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Trends and Directions of TPACK Research in Education: A Thematic Analysis of 26 Scopus-Indexed Articles from 2021–2025

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Abstract: This study aims to analyze the development of themes and focus of studies in recent research using the Technological Pedagogical Content Knowledge (TPACK) framework in the field of education. A total of 600 initial documents with the keyword "TPACKFramework" were retrieved from the Scopus database, then filtered based on the year of publication (2021–2025), document type (article), language (English), open access, and content relevance. A further filtering process was carried out through the rayyan.id platform by removing review-type articles and selecting only articles that explicitly discuss TPACK in the context of education. The final results of 26 articles were further analyzed using a thematic analysis approach to identify key patterns and emerging scientific trends. Data visualization was performed using VOSviewer software to map relationships between keywords, theme clusters, and temporal dynamics. The results show that TPACK has developed into an operational framework in teacher training, STEM education, and the integration of digital learning at various levels of education. Furthermore, the emergence of derivative approaches such as DPACK and AI-TPACK demonstrates the evolution of concepts in response to the increasingly complex needs of technology-based learning. Studies also show that mastery of TPACK has a direct impact on improving critical thinking skills, creativity, and innovation in both teachers and students. This study concludes that the direction of TPACK research is shifting from emergency pandemic responses to more adaptive, technology-based long-term learning designs.

Keywords: Bibliometric visualization; Education; Technology integration; TPACK; Scopus

Introduction

The challenges faced in Indonesia relate to the low quality of education as a means of developing human resources. Rapid technological developments have had a significant impact on various sectors of life, including education. In education, technology integration is no longer an option but an urgent necessity to provide learning that is more relevant to the demands of the digital era. Furthermore, according to (Falani, 2023), digital literacy aims to improve skills in reading, analyzing, and utilizing information in the digital environment (Big Data). One framework currently widely used to guide the process of technology integration in learning is TPACK (Technological Pedagogical Content Knowledge), first proposed by (Kusaini et al., 2022). This framework combines three key knowledge domains required for modern educators: content knowledge, pedagogical knowledge, and technological knowledge.

In Indonesia, attention to the development of TPACK (Teacher-Based Competency-Based Competency-Based Competency) is increasing, particularly in the context of teacher education. Teacher readiness in TPACK-based learning is crucial for effectively integrating technology into educational practice, particularly in the context of 21st-century learning. Mastery of TPACK is crucial for prospective teachers to engage effectively in digital learning environments, as it enables them to create innovative learning media and integrate technology into their teaching practices (Rosmaladewi et al., 2023). Training programs based on the TPACK framework have been shown to significantly improve teachers' digital skills,

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enabling them to effectively integrate technology into their teaching practices. These programs are designed to meet diverse needs and address barriers to implementing digital training (Oktaviani & Utami, 2024).

Research by (Mustadi et al., 2024), shows that the TPACK-based flipped classroom learning model (FC-TPACK) can significantly improve the critical and creative thinking skills of prospective elementary school teachers. In this study, the use of FC-TPACK not only shifted the lecturer's role from teacher to facilitator but also enabled students to more actively explore learning materials independently before face-to-face sessions. MANOVA test results indicated that this model had a significant impact on the development of higher-order thinking skills, which are crucial in 21st-century learning contexts. Other research in Indonesia also reinforces the urgency of TPACK implementation. For example, (Sulistyarini et al., 2022), in the International Journal of Multicultural and Multireligious Understanding examined the correlation between teachers' TPACK mastery and students' innovative skills and found that improving the quality of teachers' TPACK positively impacted student engagement and creativity.

Referring to the analysis of 26 previously screened articles, it is clear that TPACK is not only a theoretical tool but also an operational framework that can be applied in various educational contexts. With the help of technology and the right pedagogical approach, teachers can adapt learning to be more interactive, contextual, and meaningful for students. Therefore, further comprehensive studies are needed to understand the dynamics of TPACK implementation in local and global contexts and to identify challenges and opportunities for its future development.

Method

This study used a descriptive qualitative approach with document analysis to systematically review 26 scientific articles focusing on the implementation and development of TPACK in education, both nationally and internationally. Document analysis was chosen because it allows for in-depth exploration of information, trends, and empirical findings from various relevant studies. As explained by (Braun & Clarke, 2006), document analysis is a systematic process of reviewing or evaluating documents, both printed and electronic, that contain factual or interpretive data. The data for this study was obtained through the Scopus platform, using the single keyword "TPACKFramework." The initial search yielded 600 documents. After filtering based on the years 2021 to 2025, the number of documents was narrowed to 313. Of these, the focus was solely on articles (229 documents), journals (228 documents), English-language sources (225 documents), and open access sources (137 documents).

The searched documents were then downloaded in RIS format and uploaded to the rayyan.id platform for further screening. The first stage involved an exclusion process, which filtered documents that fell into the categories of review articles, literature reviews, and systematic reviews. Next, articles that explicitly discussed TPACK in an educational context were included, determined based on a review of titles and abstracts. This process yielded 26 articles deemed relevant and used as the primary data in this study. Each article was analyzed using a thematic approach to identify patterns, key issues, and theoretical and practical contributions of each study. This step refers to the thematic analysis method, which involves data familiarization, initial coding, theme grouping, review, and report writing. To strengthen the results, visual analysis was also conducted using VOSviewer software to map keyword relationships, term frequencies, and temporal trends in the collected TPACK research.

The use of this method is supported by several similar studies. For example, in the context of FC-TPACK to measure the impact on students' critical and creative thinking skills. The Indonesian Journal of Social Sciences Education (SINTA 3) applied bibliometric analysis to examine research trends on the influence of problem-based learning models on critical thinking skills in social studies learning. This research also refers to a similar systematic model to connect thematic narratives with scientific visualization results. With this approach, it is hoped that the research will provide a comprehensive overview of the development of TPACK research, dominant thematic directions, practical contributions to educational practice, and potential for further development in the ever-changing digital era.

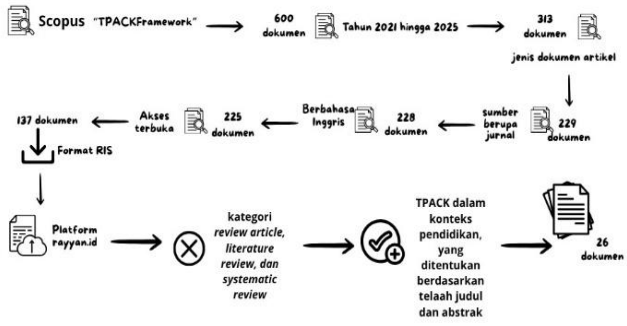

Figure 1. Search Results and Article Selection

Results and Discussion

The TPACK (Technological Pedagogical Content Knowledge) approach has become a key theoretical

framework in educational research, particularly in the context of teacher training, technology integration, and 21st-century pedagogical transformation. A screening of 26 recent articles (2021–2025) reveals how this approach has been implemented, developed, and critiqued in an international context. These articles utilize a variety of methods, including quantitative surveys and mixed methods research, and autoethnographic reflection. This study not only discusses key trends in TPACK implementation but also integrates VOSviewer-based visualization analysis from three perspectives: term density, term relationship networks, and temporal evolution of terms (overlay).

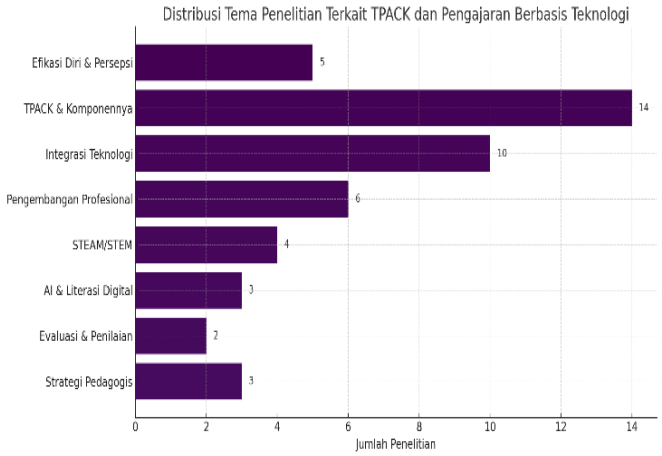

Figure 2. Distribution of research themes on TPACK and Technology-Based Teaching.

The Technological Pedagogical Content Knowledge (TPACK) framework has become a major focus in educational research, particularly in the context of technology integration in science learning. Based on an analysis of 26 recent scientific articles, several major themes can be identified that reflect current research trends and focuses. These themes include the development of TPACK and its components, technology integration, teacher self-efficacy and perceptions, professional development, STEAM/STEM learning, digital literacy and artificial intelligence (AI), pedagogical strategies, and evaluation and assessment. The most dominant theme emerging from this literature review is the development of TPACK and its components, which is the main focus in 14 studies (Aumann et al., 2024); (Gromik et al., 2023); (Hirsch & Rubach, 2024); (Jiménez Sierra et al., 2024); (Kotzebue et al., 2021); (Kyi et al., 2023a); (Polly, 2024a); (Rakes et al., 2022); (Sofwan et al., 2023); (Stinken-Rösner et al., 2023a); (Thyssen et al., 2023); (Villa et al., 2023); (Wollmann & Lange-Schubert, 2022). These studies demonstrate how TPACK serves not only as a conceptual framework but also as a practical guide for developing comprehensive technology-based teaching skills.

Furthermore, technology integration was a significant theme in 10 studies (Cowart & Jin, 2024); (Krug et al., 2023); (Mäkipää et al., 2022); (Mansour et al., 2024a); (Meletiou-Mavrotheris & Paparistodemou, 2024); (Saeed Al-Maroof et al., 2020); (Shin & Kim, 2024); (Stinken-Rösner et al., 2023b). These findings confirm that the success of technology-based teaching depends not only on mastery of TPACK but also on its practical implementation in complex and diverse classroom contexts. Teacher self-efficacy and perceptions were also addressed in five studies (Runge et al., 2025). These studies underscore the importance of teacher confidence in using technology as a crucial factor in the adoption and successful integration of technology.

Meanwhile, professional development was a frequently discussed topic in six articles (DeVaul et al., 2023); (Polly, 2024b). These studies demonstrate that effective training, whether in the form of online courses, blended learning, or context-based training modules, is crucial for equipping teachers with relevant TPACK skills. The STEAM/STEM theme emerged in four studies (Kyi et al., 2023b); (Mansour et al., 2024b); demonstrating the growing interest in interdisciplinary approaches that integrate science, technology, engineering, the arts, and mathematics through a TPACK lens. Three other studies highlighted the importance of digital literacy and artificial intelligence (AI) in higher education contexts (Al-Abdullatif, 2024); (Nantha et al., 2024). This demonstrates a shift in research direction toward contemporary issues that require teachers not only to understand technology but also to be able to teach and use it critically.

The themes of pedagogical strategies and evaluation/assessment emerged in three and two studies, respectively (Lam et al., 2024). These findings indicate that while TPACK is important, its success also depends on appropriate teaching strategies and evaluation systems that support technology-based practices. Overall, the results of this study confirm that TPACK continues to evolve as a conceptual and practical foundation for teacher professional development, technology integration in teaching, and the formulation of innovative and contextualized learning strategies. This provides an important foundation for building a conceptual framework for research on the relationship between self-efficacy, TPACK mastery, and STEAM implementation in science education contexts. The following graph shows the distribution of publications by year of study.

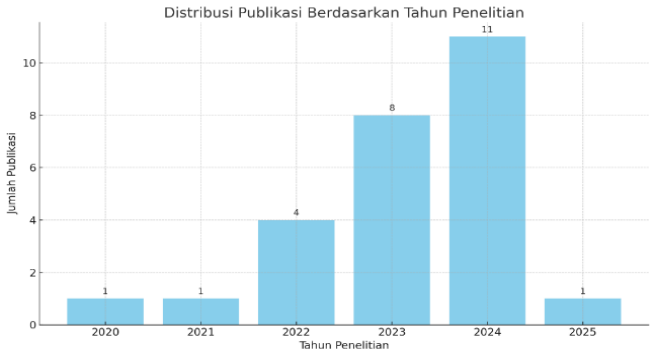

Figure 3. Distribution of Publications by Research Year.

According to collected data, 2024 was the year with the highest number of publications, with 11 publications. This reflects the increasing attention and interest of researchers in topics related to TPACK and educational technology during that year. The trend of increasing publications began to emerge in 2020, with a significant spike occurring from 2020 to 2024, marking the beginning of a positive trend in the exploration and implementation of TPACK in educational contexts. 2023 also showed quite high research activity, reflected in eight publications. Meanwhile, the number of publications from 2020 to 2022 was still relatively low, but it does indicate growing interest in research in this area. For 2025, there has only been one publication to date, which is understandable given the ongoing year and the likelihood of continued growth. Most articles indicate that TPACK is used to understand how teachers (both pre-service and in-service) integrate technology into their teaching practices.

For example, (Sawiji, 2024) showed that technology self-efficacy, ease of use, and organizational support significantly influence teachers' and students' intention to continue using e-learning. Studies like this demonstrate the importance of both technical and psychological elements in the successful implementation of technology. (Thoms et al., 2022), emphasized the importance of digital competence in science education through the DiKoLAN framework. They demonstrated that Technological Pedagogical Knowledge (TPK) played a more significant role in predicting TPACK than other components such as Technological Content Knowledge (TCK). This is consistent with the findings of (Nugroho Yanuarto et al., 2021), who revealed that the strongest relationship in structural modeling occurred between TPK and TPACK, reinforcing TPK's position as a key pillar in effective technology integration. Several studies have specifically examined the application of TPACK in STEM, science, and mathematics education. (Mailizar et al., 2020), examined the integration of technology in mathematics learning during the pandemic. They found that despite improvements in mathematics teaching practices, TPACK gains were not significant, suggesting a need for more explicit training. The I DiG STEM project demonstrated that digital game-based learning (DGBL) can strengthen TPACK-G (TPACK for Games). This study opens up new dimensions of how digital game-based pedagogical approaches can foster student engagement in STEM learning.

Nearly half of the articles in this review highlight the importance of integrating TPACK from pre-service education. For example, (Soini et al., 2021) found that pre-service teachers in Finland have positive perceptions of distance learning and have a good grasp of digital pedagogy. However, older teachers face greater challenges, indicating a generational gap in technology mastery. Studies such as (Annida Lathifa Riandy Putri et al., 2023)demonstrate how TPACK can be implemented in practice. However, Polly notes that school context and culture significantly influence the effectiveness of TPACK implementation. Meanwhile, Aumann found a tension between TPACK-based planning and actual implementation, where pre-service teachers tended to focus on technology while neglecting content. One significant finding from this analysis was the emergence of new terms such as DPACK (Digitality-related Pedagogical and Content Knowledge) and AI-TPACK (Artificial Intelligence-informed TPACK). (Abubakir & Alshaboul, 2023), introduced DPACK as an evolution of TPACK to accommodate digital transformation and sociocultural aspects.

Meanwhile, (Tan et al., 2025) examined the integration of AI in teacher education and found that participation in AI training positively contributed to AI-TPACK and perceptions of the usefulness of intelligent technology. These developments demonstrate that the TPACK framework is not static. It evolves along with the ever-changing complexity of technology and social contexts. This requires educational institutions to continuously adapt teacher training to the latest technological developments.

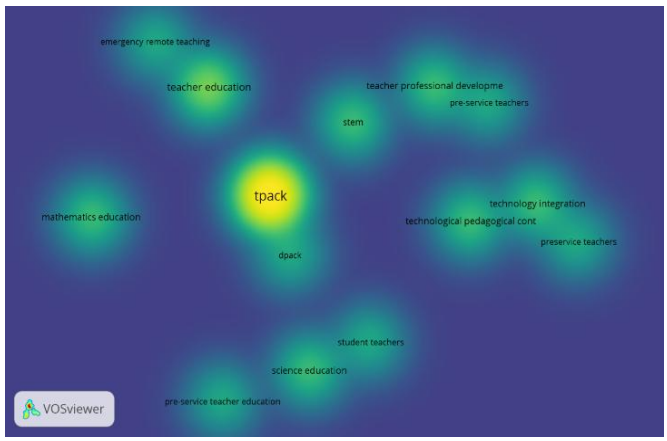

Figure 4. TPACK Article Density Visualization sourced from Scopus

The Density Map visualization places "TPACK" as the most dense point on the term map. This term is surrounded by "teachers," "teacher education," "professional development," and "technology integration," which also appear with high intensity. This density confirms that TPACK is at the heart of the technology discourse in education.

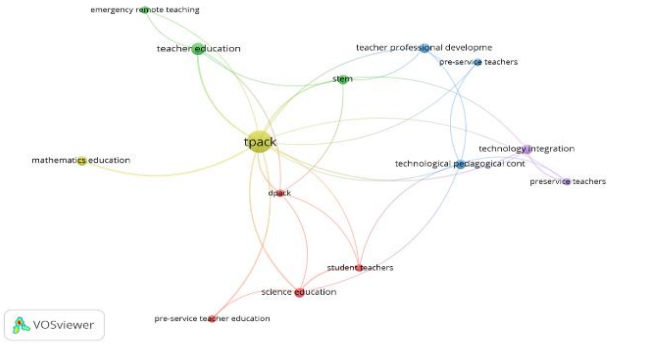

Figure 5. Network Visualization of TPACK Articles sourced from Scopus

The Network Visualization shows the division of color clusters representing research domains. The red cluster contains terms related to science and digital science, the green cluster focuses on mathematics education and instructional design, the blue cluster on pre-service teachers and technology integration, and the purple cluster reflects teacher innovation and professionalization.

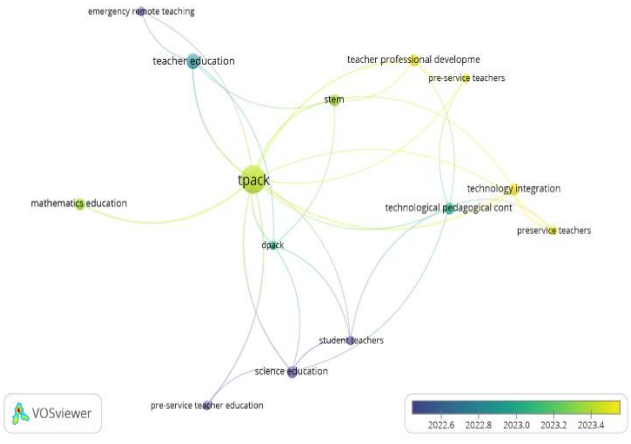

Figure 6. Overlay Visualization of TPACK Articles Sourced from Scopus

The overlay visualization shows the temporal evolution of terms. Keywords such as "emergency remote teaching" and "self-assessment" emerged earlier (in blue), while "AI-TPACK," "DPACK," and "intelligent pedagogy" emerged later (in yellow), indicating future research trends. Several articles examine the context of teacher education across countries. Compared teacher education systems in Myanmar, the Philippines, and Japan and found that only the Philippines and Japan explicitly incorporated TPACK elements. (Novita, 2023) showed that elementary school teachers in Colombia lacked the technological component of TPACK. Studies from Germany, Finland, Qatar, and Australia also reinforce the importance of context in TPACK formation. Differences in educational systems, access to technology, and organizational culture significantly influence the outcomes of TPACK training and its implementation in the field.

Articles such as (Nafukho et al., 2023), highlight the importance of effective professional training design. Cowart found that TPACK significantly improved when supported by strong online training design elements. Meanwhile, DeVaul noted the importance of flexibility and institutional support during emergency teaching. Five key themes from the interviews indicated that many lecturers lacked formal online training, yet they were still able to develop themselves through reflection and peer support. Overall, it can be concluded that the TPACK framework has become a valuable conceptual and practical tool in teacher education. However, its implementation still faces various challenges, including competency gaps, lack of contextual training, and cultural and structural barriers in schools and universities (Arnaiz-Sánchez et al., 2023); (Zickafoose et al., 2024); (Darling-Hammond et al., 2020).

Therefore, it is recommended that: Teacher education institutions strengthen hands-on training and technology simulations; Teacher education curricula incorporate advanced topics such as DPACK and AI-TPACK (Hava & Babayiğit, 2025) Further research be conducted in underrepresented developing country contexts; TPACK competency evaluation is conducted holistically, combining self-assessment, classroom observations, and student learning outcomes. In conclusion, the TPACK approach is not only relevant but also continues to evolve in line with the challenges of the times. By integrating insights from 26 scientific articles and visualizations, this study provides a strong foundation for researchers, educators, and policymakers in developing more adaptive, contextual, and long-term impactful teacher training strategies in the digital age.

Conclusion

Based on an analysis of 26 selected scientific articles from the Scopus database published between 2021 and 2025, it can be concluded that the TPACK framework plays a crucial role in developing teacher professional competencies in the digital era. TPACK serves not only as a theoretical tool but has evolved into a practical approach applied in various educational contexts, from pre-service teacher education and STEM learning to

technology integration in online and hybrid learning. These findings also reveal a shift in research trends from a focus on responding to the pandemic emergency to developing long-term digital learning strategies. Analysis using VOSviewer shows that the keyword "TPACK" serves as a key node in the research network, closely related to terms such as "teacher education," "technology integration," and "professional development." The emergence of new terms such as DPACK and AI-TPACK indicates the continued evolution of the TPACK concept, adapting to developments in digital technology and artificial intelligence. This study recommends that higher education institutions, particularly LPTK (Teacher Training Institutions), begin integrating TPACK-based training into their teacher education curricula in a systematic and sustainable manner. Teacher professional development also needs to be facilitated through training that combines theory with project-based practice or contextual lesson study. Furthermore, education researchers are encouraged to conduct further, more in-depth studies on the effectiveness of TPACK implementation in various local contexts in Indonesia, utilizing complementary quantitative and qualitative approaches.

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Author Contributions
Conceptualization, N, I, and HU; methodology, N, I; data sources, I and HU; data management, N; writing—original draft, N; writing—review and editing, N and I; visualization, N and IR; supervision, R and IF; administration, N, IR and HU. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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