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Literature Review on the Application of the TPACK Model in 21st Century Learning

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Abstract: This systematic literature review explores the implementation of the Technological Pedagogical Content Knowledge (TPACK) framework in 21st-century education, based on an analysis of 20 peer-reviewed journal articles published between 2018 and 2024. The TPACK framework integrates technological knowledge with pedagogical and content knowledge, offering a holistic model for teachers to design effective, technology-enhanced learning experiences. This study aims to identify how TPACK is developed, applied, and evaluated across various educational levels, and to highlight its impact on teaching practices and student learning. The review reveals that the TPACK framework contributes significantly to improving teacher competencies, particularly in their ability to align appropriate technologies with specific learning objectives and instructional strategies. Professional development programs that incorporate collaborative design, reflective practice, and microteaching with digital tools have shown to be effective in fostering TPACK among both pre-service and in-service teachers. Despite its benefits, challenges such as limited infrastructure, inadequate training, and time constraints often hinder the full implementation of TPACK in classroom settings. Findings also suggest that successful TPACK integration leads to higher student engagement, improved learning outcomes, and more personalized and interactive instructional approaches. However, the effectiveness of TPACK depends greatly on contextual factors, including school support, teacher readiness, and the relevance of training content. This review highlights the need for sustainable and context-sensitive TPACK development strategies to support teachers in navigating the demands of digital-era education.

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INTRODUCTION

In the evolving landscape of 21st-century education, integrating technology into teaching and learning is no longer optional—it is essential. The increasing demand for digitally competent educators has prompted a growing focus on frameworks that support meaningful and pedagogically sound technology use. One of the most prominent frameworks addressing this need is Technological Pedagogical Content Knowledge

(TPACK), introduced by Mishra and Koehler (2015), which emphasizes the intersection of teachers' content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). The framework has since been widely adopted in teacher education and professional development programs globally (Voogt et al., 2016; Wang et al., 2018).

TPACK offers a comprehensive structure for teachers to make informed decisions about selecting and integrating technological tools that align with both instructional goals and student needs. Its importance has grown with the increased use of online learning platforms, blended learning models, and digital assessments. Recent studies have demonstrated the positive impact of TPACK-oriented training on improving teachers' self-efficacy, digital literacy, and instructional design practices (Baran et al., 2020; Zhang & Zhou, 2023). Moreover, TPACK development has been shown to enhance student engagement and learning outcomes when implemented effectively (Sun, 2021; Yeh et al., 2021).

Despite its potential, challenges in applying TPACK persist. Limited infrastructure, time constraints, and fragmented teacher training programs often prevent teachers from integrating all three knowledge domains effectively (Papadakis et al., 2024; Chai et al., 2019). Some educators still struggle to move beyond basic tool usage toward transformative learning experiences that leverage technology to support active learning, collaboration, and higher-order thinking (Gökçe & Gülsün, 2021; Cordova & Chiang, 2022). Given the importance of equipping teachers with the skills to integrate technology meaningfully, this article presents a systematic literature review of 20 peer-reviewed studies published between 2015 and 2024. The objective is to explore how the TPACK framework is implemented, what professional development strategies are most effective, what challenges are encountered in real classroom settings, and how TPACK influences both teaching practices and student learning.

The article is organized as follows: the next section outlines the methodology of the literature review, followed by a synthesis of key findings categorized thematically. The discussion section interprets these findings in light of current trends in teacher education and digital pedagogy. Finally, the article concludes with recommendations for practice and future research.

METHOD

This study employs a systematic literature review (SLR) approach to investigate how the Technological Pedagogical Content Knowledge (TPACK) framework is applied in 21st-century teaching practices. The goal of this review is to synthesize findings from existing research that explore the development and implementation of TPACK in various educational contexts, particularly focusing on its impact on teacher competencies and instructional quality.

Literature Search Strategy

The literature search was conducted across reputable academic databases, including Scopus, ERIC, Web of Science, and Google Scholar, using keywords such as "TPACK framework," "technology integration in education," "teacher knowledge and digital pedagogy," and "TPACK in science/mathematics education". The inclusion criteria for article selection were as follows: Published between 2018 and 2024; Peer-reviewed and indexed in international databases (Scopus, WoS, or ERIC); Empirical or conceptual studies focused on TPACK implementation or development; Articles written in English; Research conducted in formal education settings (K–12 or higher education). Articles were excluded if they (1) did not clearly address TPACK, (2) were opinion-based without empirical or structured conceptual grounding, or (3) were duplicate studies. After initial screening and full-text analysis, 20 articles were selected that met the inclusion criteria and were subjected to in-depth review and synthesis.

Data Analysis Procedure

The selected articles were analyzed using a qualitative thematic synthesis approach. The analysis process involved:

1. Data extraction: Key information from each study was identified, including research design, context, focus area (e.g., teacher development, lesson planning), and main findings.

2. Coding and categorization: Studies were grouped into thematic categories such as TPACK development strategies, impact on teaching performance, challenges in implementation, and educational levels.
3. Narrative synthesis: A descriptive analysis was conducted to highlight emerging trends, common challenges, and implications for teacher training and policy.

This method allows for a comprehensive understanding of how the TPACK framework is being applied in contemporary educational practice, as well as providing insights into best practices and areas requiring further research.

RESULT AND DISCUSSION

The analysis of 20 peer-reviewed studies published between 2015 and 2024 confirms the pivotal role of the Technological Pedagogical Content Knowledge (TPACK) framework in supporting effective technology integration across educational levels. Four major themes emerged from the synthesis: (1) the effectiveness of TPACK in enhancing teacher competence, (2) strategies for professional development, (3) implementation barriers, and (4) impacts on student learning.

TPACK Enhances Teacher Competence

Multiple studies report that TPACK contributes substantially to the development of teachers' confidence and capability in designing meaningful technology-integrated instruction. Teachers with strong TPACK knowledge can make pedagogically informed choices about digital tools that align with content-specific goals (Mishra & Koehler, 2015; Wang et al., 2018). For instance, Baran et al. (2020) found that teachers who engaged in structured online TPACK training demonstrated significant improvements in integrating technology with classroom strategies.

Moreover, Sun (2021) showed that science teachers with well-developed Technological Pedagogical Content Knowledge (TPACK) were more effective in promoting inquiry-based learning and utilizing digital simulations to explain abstract scientific concepts. These findings emphasize that teachers who are proficient in integrating technology with pedagogical strategies and subject content are better positioned to foster student engagement and deeper understanding. Such integration allows for the creation of more dynamic, interactive, and student-centered learning environments, which are particularly beneficial in addressing the complexities of scientific inquiry and abstract reasoning.

Similar findings by Gökçe and Gülsün (2021) further underscore the significance of aligning technological tools with appropriate pedagogical approaches and curricular content, especially in the context of STEM education. They argue that the successful application of educational technology depends not merely on access to digital tools but also on the teacher's ability to strategically embed these tools within the learning process. In this regard, professional development that strengthens TPACK competencies becomes crucial for equipping educators to make informed decisions about when, how, and why to integrate technology in ways that enhance conceptual understanding and support 21st-century learning outcomes.

Professional Development Strategies for TPACK

Successful TPACK development depends heavily on the quality of teacher training. Collaborative, reflective, and hands-on approaches were consistently found to be more effective than lecture-based methods (Cordova & Chiang, 2022; Zhang & Zhou, 2023). Papadakis et al. (2024) emphasized that early childhood educators significantly benefited from STEM-integrated robotics programs guided by TPACK principles. Furthermore, Chai et al. (2019) illustrated that programs in Finland and Singapore fostered TPACK growth through iterative design tasks, peer mentoring, and lesson co-design. These findings suggest that TPACK is best cultivated in professional learning environments that promote active experimentation, contextual adaptation, and continuous feedback.

Challenges in TPACK Implementation

Despite its benefits, the implementation of TPACK faces several obstacles. Many teachers report difficulties in accessing digital tools or receiving ongoing institutional support, particularly in under-resourced schools (Voogt et al., 2016; Yalçın & Yayla, 2016). Time constraints, lack of

confidence, and fragmented professional development also limit the ability to integrate technology holistically (Li et al., 2023). Additionally, Baturay and Karadeniz (2018) found that while teachers may possess basic technological skills, they often struggle to align these tools with meaningful pedagogy. This highlights the need for training that addresses the integrated nature of TPACK rather than treating technology as a separate domain.

TPACK's Impact on Student Learning

Studies also affirm that effective TPACK implementation correlates with enhanced student outcomes. Yeh et al. (2021) found that students in TPACK-informed classrooms demonstrated increased engagement and higher levels of collaboration and problem-solving. Similarly, Amistia and Bukit (2020) showed that elementary students exhibited improved conceptual understanding and motivation when taught by teachers with strong TPACK competence. Niess (2019) suggested that TPACK also encourages teachers to adopt systems thinking and computational modeling, which are essential for developing students' critical thinking and digital literacy in science and mathematics. Overall, the literature indicates that TPACK provides a robust framework for guiding teachers through the complex process of integrating technology into pedagogy and content. However, its success depends not only on individual teacher effort but also on supportive ecosystems, including leadership, infrastructure, and collaborative cultures within schools (Angeli & Valanides, 2019).

CONCLUSIONS

The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section. The conclusion in an article should be concise, focused, and reflect the core discussion. An ideal conclusion includes a summary of the main findings or arguments presented in the article, the relevance of those findings within the broader research context or issue, the implications derived from the results, and suggestions for further research or action. The conclusion does not need to repeat the entire content of the article but should highlight the key points. This allows readers to grasp the article's main contributions in a brief and clear manner.

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AUTHOR CONTRIBUTIONS

Conceptualization, M. Alhafizin and Abelia Berliana Casandra; methodology, M. Alhafizin; data curation, M. Alhafizin; formal analysis, M. Alhafizin; investigation, M. Alhafizin and Abelia Berliana Casandra; writing original draft preparation, M. Alhafizin; writing review and editing, Abelia Berliana Casandra; visualization, Abelia Berliana Casandra; supervision, Abelia Berliana Casandra; project administration, M. Alhafizin. All authors have read and agreed to the published version of the manuscript..

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CONFLICTS OF INTEREST

Declare conflicts of interest or state "the authors declare no conflict of interest." Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. Any role of the funders in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section. If there is no role, please state "the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results"

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