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# Mastering the TPACK framework: Innovative approaches by mathematics teachers

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## Abstract

Integrating technological, pedagogical, and mathematical content knowledge poses an inherent challenge. Educators are tasked with achieving a harmonious equilibrium among these facets to ensure the productive utilization of technology to bolster mathematical learning endeavors. This study examines how mathematics teachers in West Sumatra use Technology, Pedagogy, and Content Knowledge (TPACK) in their classrooms. The investigation engaged a cohort of 15 teachers and 36 students, employing a qualitative descriptive methodology. Methodologically, the research adopted a survey-based approach, with data collection techniques encompassing literature reviews, interviews, and questionnaires. This study's findings underscored teachers' adeptness in incorporating the TPACK framework throughout the various facets of the teaching process, encompassing planning, execution, and evaluation. Educators have adeptly woven TPACK principles into the fabric of mathematics instruction, meticulously integrating technological tools across all stages of the pedagogical journey. The judicious integration of technology has yielded palpable benefits, fostering a conducive and engaging learning environment for students. Moreover, the findings of this research serve as a clarion call for further scholarly inquiry aimed at enhancing the efficacy and quality of TPACK-infused digital learning practices.

**Keywords:** mathematics teachers; qualitative descriptive; technology integration; TPACK

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## Introduction

In the contemporary digital era, using technology in mathematics education is increasingly imperative (van Leendert et al., 2022). This trend underscores educators' need to adapt and utilize digital tools effectively to enhance learning experiences and outcomes in mathematics (Putri, Juandi, et al., 2024a). However, incorporating technology in learning extends beyond merely utilizing tools or devices; it necessitates a profound understanding of how technology can be effectively integrated with pedagogical knowledge and robust mathematical content (Ardiç, 2021; Putri, Yerizon et al., 2024). Teachers' proficiency in Technological Pedagogical and Content Knowledge (TPACK) integration is crucial for effective technology integration in education (Kim, 2018). TPACK, which stands for Technological Pedagogical Content Knowledge. At its core, TPACK is a theoretical framework that emphasizes the complex interplay between three key components: technology (T), pedagogy (P), and content knowledge (CK) (Koehler & Mishra, 2009). TPACK represents a dynamic framework that outlines the knowledge teachers need to design, implement, and assess curriculum and instruction with technology (Niess, 2011). It emphasizes the interconnection of technology, pedagogy, and content knowledge that teachers must master before integrating technology into teaching and learning (Bakar et al., 2020; Koehler & Mishra, 2009).

Studies have shown that developing pedagogical content knowledge (PCK) is essential for successful technology integration, highlighting the importance of teachers acquiring PCK before incorporating technology into their teaching practices (Pamuk, 2012). By embracing TPACK, mathematics teachers can deepen their teaching and learning experiences across the curriculum, ensuring that educational outcomes in mathematics are effectively met (van Leendert et al., 2022). Research has shown that when teachers utilize TPACK, they can describe mathematical concepts effectively, motivate students to learn, provide opportunities for hands-on learning, assess student work, and facilitate communication of mathematical solutions (Casetama & Utami, 2023; Rohmitawati, 2018).

Studies have highlighted the importance of incorporating digital media and technology in mathematics teaching to enhance TPACK (Shibbriyah & Nuroh, 2023). While some research indicates that mathematics teachers have good pedagogical content knowledge, there is still room for improvement in utilizing digital media effectively during teaching practice activities (Aminah et al., 2020; Sari et al., 2024). Additionally, investigations into using TPACK when designing classroom activities, such as using GeoGebra software, have shown promising results in enhancing the quality of mathematics instruction (Kirikçilar & Yildiz, 2018). Furthermore, developing teachers' TPACK skills is essential for exploiting the potential of technology in mathematics education, especially in catering to diverse learning needs (van Leendert et al., 2022).

Assessing and enhancing mathematics teachers' TPACK is continuous (Blau et al., 2016). Studies have examined the relationship between teachers' beliefs and their TPACK, emphasizing the importance of aligning beliefs with student-centered learning and effective technology integration in mathematics education (Kim, 2018; Mensah et al., 2022). Moreover, research has explored the self-efficacy of mathematics teachers in integrating technology and

TPACK components, indicating a positive correlation between self-efficacy levels and the use of multiple software tools in teaching mathematics (Ardiç, 2021). By focusing on TPACK competencies and technology integration self-efficacy, teachers can develop a strong foundation for effective mathematics instruction (Bakar et al., 2020).

Long-term commitment is necessary for teachers to develop expertise in connecting pedagogy, content, and technology effectively, as proficiency in TPACK grows over time with practice and experience (Bakar et al., 2020). Teachers' ability to use TPACK has been found to vary, with research indicating that some educators still need more proficiency in utilizing TPACK to facilitate student learning (Kim, 2018). To enhance teachers' digital proficiency in integrating technology, frameworks like TPACK measure teachers' knowledge and guide their professional development in technology integration (Aslam et al., 2021).

Effective ICT integration requires teachers to gain proficiency in TPACK, which encompasses knowledge of technology, content, pedagogy, and their intersection (Beri & Sharma, 2019; Ndlovu & Mostert, 2018). The TPACK framework has provided educators with a theoretical foundation to unpack the complexity of technology integration and emphasizes the connections among technologies, curriculum content, and pedagogical approaches (Putri, Juandi, et al., 2024b; Redmond & Lock, 2019). By enhancing teachers' TPACK competence through reflective practice and scaffolded lesson design models, educators can improve their ability to integrate technology effectively into their lessons (Koh et al., 2017; Sari et al., 2021).

This article seeks to delineate the application of Technological Pedagogical Content Knowledge (TPACK) in the context of mathematics instruction for senior high school educators. Its primary objective is to offer insights that can enrich educational practices in Indonesia, particularly regarding advancing TPACK. Furthermore, it serves as a dependable resource for enhancing teachers' proficiencies, particularly in online pedagogy, thereby addressing the challenges of distance learning. TPACK, with its focus on the intersection of technology, pedagogy, and content knowledge, can help educators design practical online lessons that engage students and promote learning outcomes. The researcher then used the formulation of the research problem. How do educators effectively integrate technology, pedagogy, and content knowledge (TPACK) to enhance learning outcomes in the digital age?

## Methods

### Design study

This study employs a qualitative descriptive research design, incorporating survey methodology to gather comprehensive data. The qualitative approach allows an in-depth exploration of teachers' experiences and perceptions regarding TPACK integration in their instructional practices. By utilizing surveys, the research captures a broad spectrum of insights from a diverse group of mathematics teachers, ensuring a thorough understanding of the current state of technology integration. This methodological choice identifies critical trends, challenges, and opportunities in TPACK adoption, providing valuable information that can inform future professional development programs and educational strategies to enhance the effective use of technology in mathematics education.

## Participant

Conducted within senior high schools in West Sumatra, the study involved 36 students, providing a representative sample of the region's educational landscape. Including students from diverse backgrounds and academic abilities ensures a comprehensive perspective on the impact of TPACK integration on learning outcomes. This study also involved 15 mathematics teachers who completed an online questionnaire via Google Forms, and some of these teachers were further engaged in in-depth interviews. By focusing on a specific geographical area, the research offers insights into the local context and challenges students and teachers face in adopting technology in mathematics education. The research site is depicted in Figure 1.


**Figure 1**. Location of research

## Data collection and analysis

Data collection techniques encompassed: (1) literature review, gathering pertinent references from both print and digital media such as books, articles, and journals about Technological Pedagogical Content Knowledge (TPACK); (2) interviews, serving as a preliminary data collection method to identify research focal points; and (3) questionnaires, utilizing a series of written inquiries or statements for respondent feedback. The study employed three instruments: in-depth interviews, documentation, and online surveys conducted through Google Forms. In-depth interviews were conducted with three randomly selected teachers. Employing a qualitative phenomenological approach, the research aims to unveil participants' experiences within the context of TPACK from their perspectives. The interview focuses on exploring the application of TPACK, encompassing preparation, implementation, and evaluation stages.

Data acquisition occurred through the online dissemination of questionnaires via Google Forms to 15 educators across multiple schools. Interviews and observations were also conducted and transcribed verbatim to ensure accuracy. Thematic analysis was used to examine the interview data. This process began with thoroughly reading the transcripts to familiarize the researcher with the content. Next, the data were systematically coded by labeling text segments with tags summarizing key points. These codes were then grouped into broader categories representing significant themes related to the use of technology in mathematics education. The themes were reviewed and refined to ensure they accurately reflected the data. Finally, the themes were clearly defined and organized into a coherent narrative, providing insights into how educators in West Sumatra integrate technology into their mathematics teaching practices. This analysis highlighted the main challenges and successes experienced by these educators (Clarke & Braun, 2013).

## Results

The TPACK framework is a theoretical model for researchers to assess teachers' and teacher candidates' readiness to use technology effectively in education. TPACK significantly impacts teachers, as technology, pedagogy, and content are interdependent. Consequently, teachers must navigate the evolving landscape of technology, pedagogy, learning materials, and classroom content. The study indicates that high school mathematics teachers exhibit varying proficiency levels in integrating Technology, Pedagogy, and Content Knowledge (TPACK). The results are illustrated in Figure 2 below.

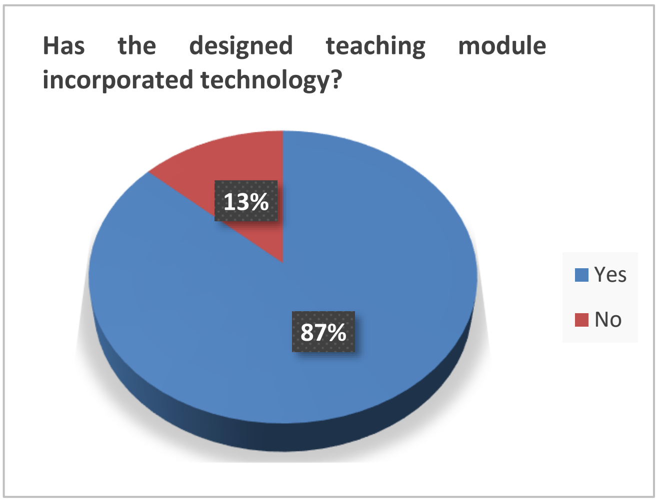


**Figure 2**. Teachers' response to the use of technology in designing teaching modules.

The questionnaire results show that more than 80% teacher had incorporated technology in creating teaching modules or lesson plans. This high percentage reflects the teachers' awareness and readiness to utilize technology as an instructional tool. It demonstrates their commitment to enhancing the educational experience by integrating digital tools and resources into their teaching strategies. Moreover, this technology adoption signifies a shift towards more modern and flexible teaching methods, which can cater to diverse learning styles and improve student engagement and learning outcomes. The questionnaire results show the types of media teachers use in the online and offline mathematics teaching process, as shown in Figure 3.

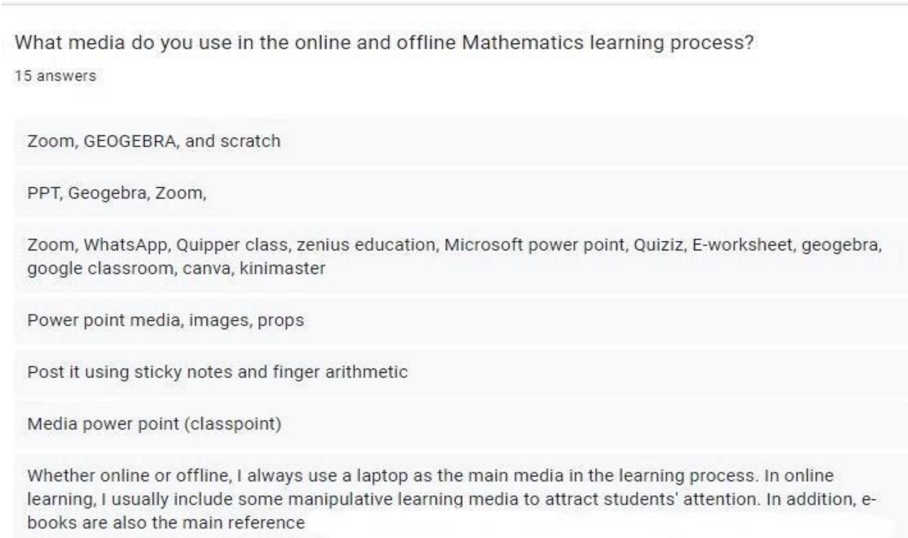


**Figure 3**. Types of media used by teachers

Based on Figure 3, it is evident that teachers employ various technologies in their teaching. These include applications such as Zoom, GeoGebra, Scratch, PowerPoint, Quipper Class, WhatsApp, Zenius Education, Quizizz, Google Classroom, Canva, and Kinemaster, among others. Using these diverse tools demonstrates the teachers' adaptability and willingness to integrate multiple forms of technology to enhance the learning experience. Zoom and Google Classroom facilitate virtual and hybrid learning environments, ensuring continuous education despite physical distance. GeoGebra and Scratch are instrumental in teaching mathematical and coding concepts interactively, making complex subjects more accessible and engaging for students.

Applications like PowerPoint, Canva, and Kinemaster enable the creation of visually appealing and dynamic presentations and educational content. Platforms like Quipper Class, Zenius Education, and Quizizz provide structured learning modules and interactive quizzes, supporting synchronous and asynchronous learning. WhatsApp is a communication tool that ensures that teachers and students remain connected and can share resources efficiently. This variety of technological tools highlights teachers' multifaceted approach to cater to different learning needs and preferences, aiming to improve student engagement and educational outcomes.

Based on the classroom observation results, it can be concluded that the mathematics teachers have implemented the TPACK approach, encompassing the processes of planning, implementation, and assessment. Teachers' use of technology in the classroom manifests in several forms. For instance, teachers employ educational videos as introductory hooks to capture students' interest and provide initial insights into the lesson's topic. These videos effectively present mathematical concepts more visually and interactively, making it easier for students to grasp the material. Additionally, software like GeoGebra explains complex geometric and algebraic concepts dynamically and interactively. GeoGebra facilitates the visualization of graphs and geometric shapes, allowing students to observe changes and relationships in real-time. PowerPoint is also employed to create systematic and engaging presentations, helping teachers deliver content in a structured manner and support student understanding through compelling visual aids.

Teachers who successfully integrate TPACK report a significant increase in student engagement and improved learning outcomes. Students respond positively to technology-enhanced lessons, which help make abstract mathematical concepts more concrete and accessible. For example, Geogebra's dynamic visualizations and interactive PowerPoint presentations enhance student interest and comprehension. Furthermore, technology integration enables formative assessment and immediate feedback, providing teachers with insights into student progress and difficulties for more tailored and practical instruction.

Despite the high rate of technology adoption, several challenges impede the effective integration of TPACK. One major challenge is limited access to adequate technological resources. The findings from the interviews conducted with teachers are as follows: In the transcripts, "R" stands for the researcher, and "T" stands for the teacher.

R: I am researching teachers' challenges in integrating technology into mathematics instruction. Could you share some of your experiences in this regard?

T: One of the main challenges I encounter is access to adequate technology resources. Our school has limited devices, and sometimes, they are not up-to-date or compatible with the software we need for mathematics activities.

R: So, the availability and quality of technology tools are significant hurdles. Are there any other obstacles you have faced?

T: Definitely. Even when we have access to technology, there is often a learning curve for both the students and me. Learning to use new software or apps effectively takes time, and it can be challenging to integrate them seamlessly into the curriculum without disrupting the lesson flow.

R: So, ongoing training and support are needed to help teachers and students navigate these tools more efficiently. Are there any specific strategies or resources you find helpful in overcoming these challenges?

T: Yes, professional development workshops and online tutorials have benefited me.

The interviews with teachers reveal that while technology integration in mathematics instruction offers significant benefits, such as increased student engagement and enhanced understanding of complex concepts, it also presents challenges. Key hurdles include limited access to up-to-date technology, the learning curve associated with new tools, insufficiently tailored professional development, and time constraints. Addressing these challenges requires a more targeted approach to training, improved access to resources, and strategies that allow for the seamless integration of technology into the curriculum without disrupting lesson flow.

## Discussion

The TPACK framework is designed to integrate technology into teaching by encompassing three primary knowledge areas: Technological Knowledge (TK), Content Knowledge (CK), and Pedagogical Knowledge (PK) (Hayati & Zaim, 2024). These knowledge domains interact dynamically (Koehler, M. J et al., 2013), as illustrated in Figure 4.

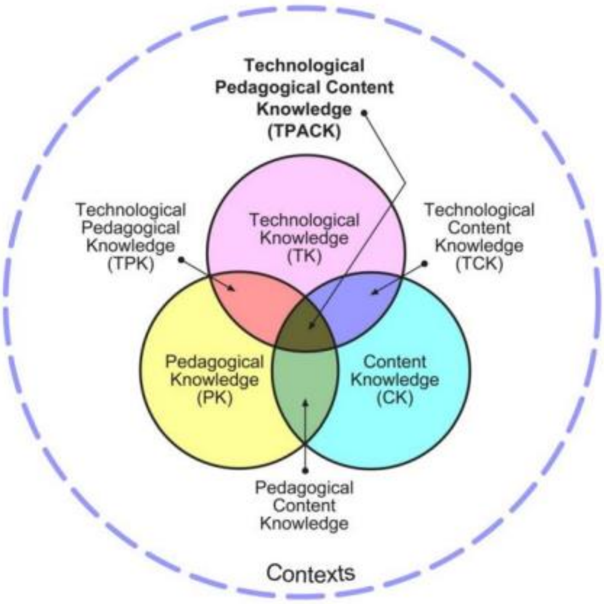


**Figure 4.** Flowchart depicting the Selection of Studies

Technological Knowledge (TK) refers to utilizing computer software, hardware, presentation tools, and traditional and contemporary educational technologies. This skill is crucial for keeping pace with current technological trends (Fayakuun & Agoestanto, 2023). Content Knowledge (CK) involves an in-depth understanding of specific subjects or learning materials. Teachers who master CK can effectively address specific problems, applying suitable approaches to meet particular educational needs. Pedagogical Knowledge (PK) pertains to managing and organizing teaching materials and activities to achieve learning objectives (Marsitin & Sesanti, 2023).

Combining these, Pedagogical Content Knowledge (PCK) merges content expertise with pedagogical strategies, focusing on how topics, problems, and issues are organized, presented, and adapted to suit students' varying abilities and interests (Koh et al., 2017). Technology Content Knowledge (TCK) explores the relationship between technology and content, offering innovative methods to present engaging learning materials that were previously difficult to achieve through traditional approaches. Technology Pedagogical Knowledge (TPK) examines the interaction between technology and pedagogy, guiding teachers in selecting appropriate digital tools and methods to meet pedagogical goals (Joubert et al., 2020). Technology Pedagogical Content Knowledge (TPACK) synthesizes TK, CK, PK, PCK, TCK, and TPK, emphasizing technology integration to fulfill pedagogical needs and effectively teach specific subjects.

This study emphasizes the importance of the TPACK framework in evaluating teachers' readiness to integrate technology into their teaching practices effectively. TPACK highlights the interconnectedness of technology, pedagogy, and content, showing that successful education in the digital era requires a balanced combination of these elements. The findings reveal that high school mathematics teachers have varying proficiency levels in applying TPACK, indicating diverse challenges and opportunities.

Most teachers (over 80%) have successfully incorporated technology into their lesson plans, signaling a solid commitment to modernizing teaching methods. The wide range of tools used, including Zoom, GeoGebra, PowerPoint, and Google Classroom, demonstrates teachers' adaptability and efforts to cater to different learning needs. These technologies have positively impacted student engagement, making complex mathematical concepts more accessible and enhancing overall learning outcomes.

However, the integration of TPACK is challenging. Teachers face issues such as limited access to up-to-date technology and the steep learning curve associated with new tools (Rohmitawati, 2018). Additionally, ongoing professional development is necessary to ensure teachers can effectively use technology without disrupting the learning process. In summary, while technology integration through TPACK has clear benefits, overcoming challenges like resource limitations and the need for continuous training is crucial for maximizing its potential in improving student engagement and learning. Teachers in underfunded schools report insufficient device availability and unreliable internet connectivity, which hinders optimal technology implementation. Therefore, government support should facilitate the provision of the Internet and devices that support technology integration in mathematics learning (Willermark, 2018).

Another challenge is the varying levels of teachers' confidence and competence in using technology (Voogt et al., 2013). While most teachers have embraced technology, some need help to keep up with rapid technological advancements and express the need for continuous support and training. It suggests that one-off professional development sessions are insufficient; a continuous and structured approach to professional learning is essential (Atun & Usta, 2019). By addressing these challenges with sustained and targeted support, professional development programs can more effectively build teachers' capabilities and confidence in utilizing technology, ultimately leading to improved educational outcomes (Koehler, M. J et al., 2013; Niess, 2011).

The findings underscore the necessity for comprehensive professional development programs that address all components of TPACK (Juhaevah & Kaliky, 2023). Effective programs should include regular workshops and hands-on training sessions on the latest educational technologies. These workshops should introduce new tools and provide practical experience in using them. Additionally, sharing best practices and innovative teaching strategies that leverage technology to enhance mathematical instruction is crucial (Fitriya et al., 2023). Establishing professional learning communities where teachers can share experiences, challenges, and solutions related to TPACK integration will foster a collaborative environment for continuous improvement (Cengiz, 2015). Furthermore, ongoing coaching and mentoring will help teachers stay updated with technological advancements and integrate them effectively into their teaching. This ongoing support is essential for maintaining the momentum of technology integration and ensuring that teachers can adapt to new developments in educational technology (Ertmer et al., 2012).

The primary conclusion of this study is that implementing the TPACK framework in secondary mathematics education has achieved notable success in technology integration. However, it also reveals challenges related to resource limitations and the need for ongoing professional development. The implications are twofold: There is a pressing need for sustained and targeted professional development programs to enhance teachers' technological skills and pedagogical strategies, and government support is crucial in providing adequate technological infrastructure. Addressing these issues will enable teachers to overcome obstacles and fully leverage technology to improve student learning outcomes.

## Conclusion

This study highlights that teachers have effectively integrated technology into the learning process using various technological tools and resources, such as instructional videos, Geogebra, Canva, and PowerPoint, to present mathematical concepts interactively and engagingly. Technology integration provides opportunities to enhance student engagement, strengthen understanding of mathematical concepts, and offer a more dynamic and enjoyable learning experience—the significance of the TPACK framework in evaluating teachers' readiness to integrate technology effectively into teaching. The findings show that high school mathematics teachers demonstrate varying proficiency levels in applying TPACK, indicating diverse challenges and opportunities in technology integration.

This study has several limitations. First, data collection relied on self-reported questionnaires and interviews, which may not fully capture the depth of teachers' TPACK integration and could introduce bias if teachers overestimate their proficiency. Additionally, the study was limited to high school mathematics teachers in West Sumatra, limiting the findings' generalizability to other regions, subjects, or educational levels. The implications of this study are significant for educational practice and policy. Despite the challenges identified, adopting high technology suggests that teachers are committed to modernizing their teaching practices. To fully leverage the benefits of TPACK, targeted professional development programs addressing both technological and pedagogical aspects are needed. Furthermore, improving access to up-to-date technological resources in schools is crucial. Educational policymakers should prioritize funding and support for technology infrastructure and continuous training to ensure effective technology integration.

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### Conflicts of Interest

There is no conflict of interest in publishing this material.

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## Author Contributions

**Amelia Defrianti Putri:** Conceptualization, writing - original draft, editing, and visualization; **Dadang Juandi:** Validation and supervision; **Al Jupri:** Validation and supervision; **Turmudi:** Validation and supervision; **Sitti Busyrah Muchsin:** Resources and data curration.

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