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# Technology, pedagogy, and content knowledge in mathematics education: a systematic literature review

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**ABSTRACT**

This literature review examines how mathematics education uses the Technology, pedagogy, and content knowledge (TPACK). This study examines how TPACK affects mathematics classroom instruction, student engagement, and learning outcomes. A detailed examination and synthesis of pertinent publications over the last decade will accomplish this. The study illuminates significant topics, including digital technology utilization, teacher professional development program enhancement, and TPACK acceptability. It also highlights long-standing issues such as limited technology budgets, teacher training issues, and the need for ongoing support. This post provides current ideas and a full literature review to assist us in understanding TPACK. The findings impact educational policymakers, teacher professional development programs, and math teachers. The paper then advises future research. One is a longitudinal study of different educational environments to determine long-term effects on teaching and student growth. Policymakers, educators, and academics can utilize this study review to advocate for acceptable technology usage in mathematics education.



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## 1. INTRODUCTION

The combination of technology, pedagogy, and content knowledge (TPACK) in mathematics education has sparked widespread interest and study. Koehler and Mishra [1] created the TPACK paradigm in 2005, which has given a significant lens for understanding how these three knowledge domains overlap in the context of teaching and learning mathematics. This approach highlights the significance of instructors knowing how to properly integrate technology, pedagogy, and material to improve students' learning experiences [2]. Teaching employs the TPACK for technology integration, defining it as the interaction and junction of technology, pedagogy, and subject knowledge in mathematics teaching [3], [4]. The TPACK facilitates the creation and validation of mathematics education tools that describe the integration of technology knowledge in secondary school settings [5], [6]. The TPACK is used to investigate how teacher candidates incorporate technology into mathematics education, and it specifies five levels of TPACK: recognizing, accepting, adapting, exploring, and advancing [7].

The TPACK helps pre-service mathematics instructors prepare for life in the twenty-first century. The TPACK, designed for twenty-first-century skills, provides instructors with a framework for efficiently integrating technology, pedagogy, and content, ultimately improving students' learning experiences [8]. The TPACK can also help pre-service mathematics instructors comprehend mathematical practices and approaches to teaching mathematics. The mathematics teacher's competency, or TPACK, has a direct influence on student mathematical learning [9]. The TPACK has practical applications in mathematics teaching. It lays the groundwork for identifying critical components of technology usage in the mathematics classroom, showing strong TPACK through classroom vignettes, and addressing the instructional consequences of technology use. By integrating technology, pedagogy, and topic knowledge, instructors may improve their capacity to negotiate the difficulties of modern mathematics teaching and provide meaningful learning experiences for their pupils [10]. Teachers may also utilize the TPACK to improve their knowledge in the mathematics classroom. It underlines the significance of understanding the relationship between pedagogy and technology in the development of topic-specific TPACK in mathematics courses. This emphasis on TPACK reflects the changing nature of teacher knowledge, especially in more technologically advanced educational settings [11]. The necessity to assess the effective integration of technology into teaching and learning in the field of mathematics education has resulted in the creation of a variety of techniques and instruments. Handal *et al.* [12] created and validated an instrument to assess the integration of technical knowledge in secondary school mathematics teaching. A sample of 280 instructors in Australia completed the questionnaire based on the TPACK framework, and factor analysis validated the instrument's structural soundness.

Researchers have also used the TPACK framework to improve teacher understanding in math courses [13], [14]. Guerrero emphasized the necessity of understanding the interaction of pedagogy and technology while developing topic-specific TPACK in mathematics courses. This emphasis on TPACK reflects the changing nature of teacher knowledge, especially in more technologically advanced educational settings [11]. In addition to theoretical advancement, the TPACK has practical applications in mathematics teaching. It serves as a foundation for identifying critical components of technology usage in the mathematics classroom, showing robust TPACK using classroom vignettes, and discussing the instructional consequences of technology use [15]. By integrating technology, pedagogy, and topic knowledge, instructors may improve their capacity to negotiate the difficulties of modern mathematics teaching and provide meaningful learning experiences for their pupils [16]. The TPACK remains a useful tool for understanding and enhancing the integration of technology, pedagogy, and topic knowledge in mathematics education [17]. Its use in instrument development, the advancement of teacher knowledge, and practical consequences for teaching and learning demonstrate its importance in the discipline. As technology plays an increasingly important role in education, the TPACK provides a solid foundation for ensuring that technology integration is deliberate, pedagogically sound, and linked with mathematics education's content goals [18], [19].

Some examples of effective TPACK-based mathematics education programs are: i) AMTE Technology Committee's TPACK Mathematics Teacher Standard: The Association for Mathematics Teacher Educators (AMTE) has proposed the TPACK Mathematics Teacher Standard, which serves as a framework for guiding professional practices that promote the improvement of mathematics teaching and learning. This standard focuses on the organization, design, and growth of digital-age learning experiences and settings, the capacity to grasp mathematical practices and techniques of teaching mathematics, and the influence of mathematics teacher TPACK competency on student learning [20]. ii). Implementation of the TPACK Framework in Indonesian Online Mathematics Teacher Training: research explained how the TPACK framework was used in online mathematics teacher training in Indonesia. The goal of this implementation was to improve mathematics teaching quality by integrating TPACK [21]. iii). Professional Development Programs: Several professional development programs have been established to help instructors improve their TPACK abilities. For example, teachers' TPACK was developed through an online course that engaged teachers in exploring spreadsheet capabilities within specific mathematics and science units, integrating spreadsheets into themes and units, considering assessment for student outcomes when solving math and science problems with spreadsheets, and planning and scaffolding student learning with spreadsheets. Teachers who completed this TPACK-based curriculum provided favorable and encouraging feedback on their knowledge areas as depicted within the TPACK framework [22]. These examples show how the TPACK framework has been successfully applied in mathematics education, with an emphasis on integrating technology, pedagogy, and topic knowledge to improve teaching and learning experiences.

## 2. THEORETICAL FRAMEWORK

### 2.1. Overview of technology, pedagogy, and content knowledge framework

Mishra and Koehler's TPACK paradigm provides the theoretical underpinnings for this investigation. Pedagogical knowledge (PK), content knowledge (CK), and technology knowledge (TK) form the trifecta of the TPACK framework, an all-encompassing method of teaching and learning. Mishra and Koehler argue that good teaching necessitates harmony and integration of these three domains of knowledge.

The complementary character of these three fields of study is one of the most crucial components of good educational practices, according to them [23].

### 2.2. TPACK components: technology, pedagogy, and content knowledge

Having proficiency in technological areas is what the abbreviation "TK" stands for technological knowledge of various technologies and how they could be used to bolster subject-specific learning is central to TPACK. TK is defined by Harris *et al.* [24] as the capacity to select and integrate technology resources strategically to achieve mathematics education pedagogical goals. PK, a component of TPACK, addresses issues related to prior knowledge in the subject and emphasizes the methods, processes, and tactics teachers use to design and implement productive classrooms. According to Shulman [25] that PK practitioners need to be well-versed in a variety of teaching styles and adept at tailoring those tactics to the requirements of their students. Within the TPACK framework, there is an interdependence between technical, procedural, and content knowledge. CK in the context of TPACK means fully grasping the subject matter. Research by Hill *et al.* [26] provide a definition of CK in mathematics education as being well-versed with both the subject matter and the usual learning styles of pupils, as well as their potential for misunderstandings.

### 2.3. Integration in mathematics education

According to Niess, collaboration between TK, PK, and CK is the only method for all students to completely benefit from TPACK in mathematics classes [27]. Mathematical themes may be difficult for children to grasp; therefore, teachers must navigate an increasingly computerized educational environment [28]. For educators who want to thrive in such a competitive atmosphere, mastering the skill of dynamic engagement is important. Thompson and Mishra concluded that an analysis of TPACK in mathematics teacher preparation courses necessitates an educational method that is both analytical and purposeful in its approach [29]. Mathematics instruction must be rigorous and painstakingly planned to properly utilize the TPACK framework in the classroom. The interplay among classroom instruction, technological advancements, and expert-level topic knowledge served as the impetus for this theoretical framework. Mathematical instruction that makes use of both theoretical and practical knowledge was the focus of this work.

## 3. METHOD

A systematic search method was utilized to conduct a thorough literature evaluation on the integration of TPACK in mathematics instruction. The goal of the search was to find scholarly works that had been published within the past ten years so that the information would be up-to-date. The following databases were thoroughly searched: ERIC, PsycINFO, and IEEE Xplore, with a mix of keywords such as "TPACK," "mathematics education," and "technology integration." This systematic literature review only includes studies that fulfilled strict requirements for rigor and relevance. Articles that met the inclusion requirements were published in English-speaking, peer-reviewed publications and had a clear focus on mathematics education and the integration of TPACK. Research that did not center on mathematics education or that did not tackle TPACK head-on was not considered. This review primarily relied on academic databases, prestigious education publications, and pertinent conference proceedings for its data collection and analysis. To make sure that important research and seminal works that might not have come up in the automated searches were included, a manual search of reference lists in the identified papers was also carried out.

Several steps were engaged in the selection of the studies. Article titles and abstracts served as the basis for the initial screening process. The next step in determining eligibility according to the inclusion and exclusion criteria was to conduct full-text reviews. In the event of a disagreement, the review team met to deliberate and reach a consensus. To extract useful information from the chosen papers, we methodically gathered details like the authors, publication year, research strategy, sample size, important findings, and implications for TPACK in math education. To find similarities, trends, and patterns among the chosen research, the synthesized data was further examined thematically. By following these steps, we were able to comprehend the present situation of TPACK in math instruction consistently and thoroughly.

## 4. RESULTS AND DISCUSSION

### 4.1. Systematic literature review

Several studies reviewed in this systematic literature review highlight a discernible trend in the integration of digital tools and resources to support the teaching and learning of mathematical concepts. Other Authors emphasize the role of technology in providing interactive and dynamic platforms for exploring abstract mathematical ideas [30]. The trend suggests a shift towards leveraging digital resources to enhance the visualization of mathematical concepts and promote a deeper understanding among students. One notable trend identified in the literature is the emphasis on teacher professional development initiatives aimed at fostering TPACK in mathematics education. The researcher underscores the importance of equipping educators with the necessary knowledge and skills to effectively integrate TPACK [31]. Professional development programs are increasingly recognized as instrumental in addressing challenges and promoting the sustained implementation of TPACK in mathematics classrooms.

The literature reveals diverse models and frameworks for implementing TPACK in mathematics instruction. Scholars such as Wang *et al.* [32] propose specific models that outline the systematic integration of TPACK. These models provide educators with practical guidelines for designing and implementing TPACK-infused lessons. The identified trends suggest a move towards more structured approaches to TPACK, enhancing its applicability in varied educational settings. The synthesis of these trends contributes to a nuanced understanding of the current landscape of TPACK in mathematics education. The identified patterns provide insights for educators, policymakers, and researchers aiming to stay abreast of the evolving practices and innovations in the field. The next section of this systematic literature review will delve into the challenges and barriers associated with TPACK in mathematics education.

### 4.2. Challenges and barriers

Several studies reviewed in this systematic literature review highlight a discernible trend in the integration of digital tools and resources to support the teaching and learning of mathematical concepts. Authors such as Hoyles emphasize the role of technology in providing interactive and dynamic platforms for exploring abstract mathematical ideas [33]. The trend suggests a shift towards leveraging digital resources to enhance the visualization of mathematical concepts and promote a deeper understanding among students. The literature consistently highlights the challenge of teacher preparedness and training in effectively integrating TPACK into mathematics instruction. Authors such as Tondeur *et al*. [34] emphasize that many educators may not feel adequately prepared to navigate the complex interplay between TPACK. The need for targeted professional development programs to enhance teacher competencies in TPACK remains a prominent challenge within the field.

To keep the TPACK in mathematical curricula, teachers must continue to work together. Researchers found that teachers would have trouble keeping up with the rapid adoption of TPACK if they did not have consistent professional development and access to relevant materials [35]. Time constraints and a lack of chances for career growth seem to be threatening the sustainability of TPACK initiatives in the long run. The literature acknowledges that cultural and institutional factors play a significant role in shaping the success of TPACK in mathematics education. Studies such as Voithofer *et al*. [36] discuss how varying cultural perspectives on technology use in education and institutional policies can impact the adoption of TPACK. Understanding and navigating these cultural and institutional factors are crucial for effectively addressing challenges associated with TPACK. Researchers, educators, and politicians who want to see TPACK widely and fairly used in math education must first identify and comprehend these obstacles. Examining how TPACK affects pedagogical approaches and learning outcomes is the next element of this research review.

### 4.3. Impact on teaching practices

The investigated literature consistently returns to the topic of how educators see the incorporation of TPACK into their teaching practices. Research by Marban and Sintema [37] explores the viewpoints of maths educators who have used TPACK in the classroom. The results show that when instructors carefully integrate technology into their lessons, it frequently changes the way they teach maths. This, in turn, gives teachers more confidence and allows them to be more creative when delivering the material. Incorporating TPACK into teacher preparation programs: the systematic review highlights the importance of equipping future educators with the knowledge and skills needed for effective TPACK. Mathematics teacher preparation programs should consider integrating TPACK components into their curricula to ensure that future teachers are well-prepared for the demands of 21st-century classrooms [38]. Providing ongoing professional development: the challenges associated with teacher preparedness underscore the need for continuous professional development opportunities. School districts and educational institutions should invest in ongoing training programs that support educators in enhancing their TPACK competencies [39]–[41].

Mathematical engagement and performance are both improved when TPACK is used, according to many research. Yang *et al*. [42] found that students are more engaged and enthusiastic in classes that use technology and have interactive parts. Supporting the idea that TPACK improves instruction, we find that students' improved arithmetic performance and comprehension occurs alongside its incorporation into the classroom. Tailoring professional development to contextual needs: the variation in TPACK patterns suggests that one-size-fits-all professional development may not be effective. Tailoring programs to address the specific contextual needs of educators, as discussed by Koh *et al*. [43], is essential for successful TPACK implementation. Promoting collaborative learning communities: creating collaborative learning communities within schools can facilitate the sharing of best practices and provide educators with a supportive network. This approach aligns with the findings by Koh *et al*. [43], who emphasize the value of teacher perspectives in shaping effective TPACK strategies.

Numerous success stories and case studies in the literature show how TPACK has been put into practise in mathematics classes. Research by Mouza *et al.* [44] is only one of many notable instances that show how technology, pedagogy, and subject knowledge may be effectively combined by teachers to produce excellent educational outcomes. Instructors looking to apply TPACK in a variety of contexts might find example illustrations in these situations. The synthesis of these findings underscores the transformative impact of TPACK on teaching practices and student experiences in mathematics education. Understanding these impacts is critical for educators, administrators, and policymakers aiming to leverage TPACK effectively for enhanced teaching and learning outcomes. The subsequent section of this systematic literature review will provide an overarching synthesis of key findings and identify gaps in the existing literature.

To address the challenge of access to technology, educational policymakers should prioritize investments in technological infrastructure in schools [45], [46]. This includes ensuring equitable access to digital tools and resources for all students and educators, as recommended by Mucundanyi and Woodley [47]. Introducing incentives or recognition programs for educators who successfully integrate TPACK can motivate teachers to embrace innovative practices. Policy initiatives should consider acknowledging and rewarding exemplary TPACK efforts within school systems [48]. The implications for practice drawn from the systematic literature review offer practical guidance for mathematics educators, teacher professional development programs, and educational policymakers [49], [50]. By incorporating these recommendations, stakeholders can contribute to the effective integration of TPACK in mathematics education, fostering enhanced teaching and learning experiences.

### 4.4. Synthesis of findings

The synthesis of findings from the systematic literature review reveals several key themes that underscore the multifaceted nature of integrating TPACK in mathematics education. Common themes include the transformative impact on teaching practices, the positive influence on student engagement and learning outcomes, and the critical role of teacher professional development in successful TPACK implementation. Technology, pedagogy, and subject knowledge must all be integrated for students to get a successful mathematics education, according to these classes. TPACK may be incorporated in several ways; this study has shown that some of these techniques are consistent while others are not. Many teachers encounter problems while trying to use TPACK in the classroom. Lack of resources, insufficient teacher preparation, and inconsistent support are some of these challenges. According to Greene and Jones [51] that expert solutions customized to specific contextual issues are essential due to the different ways in which TPACK may be implemented.

There has been a lot of research on TPACK in maths classrooms, but there is still a lot of room for improvement. Longitudinal studies examining the effects of TPACK on classroom instruction and student achievement are few. A thorough investigation into the institutional and cultural elements that impact the implementation of TPACK is also really important. If you could fill in the gaps, we would have a better grasp of the challenges related to TPACK deployment in different classes. Using the findings synthesis, we thoroughly assess how far along the path to TPACK of mathematics education is. The synthesis of findings offers a comprehensive overview of the current state of TPACK in mathematics education. By identifying key themes, patterns, and existing gaps, this synthesis contributes to the broader conversation on effective technology integration in educational settings. The subsequent section of this systematic literature review will explore the implications of the findings for practice and propose recommendations for educators, policymakers, and researchers.

### 4.5. Future research directions

Examining long-term impact on teachers: despite the transformative potential of TPACK, limited research explores the long-term impact on teachers' instructional practices. Future studies should employ longitudinal designs to track how TPACK implementation evolves and its sustained effects on teachers' pedagogical approaches [52]. Investigating persistent challenges: longitudinal studies can provide insights into persistent challenges associated with TPACK. Understanding how challenges evolve and persist over time is crucial for developing targeted interventions and support mechanisms. Diverse contexts and populations: the existing literature predominantly focuses on TPACK in mainstream classrooms. Future research should explore TPACK in diverse educational settings, including special education, bilingual education, and schools with varying socioeconomic contexts. According to these and previous studies, people living in poverty might value TPACK more highly. This is a teacher-perspective examination of TPACK:

Looking at the global adoption of TPACK might help us understand the many social and environmental factors better. Maybe we may understand the rationale behind TPACK if we take a look at how other nations educate their students.

Some possible models that might aid teachers in improving their craft are: additional study is needed to identify the most effective professional development courses that can assist instructors in utilizing TPACK. Topic knowledge, instructional tactics, and technical competence are three areas where teachers might profit from the data given by comparison assessments. The effectiveness of TPACK depends on its capacity to imbue students with the capacity to retain and apply what they have learned. The major objective of this project is to investigate if and how students' mathematical abilities and perspectives on mathematics education are enhanced by TPACK-guided training. The outlined future research directions aim to address gaps identified in the systematic literature review and contribute to the evolving understanding of TPACK in mathematics education. By exploring longitudinal effects, diverse educational settings, and global perspectives, researchers can advance the field and inform evidence-based practices for educators and policymakers.

## 5. CONCLUSION

In this systematic literature review, an in-depth exploration of the integration of TPACK in mathematics education has been undertaken. Key findings from the reviewed studies highlight the transformative impact of TPACK on teaching practices, the positive influence on student engagement and learning outcomes, and the critical role of teacher professional development in successful TPACK implementation. This review contributes valuable insights to the field of mathematics education by synthesizing current research on TPACK. The identification of key themes, patterns, and variations in TPACK implementation provides a nuanced understanding of the complexities involved in marrying TPACK in mathematics classrooms.

The implications drawn from the synthesis of findings offer practical guidance for mathematics educators, teacher professional development programs, and educational policymakers. Recommendations include the incorporation of TPACK in teacher preparation programs, ongoing professional development initiatives, and policy measures to address challenges related to access to technology. Identified gaps in the existing literature pave the way for future research directions. The call for longitudinal studies on TPACK implementation, exploration of TPACK in diverse educational settings, and assessments of the long-term impact on both teachers and students offers a roadmap for researchers to contribute to the evolving knowledge base in this field. As technology continues to advance and education transforms, the integration of TPACK in mathematics education emerges as a dynamic and evolving field. The insights gained from this systematic literature review underscore the need for continuous research, innovation, and collaboration to ensure that TPACK remains responsive to the changing needs of educators and students in the ever-evolving landscape of mathematics education. The synthesis of findings and future research directions presented in this review contributes to the ongoing dialogue on TPACK in mathematics education, providing a foundation for informed decision-making, policy development, and instructional practices in the field.

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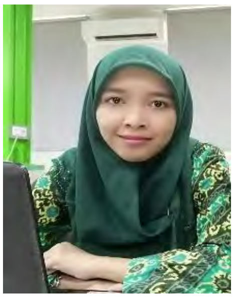

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