) provides a comprehensive lens through which to examine the multifaceted influences on technology integration within educational settings. This expanded model delineates three distinct levels of contextual factors (micro, meso, and macro) each playing a critical role in shaping the effectiveness and extent of technology use in education (see **Figure 2**).

At the micro level, contextual factors are intimately tied to the immediate environment of classroom teaching and learning (Porras-Hernández & Salinas-Amescua, 2013). This level encompasses the practicalities and nuances of daily educational interactions, such as the availability and accessibility of digital devices, software applications, and the internet. It also includes teachers' understanding and navigation of classroom norms, student dynamics, and individual learning needs. These micro-level factors directly influence how technology is integrated into specific lessons and activities, affecting the immediacy and quality of teaching and learning experiences. The meso level extends to encompass the broader school and community context (Porras-Hernández & Salinas-Amescua, 2013). This includes the culture and systems within a school, leadership support, educational infrastructure, and the involvement of local communities. At this level, the focus is on how institutional policies, resources, and collective attitudes towards technology adoption create an enabling or restrictive environment for integration efforts. School-wide initiatives, professional development opportunities, and the presence of a supportive educational community are pivotal in fostering or impeding technology integration. Finally, the macro level considers the wider socio-political and economic landscape that envelops the educational system (Porras-Hernández & Salinas-Amescua, 2013). This encompasses national and international policies, cultural norms, economic conditions, and the overarching educational framework within which schools operate. Macro-level factors include national curriculum standards, education policies, funding allocations for technology in education, and broader societal attitudes towards technology and learning. These elements shape the strategic direction and priorities for technology integration at a systemic level, influencing the resources available to schools and the expectations placed on educators and learners.

By integrating these three levels of contextual factors into TPACK framework, as advocated by Mishra (2019), educators and researchers can gain a deeper, more nuanced understanding of the influences on technology integration. This holistic perspective is crucial for developing targeted strategies that address the specific challenges and opportunities at each contextual level, ensuring that technology integration efforts are not only pedagogically sound but also aligned with the broader educational ecosystem (Li & Li, 2024). Such an approach underscores the complexity of integrating technology into teaching and learning, highlighting the need for coordinated efforts that span from the individual classroom to the global education community.

Review of Technology Integration Scales in Education

In the scholarly pursuit to gauge teachers' readiness and attitudes toward technology integration in education, numerous scales have been developed. These scales often encapsulate various dimensions, such as attitudes, TPACK, TAM, and contextual factors influencing technology adoption. This section critically examines previous studies on developing and validating these scales, compares them, and discusses their advantages and disadvantages.

TPACK framework has become a cornerstone in understanding how teachers use technology in educational settings (Mishra et al., 2023; Niess, 2016). Various instruments have been developed to operationalize TPACK framework into quantifiable scales to measure teachers' capabilities in integrating technology within their pedagogical practice (Li et al., 2024). TPACK survey by Schmidt et al. (2009) is one of the more prominent instruments to assess this complex interplay of knowledge domains (Scott, 2021). It offers a comprehensive view of mathematics, social studies, science, and literacy teachers' readiness to employ technology in the classroom. The survey encompasses various indicators, from teachers' self-assessment of their technological knowledge to their ability to incorporate digital tools pedagogically soundly that enhance content delivery. Subsequently, based on Schmidt et al. (2009), an increasing number of TPACK scales were developed to measure teachers' knowledge to integrate digital technology in classroom teaching, such as Chai et al. (2013), Sahin (2011), and Li (2023). While valuable, TPACK survey's thoroughness presents challenges due to its expansive scope. For example, the scale developed by Li (2023), which comprises 52 items, lacks items on contextual factors, limiting its comprehensiveness in addressing the broader influences on technology integration. This complexity underscores the need to balance the depth of insight such surveys provide and the pragmatic realities of educators' availability for professional development activities.

Moreover, while the surveys capture a snapshot of teachers' TPACK self-perceptions, they may not fully capture the dynamic, situational factors that influence the day-to-day integration of technology. These factors include classroom management, student responsiveness to technology, the logistical aspects of incorporating digital tools into lesson plans (Graham, 2011), leadership support, national curriculum and policy, and parental and community involvement (Porras-Hernández & Salinas-Amescua, 2013). Furthermore, while TPACK framework provides a theoretical underpinning for technology integration, its operationalization through surveys and other instruments may not adequately account for the rapidly evolving nature of technology or the contextual adaptations required for different subject areas. Realizing these deficiencies, researchers combined TPACK with other theories to gauge teachers' knowledge of integrating digital technology more comprehensively in teaching and learning. For instance, based on TPACK and TAM, the attitudes toward technology scale designed by Teo et al. (2019) is instrumental in evaluating educators' sentiments towards technology. It effectively captures key TAM constructs like perceived ease of use and perceived usefulness. However, it stops short of delving into the rich interplay of TPACK components–technology, pedagogy, and content knowledge–crucial for comprehensive technology integration, especially in disciplines like mathematics education. Here, the use of technology is not only about utility and ease but also about the nuanced application of digital tools to convey complex mathematical concepts effectively (Teo et al., 2019).

These assessment scales of attitudes and TPACK provides a foundational understanding of educators' technology acceptance and knowledge of technology integration, yet they may not fully encapsulate the depth of knowledge and contextual savvy required to integrate technology into mathematics instruction. While these assessment scales of attitudes and TPACK provide a foundational understanding of educators' technology acceptance and knowledge of technology integration, they do not fully encapsulate the depth of knowledge and contextual awareness required to effectively integrate technology into mathematics instruction. Indeed, to truly understand and support technology integration in mathematics education, it is paramount that scales account for both the individual competencies reflected in frameworks like TPACK and the broader contextual factors at the micro, meso, and macro levels (Porras-Hernández & Salinas-Amescua, 2013). Bridging this gap requires a dual approach: enhancing teacher training to build robust TPACK skills while sustaining and enhancing the three levels of support structures (micro, meso, and macro) to foster a conducive environment for technology adoption.

The critical examination of existing scales and frameworks for evaluating technology integration in education underscores the need for the current study. While prior instruments have laid the groundwork for understanding the multifaceted nature of technology integration, they often do not account for the specific challenges and opportunities in primary mathematics education, particularly in the post-pandemic era, where digital tools have become essential. For example, primary mathematics teachers face the challenge of effectively engaging young learners in a virtual environment while ensuring that foundational mathematical concepts are understood. Digital tools offer opportunities to create interactive and visually appealing content that can make learning more engaging and accessible for young students, but they also require primary mathematics teachers to develop new pedagogical strategies and technical skills. To address these challenges, the current study seeks to fill this gap by developing a scale that not only measures educators' general attitudes and TPACK competencies but also intricately maps these competencies onto the specific content requirements of mathematics education and the unique contextual factors at play within the educational ecosystem, in this case, Chongqing, China. The scale developed during the current study is designed to be comprehensive and practical, aiming to avoid the pitfalls of lengthiness and impracticality observed in other measures. Providing a more streamlined and focused assessment will better align with the time constraints and specific needs of educators in the field. Moreover, integrating constructs from both TPACK and TAM, alongside a keen understanding of micro, meso, and macro contextual influences, equips this scale with the potential to offer deeper insights into the actualization of technology in mathematics instruction. This approach acknowledges the rapidly evolving technological landscape and the necessity for teachers to adapt to these changes within their instructional practices.

Therefore, the significance of this study lies in its potential to offer a nuanced tool that can effectively guide professional development and policymaking in technology integration. It impacts not just the educators in Chongqing but also the broader educational community by providing a model for developing scales sensitive to the complexities of subject-specific technology integration within varied educational contexts.

METHOD

Research Design

This study is part of a mixed-methods exploratory study (Creswell & Clark, 2018) for doctoral research, and the quantitative phase was conducted utilizing a structured survey methodology. This approach enabled the collection of objective and systematic data, informed, and enriched by insights gained from the analysis of interviews conducted during the qualitative phase of the research (authors, submitted). TPR scale was developed based on a deductive analysis grounded in TPACK and TAM frameworks, combined with inductive insights from interviews to identify additional relevant variables. This comprehensive approach ensures that the scale accurately reflects the multifaceted aspects of technological readiness, incorporating primary mathematics teachers' attitudes, TPACK, and contextual factors. TPR scale measures these dimensions to evaluate teachers' propensity to integrate digital technology into their mathematics teaching practices, thereby providing a robust tool for assessing TPR.

The focus on these specific constructs is informed by interviews and prior studies, such as Schmidt et al. (2009), Chai et al. (2013), and Li et al. (2023), which utilized factor analysis for validation.

The quantitative strategy is particularly apt for this study as it allows for statistical analyses to explore and confirm the reliability and validity of TPR scale. This methodological choice aligns with scholars like Heitink et al. (2016), who highlight the utility of quantitative approaches in unveiling the factors that impact technology use in educational settings. Through these analyses, the study aims to yield findings that are statistically significant and generalizable to the broader population of primary mathematics teachers in mathematics education. This approach will enable the research to contribute empirical evidence to the existing body of knowledge, following the precedent set by studies such as Tondeur et al. (2017), which investigate the role of teacher beliefs and contextual variables in technology integration.

By employing exploratory and confirmatory statistical techniques, such as those detailed by Brown (2015), the study seeks to validate the structure of TPR scale and assess its internal consistency and construct validity. These steps are crucial to ensuring that the scale reliably measures the constructs it purports to measure and can accurately capture the dynamics of technology integration among educators, as discussed by Field (2013). Therefore, the methodological framework of this study is rigorously designed to align with established quantitative research practices in educational technology, paving the way for insights that could inform policy, practice, and future research within the domain of mathematics education and beyond.

Participants

The composition of the study's participants was carefully curated to encompass a diverse spectrum of primary mathematics teachers from various educational settings in Chongqing, China (**Table 1**). Chongqing, a tier 1 city, boasts significant educational achievements and a robust educational system. The city's focus on educational excellence is evident in its substantial investment in education and its high regard for teacher quality. In China, unlike in many other educational systems, there are specialized mathematics teachers even at the primary level, underscoring the country's emphasis on mathematics education from early schooling (Zhao et al., 2017). This specialization allows for a more focused and in-depth approach to teaching the subject, reflected in the composition of our study's participants, providing valuable insights into technology integration within this specific teaching cohort. The unique educational context of Chongqing highlights the advanced practices and high standards that can inform broader educational strategies across different regions.

Table 1. Demographic information

Variable		Frequency	Percentage
Gender	Female	406	73.3
	Male	148	26.7
	Total	554	100
Teaching grade	1	90	16.2
	2	102	18.4
	3	93	16.8
	4	94	17.0
	5	82	14.8
	6	93	16.8
	Total	554	100
Teaching experience	0-5	89	16.1
	6-10	174	31.4
	11-15	107	19.3
	Above 15	184	33.2
	Total	554	100

A stratified random sampling strategy was adopted to capture a breadth of experiences, backgrounds, instructional environments. This approach facilitated the inclusion of teachers across various school types, thus ensuring a representative cross-section of the region's primary mathematics educators and allowing for a nuanced analysis of the contextual factors influencing the technology integration landscape. Demographic data pertaining to the study population is summarized in **Table 1**. Of the 554 participating primary mathematics teachers, a considerable majority, approximately 73.3%, were female (n=406), while the remaining 26.7% were male (n=148), reflecting the gender distribution within the primary mathematics teaching profession in the region (Yao & Zhao, 2022). The participants' grade-level teaching assignments were distributed, as follows: grade 1 (n=90, 16.2%), grade 2 (n=102, 18.4%), grade 3 (n=93, 16.8%), grade 4 (n=94, 17.0%), grade 5 (n=82, 14.8%), and grade 6 (n=93, 16.8%). This distribution ensured insights could be drawn from educators teaching across the entire span of primary grades. In terms of teaching experience, the sample was segmented into four groups to reflect varying levels of professional tenure: zero-five years (n=89, 16.1%), six-10 years (n=174, 31.4%), 11-15 years (n=107, 19.3%), and above 15 years (n=184, 33.2%). This stratification allowed for exploring potential correlations between technology integration and the length of service in the teaching field. This classification was based on existing literature on teacher professional development and technology integration, which categorizes teaching experience to examine how different stages of a teaching career influence the adoption and use of technology in educational settings (Li et al., 2023).

The demographic distribution of the participants ensures that this study's findings reflect the heterogeneity inherent within the educational context of Chongqing's primary mathematics teachers, providing a robust foundation for the assessment of the newly developed TPR scale.

Instrument Design

TPR scale was constructed following a rigorous process that included an extensive literature review (Chai et al., 2013; Li et al., 2023; Schmidt et al., 2009), and, interviews of primary mathematics teachers and school principals, consultations with domain experts, and a series of pilot tests. This multi-faceted approach ensured a thorough and robust development of the scale, drawing on diverse perspectives and evidence to capture the complexity of technology integration in education. Also, this multi-phase development ensured that each item on the scale was empirically grounded and contextually relevant to the domain of primary mathematics education in Chongqing. The scale is segmented into multiple components to capture a holistic view of the factors influencing technology integration. These components assess constructs derived from TPACK, TAM, and additional contextual factors pertinent to educational technology use.

The constructs and corresponding items of TPR scale are, as follows (see **Appendix A**): TPACK is evaluated through items eight to 11, which probe into the synthesis of technology, pedagogy, and content knowledge. technological pedagogical knowledge (TPK), reflecting the intersection of technology with pedagogical practices, is measured by items 12 to 14. Technological content knowledge (TCK), gauging the interaction between technological tools and subject matter, is assessed by items 15 to 17. The construct of perceived usefulness (PU), a core component of TAM relating to the perceived benefits of technology in teaching, is captured by items 18 to 22. Perceived ease of use (PEoU), another TAM construct that addresses the perceived effortlessness of technology use, comprises items 23 to 27. Technological knowledge (TK), evaluating teachers' familiarity with technology, is measured by items 28 to 32. Professional development (PD), which encompasses teacher training and learning opportunities, is assessed through items 33 to 36. Contextual factors (CF), which include the environmental and institutional conditions that affect technology integration, are evaluated by items 37 to 41. Educational challenges (EC), assessing obstacles faced in technology integration, are uniquely captured by item 42, a matrix-style question encompassing sub-items 42-1 to 42-5. The scale also investigates teachers' perceptions of students' technology literacy (STL) through items 45 to 49 and parental and community involvement (PCI) in technology-related educational processes through items 50 to 53. TPR scale's utilization is justified by its all-encompassing design, which facilitates a thorough evaluation of the multifaceted nature of technology integration within mathematics education. It is specially tailored to encapsulate the technological, pedagogical, and contextual dimensions that primary mathematics teachers in Chongqing navigate, thereby offering valuable insights for research and practice in the effective use of educational technology.

Data Collection

Data were collected via an online questionnaire administered to a stratified random sample of primary mathematics teachers across Chongqing, China. The questionnaire, formatted as a 5-point Likert scale (Boone & Boone, 2012), leveraging the ubiquity and convenience of WeChat, a widely used Chinese social media platform, incorporated TPR scale items and demographic queries to capture essential background information on the participants. The Chongqing Education Commission played an instrumental role in the recruitment process, extending its support to effectively disseminate the survey across the designated schools. Participation in the study was voluntary, with a comprehensive informed consent process ensuring that all respondents were fully aware of the study's nature and role (Cohen et al., 2018). To maximize the response rate, a thoughtfully designed social media post detailing the study's purpose and significance was employed, and the data collection period spanned two months, a timeframe chosen to provide participants with sufficient opportunity to engage with the survey. This extended window not only accommodated teachers' varying schedules but also mitigated the pressure of immediate response, which, in turn, could contribute to a higher quality of data (Fowler Jr, 2013).

Data Analysis

The data analysis incorporated both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to substantiate the validity of TPR scale. Initially, EFA was deployed to discern the latent factor structure inherent within the scale, facilitating categorizing items into discrete factors that epitomize distinct constructs (Byrne, 2016). The use of EFA was critical in this context as it allowed for an empirical exploration of the underlying dimensions of TPR scale without preconceived hypotheses about the structure. This step was essential in ensuring that the scale components genuinely represented the diverse factors influencing technology integration. By identifying and validating these latent constructs, EFA helped in refining the scale to capture a holistic view of the various elements that impact technology integration in primary mathematics education. Subsequently, CFA was employed to validate the factor structure identified by EFA, ascertain the scale's reliability, and appraise the congruence of the measurement model with the empirical data (Hair et al., 2018). Ancillary analyses, including reliability assessments like Cronbach's alpha for internal consistency (Cronbach, 1951) and inter-item correlation analysis, were executed to fortify the scale's robustness. The analyses were conducted utilizing the statistical package for the social sciences (SPSS) version 28 and the analysis of moment structures (AMOS) version 28 software, with inferential statistics adjudicated significant at $p<0.05$. This rigorous methodological stratagem was anticipated to engender substantive evidence regarding TPR scale's reliability and validity, thereby illuminating the determinants of technology integration among primary mathematics educators in Chongqing, and subsequently guiding prospective pedagogical interventions and policy formulation.

FINDINGS

Exploratory Factor Analysis

The prerequisites for conducting EFA were satisfied, as evidenced by Kaiser-Meyer-Olkin (KMO) measure of 0.935, exceeding the commonly accepted threshold of 0.6 (Kaiser, 1974), and the significant result of Bartlett's test of sphericity (approx. Chi-square=16,125.717, df=1081, $p<0.01$) (Roni, 2021). These findings confirm the adequacy of the dataset for factor analysis, justifying the subsequent steps in validating TPR scale.

An analytical approach to item deletion

In the phase dedicated to refining TPR scale, an analytical process was employed to assess the item structure through EFA. This procedure was pivotal in ensuring the psychometric robustness of the scale by identifying items that did not sufficiently align with their respective constructs (Roni, 2021). The criterion for retention was set at a factor loading threshold of 0.5, a standard benchmark that signifies a moderate to strong relationship between the item and its factor, thus indicating its relevance and contribution to the construct it is intended to measure (Costello & Osborne, 2005).

Table 2 lists the items that were retained for the range of constructs in TPR questionnaire and those that were deleted following the item deletion process. See **Appendix A** for the retained items. Items 18, 23, and 44 were excised from the scale. The decision was based on their factor loadings falling below the established threshold of 0.5, indicating a less-than-optimal contribution to the scale's construct validity. This item deletion process serves two primary functions: scale development and validation.

First, it enhances construct validity by ensuring that each construct is measured by items that strongly reflect the underlying theoretical dimensions (DeVellis, 2017). Second, it contributes to the overall reliability of the scale, as items with low factor loadings can detract from the internal consistency of the construct they are meant to represent (Tabachnick et al., 2013). The implications of these findings are twofold. On one level, they underscore the necessity of rigorous scale refinement processes in educational research to ensure that measurement instruments accurately capture the constructs of interest. On the other hand, they highlight the challenges and considerations inherent in developing scales for evaluating technology integration in education, a task that requires a delicate balance between theoretical fidelity and empirical utility.

Table 2. Items in TPR scale

Construct	Item numbers
TPACK	8, 9, 10, & 11
TPK	12, 13, & 14
TCK	15, 16, & 17
PU	18*, 19, 20, 21, & 22
PEoU	23*, 24, 25, 26, & 27
TK	28, 29, 30, 31, & 32
PD	33, 34, 35, & 36
CF	37, 38, 39, 40, & 41
EC	42, 43, & 44*
STL	45, 46, 47, 48, & 49
PCI	50, 51, 52, & 53

Note. Number with * means that the item was deleted based on EFA

Factor loadings

EFA conducted to validate TPR scale yielded profound insights into its factor structure and reliability. Utilizing principal component analysis with Promax rotation, this analytical phase discerned significant factor loadings across a spectrum of constructs, effectively capturing the complex nature of technology integration in primary mathematics education. Based on the initial eigenvalues, 11 factors were identified that together explain approximately 73.3% of the total variance in the data set. The results delineate the factor loadings for each item alongside the corresponding Cronbach's alpha values, which serve as robust indicators of internal consistency for each construct.

The constructs' Cronbach's alpha values spanned from 0.840 to 0.917, indicating high internal consistency and affirming that the items within each construct cohesively measure the intended underlying attributes. These alpha values significantly exceed the generally accepted benchmark of 0.700 for Cronbach's alpha, reinforcing the appropriateness of the scale items in evaluating their designated constructs.

The factor loadings ranged from 0.771 to 0.899 (see **Table 3**), further illuminating strong correlations between items and their respective constructs. Noteworthy constructs such as TPACK, PU, and PEoU exhibited high loadings, reflecting educators' preparedness and attitudes toward integrating technology in education. Similarly, significant loadings were found for constructs addressing TK, PD, CF, EC, STL, and PCI. This finding underscores the broad

Table 3. Factor loadings

	α	EC	TK	STL	CF	PU	PEoU	TPACK	PCI	PD	TCK	TPK
Q8	0.883							0.846				
Q9								0.878				
Q10								0.859				
Q11								0.789				
Q12	0.840											0.841
Q13												0.844
Q14												0.875
Q15	0.847										0.874	
Q16											0.839	
Q17											0.885	
Q19	0.890					0.870						
Q20						0.894						
Q21						0.874						
Q22						0.818						
Q24	0.884						0.872					
Q25							0.847					
Q26							0.899					
Q27							0.799					
Q28	0.898		0.786									
Q29			0.800									
Q30			0.866									
Q31			0.879									
Q32			0.843									
Q33	0.870									0.825		
Q34										0.834		
Q35										0.872		
Q36										0.823		
Q37	0.895				0.800							
Q38					0.845							
Q39					0.817							
Q40					0.867							
Q41					0.813							
Q42_1	0.917	0.836										
Q42_2		0.825										
Q42_3		0.842										
Q42_4		0.877										
Q42_5		0.827										
Q43		0.812										
Q45	0.892			0.838								
Q46				0.844								
Q47				0.874								
Q48				0.829								
Q49				0.771								
Q50	0.878								0.897			
Q51									0.835			
Q52									0.833			
Q53									0.833			

Note. Principal Component Analysis; Promax with Kaiser normalization; & Symbol α denotes Cronbach's alpha.

spectrum of factors, from teachers' competencies to external supports and challenges, that influence technology integration in the educational context. These findings verify the construct validity of TPR scale and confirm its capacity to comprehensively measure critical dimensions of technology adoption in education. The loadings across diverse constructs affirm that the scale is aptly designed to evaluate not only specific aspects of technology integration, such as those delineated by TPACK and TAM but also to consider the wider contextual and environmental factors that facilitate or impede technology's effective implementation in teaching practices. This holistic approach to assessing technology integration ensures a nuanced understanding of the various determinants of technology use.

Table 4. Model fit values (Hair et al., 2018)

Fit indices	Good fit values	Acceptable fit values	Scale fit values
x^2/df	$0<x^2/df<3$	$3\leq x^2/df<5$	1.111
RMSEA	0<RMSEA<0.05	0.05≤RMSEA<0.10	0.014
SRMR	0<SRMR<0.05	0.05≤SRMR<0.08	0.027
GFI	0.95≤GFI≤1.00	0.90≤GFI<0.95	0.924
AGFI	0.90≤AGFI≤1.00	0.85≤AGFI<0.90	0.913
NFI	0.95≤NFI≤1.00	0.90≤NFI<0.95	0.935
CFI	0.95≤CFI≤1.00	0.90≤CFI<0.95	0.993
TLI	0.95≤TLI≤1.00	0.90≤TLI<0.95	0.992

Table 5. Validity analysis

	CR	AVE	EC	TK	STL	CF	PU	PEoU	TPACK	PCI	PD	TCK	TPK
EC	0.917	0.649	**0.806**										
TK	0.899	0.640	0.375*	**0.800**									
STL	0.892	0.623	0.340*	0.276*	**0.790**								
CF	0.895	0.631	0.578*	0.291*	0.373*	**0.795**							
PU	0.890	0.670	0.326*	0.346*	0.359*	0.271*	**0.818**						
PEoU	0.884	0.655	0.338*	0.315*	0.385*	0.284*	0.555*	**0.809**					
TPACK	0.883	0.654	0.341*	0.554*	0.287*	0.282*	0.398*	0.381*	**0.809**				
PCI	0.878	0.643	0.295*	0.329*	0.537*	0.366*	0.378*	0.324*	0.346*	**0.802**			
PD	0.870	0.626	0.554*	0.343*	0.396*	0.514*	0.317*	0.316*	0.367*	0.340*	**0.791**		
TCK	0.848	0.650	0.340*	0.551*	0.268*	0.225*	0.357*	0.360*	0.542*	0.300*	0.344*	**0.806**	
TPK	0.840	0.637	0.365*	0.600*	0.331*	0.257*	0.317*	0.353*	0.535*	0.364*	0.352*	0.513*	**0.798**

Note. Bold number=$\sqrt{AVE}$ (e.g., EC $\sqrt{0.649} \approx 0.806$) & *p< 0.01

Confirmatory Factor Analysis

Model fit

Following EFA, CFA was undertaken to validate TPR scale further, focusing on the model's fit to the observed data. CFA process utilized various fit indices to evaluate the adequacy of the theoretical model, as outlined by Hair et al. (2018). The results, detailed in **Table 4**, provide a comprehensive overview of how well the model fits the empirical data, using a spectrum of fit indices including the chi-square to degrees of freedom ratio (x^2/df), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), goodness of fit index (GFI), adjusted goodness of fit index (AGFI), normed fit index (NFI), comparative fit index (CFI), and Tucker-Lewis index (TLI). Chi-square to degrees of freedom ratio (x^2/df) achieved a value of 1.111, well within the range indicative of a good fit ($0<x^2/\text{df}<3$), suggesting that the model is a reasonable approximation of the real data structure. RMSEA value of 0.014 falls within the threshold for a good fit (0<RMSEA<0.05), indicating a close fit between the hypothesized model and the observed data. Similarly, the SRMR value of 0.027 is well below the 0.05 cutoff, confirming the model's adequacy. Regarding the goodness of fit indices, GFI achieved a value of 0.924, which falls within the acceptable fit range, while AGFI reached 0.913, meeting the criteria for a good fit. This suggests a satisfactory level of fit, indicating that the model reasonably reproduces the observed data. NFI, CFI, and TLI values of 0.935, 0.993, and 0.992, respectively, surpass the acceptable thresholds, with CFI and TLI particularly highlighting an excellent fit between the model and the data.

Therefore, CFA results demonstrate that TPR scale's theoretical structure is well supported by the empirical data, with the majority of fit indices falling within the acceptable to good fit ranges. The high values of CFI and TLI, alongside a very low RMSEA and SRMR, underscore the robustness of the scale's construct validity. These findings affirm the scale's effectiveness in capturing the multifaceted nature of technology integration within primary mathematics education, providing a solid foundation for its application in research and practice. The model fit values, particularly those exceeding the thresholds for a good fit, reinforce the scale's utility in evaluating the constructs of interest with a high degree of precision and reliability.

Comprehensive validity & reliability assessment of TPR scale

The validity analysis of TPR scale, as summarized in **Table 5**, employs composite reliability (CR) and average variance extracted (AVE) alongside the square root of AVE and inter-construct correlations. This comprehensive approach provides a robust assessment of the scale's construct validity, ensuring the constructs are distinct yet related per the theoretical framework.

The factor loadings from the standardized regression weights are reported in **Figure 3**. These findings indicate strong and significant associations between the constructs (such as EC, TK, STL, CF, PU, PEoU, TPACK, PCI, PD, TCK, and TPK) and their respective items, with

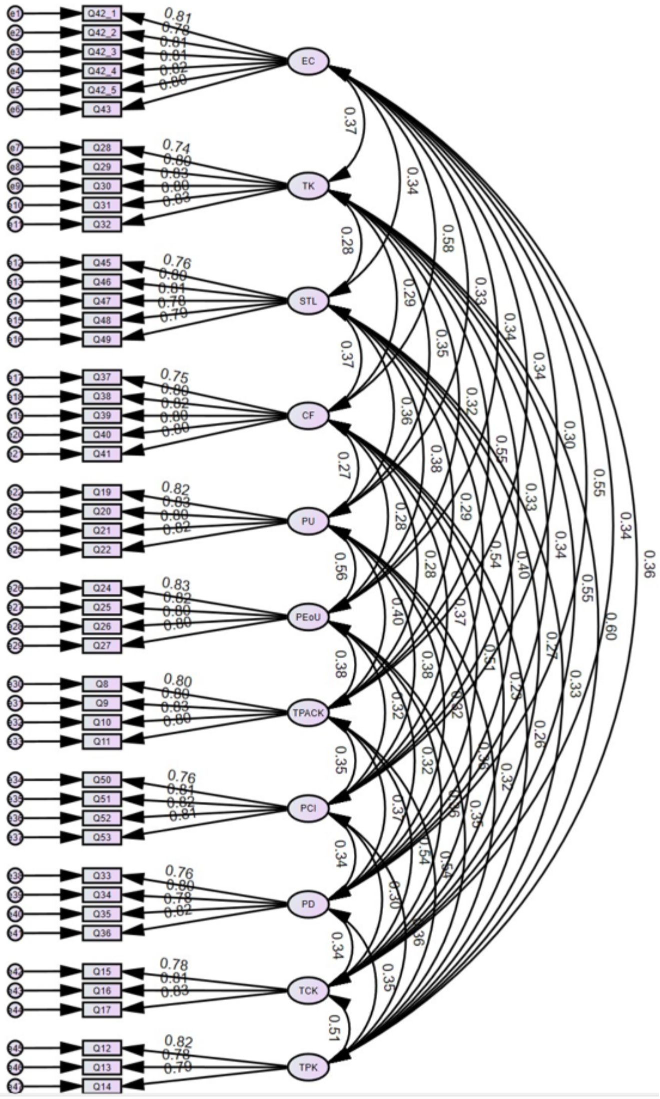

Figure 3. Factor loadings for the CFA model (Source: Authors' own elaboration)

estimates ranging from 0.742 to 0.833 (See loadings for items with construct in **Figure 3**). The findings demonstrate a robust linkage between each item and its underlying construct, affirming the constructs' validity within the Default model. The inter-construct correlations reported in **Figure 3** are also reported in **Table 5** along with CR and AVE values for each construct.

CR values across all constructs ranged from 0.840 to 0.917, exceeding the threshold of 0.7, indicating high internal consistency and reliability within each construct (Hair et al., 2018). AVE values, which measure the average proportion of variance explained by the constructs, were between 0.623 and 0.67, surpassing the recommended value of 0.5. This suggests that a significant portion of the variance in the observed variables is accounted for by their respective constructs, confirming their convergent validity. In addition, the square roots of AVE values, represented by the bold numbers on the diagonal in **Table 5**, serve as the benchmark for assessing discriminant validity by comparing them against the inter-construct correlations. For each construct, the square root of AVE was higher than its correlations with other constructs, as evidenced by values such as 0.806 for EC and 0.800 for TK, among others. This pattern, consistent across the board, indicates strong discriminant validity; each construct captures a distinct component of technology integration that is not overly conflated with others.

The inter-construct correlations, marked with an asterisk to denote significance at $p<0.01$, ranged from moderate to high, suggesting meaningful relationships between constructs. For instance, the correlation between TPACK and TK (0.554*) and between TCK and TPK (0.513*) were significant, illustrating the interconnected nature of technological knowledge and pedagogical application in the context of technology integration in mathematics education.

These validity analysis findings underscore TPR scale's robustness in measuring the multifaceted phenomenon of technology integration within primary mathematics education. The high CR values attest to the reliability of the constructs, while AVE results and discriminant validity assessments confirm that the scale effectively captures distinct yet theoretically related aspects of technology use in teaching. The significant inter-construct correlations further highlight the complex interplay among various dimensions of technology integration, reinforcing the scale's comprehensive nature and potential utility in research and practice. This analytical rigor not only substantiates the scale's theoretical underpinnings but also validates its application in exploring the dynamics of technology adoption among primary mathematics teachers.

DISCUSSION

TPR scale represents a significant advancement in measuring technology integration within primary mathematics education. In this section, the scale's comparative advantages, theoretical alignment, and practical implications, along with its limitations and future research and application avenues are discussed.

Comparison with Existing Scales

TPR scale represents a novel contribution to assessing technology integration in education, particularly primary mathematics. Its development responds to the need for more contextually rich tools to capture the multifaceted nature of technology use in educational settings. Traditional scales such as TPACK survey instrument developed by Schmidt et al. (2009), the survey instrument on pre-service teachers' perceptions by Chai et al. (2013), and more recent contributions like the technology acceptance studies by Khong et al. (2023), have laid significant groundwork by focusing on the intersections of attitudes toward technology integration, technology, pedagogy, and content knowledge.

However, these instruments often emphasize individual teacher competencies and perceptions at a classroom level without extensively investigating external factors influencing technology adoption. TPR scale extends beyond these foundational aspects by integrating evaluations of contextual elements, educational challenges, and the role of community and parental involvement in the technology integration process. For instance, while TPACK framework (Mishra & Koehler, 2006) offers a comprehensive view of the knowledge teachers need to integrate technology effectively, it does not explicitly address how contextual factors like school infrastructure, administrative support, and community engagement impact this integration (Porras-Hernández & Salinas-Amescua, 2013). Similarly, TAM (Davis, 1989) provides insights into the determinants of technology use. However, it may not fully account for the specific challenges faced in the mathematics education context, such as the need for specialized software or the alignment of technology with curriculum standards requirements.

TPR scale's incorporation of broader dimensions, such as educational challenges and community involvement, significantly departs from traditional technology integration assessments. This expanded focus recognizes the multifaceted nature of technology integration, not merely as an outcome of teacher beliefs and pedagogical knowledge but as a complex process shaped by many factors within the educational ecosystem. Such an approach is in line with the perspectives of Ertmer and Ottenbreit-Leftwich (2010) and Tondeur et al. (2017), who argue for a nuanced understanding of technology adoption in schools that transcends individual teacher competencies to include systemic barriers and facilitators. Recognizing these external contextual influences is crucial, as it acknowledges that the successful integration of technology in education is contingent upon a supportive environment beyond the classroom. Further, by explicitly addressing educational challenges and the role of community involvement, TPR scale responds to the growing consensus on the need for comprehensive evaluations of technology integration efforts. Dexter (2008) and Hew and Brush (2007) have highlighted the critical role of stakeholder engagement, including parents, local communities, and educational authorities, in fostering educational innovation and change. The scale's attention to these areas emphasizes the importance of collaborative efforts and the mobilization of resources to overcome obstacles to technology use, echoing the views of scholars like Frank et al. (2004), who stress the impact of social, cultural, and material resources on educational outcomes.

Moreover, TPR scale's holistic perspective supports the implementation of targeted interventions and developing policies that address the specific needs and challenges of schools and communities seeking to improve primary mathematics teaching. By capturing a broad range of factors influencing technology integration, educators, policymakers, and researchers can identify areas, where support is most needed, facilitating more effective and sustainable integration strategies. This aligns with the work of (Mishra et al., 2023), who advocate for thoughtful consideration of TPACK in designing educational technologies that are both effective and contextually appropriate. Therefore, TPR scale represents a forward-thinking tool that embodies the complexity of technology integration within the educational landscape for the teaching of primary mathematics. Its comprehensive approach enriches the assessment of technology adoption in schools and serves as a foundation for future research and practice to enhance mathematics educational practices through technology. By acknowledging the diverse elements that contribute to the success of technology integration, TPR scale sets the stage for more informed, collaborative, and strategic efforts to harness the potential of digital technologies in enhancing mathematics teaching and learning.

Implications for Mathematics Education

The practical and theoretical implications of the findings from TPR scale application are profound, particularly within primary mathematics education. The scale's robust construct validity and alignment with models such as TPACK and TAM reaffirm the relevance of these frameworks and innovate upon them by weaving in the critical dimensions of contextual factors. This holistic perspective underscores the notion that effective technology integration transcends the mere amalgamation of pedagogical and content knowledge, venturing into the realm of systemic understanding that encompasses infrastructure, policy, and community engagement (Mishra et al., 2023; Porras-Hernández & Salinas-Amescua, 2013).

Practical Implications

On a practical level, TPR scale illuminates the path forward for implementing technology in primary mathematics education more effectively. By identifying the significance of professional development and pinpointing educational challenges, the scale offers actionable insights for educators and administrators. For instance, the emphasis on professional development underlines the necessity of equipping primary mathematics teachers with the technical skills required for technology integration and the pedagogical strategies that leverage technology to enhance learning outcomes. This could lead to the development of targeted training programs that address both the adoption of new digital technologies and the integration of these tools into mathematics curricula in ways that foster deeper conceptual understanding among students. Moreover, the scale's focus on educational challenges and systemic barriers suggests that initiatives to bolster technology integration should adopt a multifaceted approach. This involves addressing the individual needs of mathematics teachers and engaging with the wider educational ecosystem to mitigate infrastructural limitations and policy constraints. For example, schools could collaborate with local communities and policymakers to secure the necessary resources and support for technology-enhanced learning environments, thereby creating a more conducive setting for adopting and effectively using digital tools such as artificial intelligence in mathematics education.

Theoretical Implications

Theoretically, TPR scale's findings contribute significantly to the discourse on technology integration in education. By effectively capturing the complexity of technology adoption and its impact on mathematics education, the scale extends existing frameworks like TPACK and TAM, providing empirical evidence that supports the integration of contextual and external factors into these models. This contributes to a more nuanced understanding of technology integration, highlighting the interdependence of pedagogical strategies, technological tools, and the educational context in which they are deployed. Furthermore, the scale's comprehensive approach to measuring technology integration offers a foundation for future research to explore the dynamic interplay between technology and education. It encourages scholars to consider the broader contextual factors that influence technology adoption, moving beyond the classroom to include institutional policies, community involvement, and the socio-economic landscape. This expanded perspective could inspire new theoretical models that account for the complexity of integrating technology into mathematics education, paving the way for research that not only investigates the direct effects of technology on learning outcomes but also examines the systemic conditions that facilitate or hinder its effective use.

Limitations & Future Research Directions

Despite its strengths, TPR scale is not without limitations. One potential source of bias arises from its reliance on self-reported data, which may be influenced by social desirability or personal reflection inaccuracies. Additionally, the scale's focus on primary mathematics education in Chongqing, China, may limit the generalizability of its findings to other subjects or cultural contexts. Future research could address these limitations by incorporating observational data or cross-validating the scale across different educational settings and disciplines. Future research directions could also explore longitudinal studies to assess how technology integration evolves and the impact of specific interventions. Further refinement of TPR scale to include emerging technologies and pedagogical trends would ensure its ongoing relevance and utility. Practical applications of the scale could involve its use in teacher training programs to identify areas for improving pre-service teacher education, professional development or in policymaking to inform technology integration strategies.

CONCLUSIONS

The research surrounding the development of TPR scale has unveiled significant insights into technology integration within primary mathematics education in China. This study's findings underscore the multifaceted and nuanced nature of technology adoption, highlighting the importance of a comprehensive approach that accounts for internal pedagogical dynamics and external systemic factors. Central to this research is the validation of TPR scale, which has demonstrated robust construct validity and reliability across its diverse constructs, encompassing TPACK, TAM components (PU and PEoU), and additional factors such as contextual factors, professional development, and parental and community involvement. The scale's strong factor loadings and alignment with established theoretical frameworks have affirmed its efficacy in capturing the complexity of technology integration in education. The significance of this research lies in its contribution to a deeper understanding of how technology can be effectively integrated into mathematics education, moving beyond traditional models to include a broader range of influencing factors. For practitioners in China and similar contexts, TPR scale offers a practical tool for assessing the current state of technology integration and identifying areas for improvement. Educators can utilize the scale to pinpoint specific challenges and opportunities within their schools, facilitating targeted interventions that address teacher training needs and infrastructural enhancements. Moreover, the scale can guide the development of community engagement strategies that leverage local resources and support to bolster classroom technology adoption.

The broader implications of this research extend to educational policy and practice, advocating for policies that recognize and support the complex ecosystem of technology integration. Policymakers should consider the range of internal and external factors in their contexts and adapt this instrument for their own use when designing technology-related educational initiatives, ensuring that programs are equipped with the necessary technological tools and accompanied by comprehensive support systems. This includes professional development for teachers, infrastructural upgrades, and community involvement programs that collectively foster an environment conducive to effective technology use. Additionally, this study underscores the need for ongoing research, encouraging further exploration into dynamic interplay between technology and education.

Future studies could expand upon TPR scale's findings, exploring the longitudinal effects of technology integration strategies and their impact on student learning outcomes. Such research is essential for continually refining educational practices and policies in response to technological advancements and evolving pedagogical approaches. It can be said that TPR scale represents a significant advancement in our understanding of technology integration in primary mathematics education, providing a comprehensive framework for assessing and enhancing technology use in classrooms. Its validation and application in China offer valuable insights for educators, policymakers, and researchers, highlighting the importance of a holistic approach to technology integration. As technology continues to shape educational landscapes, TPR scale is critical for navigating the complexities of integrating digital tools into teaching and learning processes, ultimately contributing to advancing educational policy and practice in the digital age.

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

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APPENDIX A

TPCK

8. I can effectively integrate digital technology, mathematics knowledge and teaching methods in online mathematics classes.
9. I can effectively integrate digital technology, mathematics knowledge and teaching methods in face-to-face mathematics classes.
10. I can guide students to use digital technologies (such as internet resources, AI tools, various learning software, etc.) to learn mathematics.
11. I can design online-based self-directed learning activities according to the mathematics curriculum. (e.g., I can create instructional videos and assignments that enable students to study mathematics independently).

TPK

12. I can guide students to engage in online collaborative learning.
13. I can use digital resources to design student-centered mathematics teaching activities.
14. I can use digital technologies to design real-time quizzes that assess students' learning effectiveness in class.

TCK

15. I can use digital technologies to visualize abstract mathematical concepts, for example, by dynamically presenting geometric figures on interactive whiteboards.
16. I can use digital technology to conduct in-depth analyses of homework data and adjust teaching content accordingly.
17. I incorporate discussions on academic integrity in my mathematics classes, emphasizing guidance and regulations on plagiarism in the age of intelligent education.

PU

19. The visualization capabilities of digital technology can enhance students' understanding of mathematical concepts.
20. Using digital technology in my mathematics teaching enables me to effectively achieve instructional objectives.
21. The integration of digital technology with teaching practices can enhance my professional competence in mathematics instruction.
22. My experiences of successfully applying digital technology in mathematics classes encourage me to continue using these technologies.

PEoU

24. After becoming familiar with digital technologies, I am more willing to integrate them into my mathematics teaching.
25. I am willing to use digital technologies in mathematics classes when they are easy to operate.
26. In mathematics class, I prefer to use digital technologies that can be quickly mastered.
27. When learning digital technologies requires less effort, I am more willing to integrate them into my mathematics teaching.

TK

28. I believe that AI-driven mathematics tutoring systems can help students improve their learning abilities in mathematics.
29. Digital technologies play a crucial role in improving the quality of mathematics teaching and learning.
30. AI tools can assist me in enhancing the effectiveness of my instruction.
31. Using digital technologies in mathematics classes significantly improves student motivation.
32. I pursue professional development opportunities to improve the integration of AI tools in mathematics education.

PD

33. The national teacher professional development programs help me to master various educational digital technologies.
34. The teacher professional development programs organized by the school can improve my ability to integrate digital technologies.
35. The training courses provided by companies specializing in educational technology can improve my ability to integrate digital technologies.
36. I frequently engage in self-directed learning to improve my ability to integrate digital technologies in my mathematics classroom.

CF

37. I know about the information technologies available in the classroom that can be utilized for mathematics instruction.
38. I have a comprehensive understanding of my students' information technology skills.
39. School leadership support enhances my confidence in integrating digital technologies in the classroom.
40. The educational environment provides me access to diverse educational resources.
41. I know the educational policies implemented to enhance the information technology proficiency of mathematics teachers.

EC

42. Please rate how strongly you agree or disagree that the following factors motivate your integration of digital technology into mathematics teaching:

Table A1. Rating

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Competitive nature of mathematics	○	○	○	○	○
Teacher performance pressure	○	○	○	○	○
Attending demonstration lessons	○	○	○	○	○
Standardized tests	○	○	○	○	○
Improving students' academic performance	○	○	○	○	○

43. Working with fellow teachers is an important method to address the problems of integrating digital technology into classroom instruction.

STL

45. My students are familiar with digital technologies commonly used in mathematics teaching.
46. My students can use digital resources to enhance their mathematics problem-solving skills.
47. My students can use digital communication tools (such as DingTalk, WeChat, and QQ) to collaborate on mathematics tasks.
48. My students easily embrace the new digital technologies used in mathematics classes.
49. My students can use educational resources (e.g., mathematics teaching videos, AI, and adaptive systems) to enhance their mathematics skills and knowledge.

PCI

50. Effective collaboration among teachers, parents, and the community positively influences technology use in mathematics teaching and learning.
51. Parents' information technology skills play a crucial role in assisting their children's mathematics learning.
52. Parents' information technology skills are essential for creating an effective educational environment.
53. Community support influences teacher' attitudes towards using digital technologies in mathematics learning.