

Mapping the Literature of Technological Pedagogical and Content Knowledge (TPACK) in Elementary Education: A Bibliometric Review

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Abstract: This study aims to identify and analyze trends in Technological Pedagogical and Content Knowledge (TPACK) research in primary education, while also exploring opportunities for further research development. Using the Systematic Literature Review (SLR) method, 226 relevant publications were found in the Scopus and Publish or Perish databases, with 31 documents from the period 2019-2023 selected and analyzed based on inclusion criteria. The literature review process followed PRISMA guidelines to ensure the quality of results, and the data were analyzed using bibliometric methods with the assistance of VOSviewer 1.6.20 software. The results showed a relatively stable increase in TPACK article publications in primary education, despite a slight decline in 2020 and 2023. Most publications originated from China, Turkey, and the United States, with quantitative and qualitative methods being the most commonly used approaches. The main themes explored included technology integration, teacher training, professional development, and educational technology. Density mapping analysis revealed that content, pedagogical, and technological knowledge remain underexplored in depth, indicating that further research is needed to expand understanding of TPACK application in primary education.

Keywords: Bibliometric Review; Primary Education; TPACK; VOSviewer; Systematic Literature Review

Introduction

Education in the era of the industrial revolution, known as Education 4.0, marks the transition to a new paradigm influenced by technology and learning innovations (Maria et al., 2018; Mohd Adnan et al., 2019). Education 4.0 emerged as a response to the increasingly complex societal needs, where technologies such as Artificial Intelligence (AI), Virtual Reality (VR), Augmented Reality (AR), and data analytics are applied in the learning process, creating a more dynamic, interactive, and personalized learning environment (González-pérez & Ramírez-montoya, 2022; Jang et al., 2021; Velander et al., 2023). Research by González-pérez & Ramírez-montoya (2022) shows that the integration of

these technologies enhances the dynamics and interactivity of learning. Furthermore, a study by Miranda et al. (2021) emphasizes the importance of digital competence for teachers, which includes the ability to integrate technology into learning and design innovative and relevant learning experiences. Mastery of the Technological Pedagogical and Content Knowledge (TPACK) framework by teachers, as outlined by Zulhazlinda et al. (2023) and Supriyadi et al. (2018), is a key indicator of this ability. Therefore, teachers must continually adapt and develop their digital competencies to effectively implement Education 4.0, thus preparing to face the challenges and leverage the opportunities of advanced technology for optimal student outcomes.

How to Cite:

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A review of various previous studies shows that technology integration in teaching is effective and supports learning objectives (Abubakir & Alshaboul, 2023; Shafie et al., 2019). Teachers with TPACK skills can more effectively address challenges arising from the use of technology in education, including issues of access, the digital skills gap, and ineffective technology integration (Cekerol & Ozen, 2020; Keser & Sari, 2021; Khlaif et al., 2023). The integration of technology into the learning process provides significant benefits to students, particularly in understanding subjects such as science and mathematics. Learning should ideally be designed to be more concrete, contextual, or realistic by utilizing technology, in accordance with students' level of thinking. TPACK aims to support the development of technological thinking to help students understand concepts and relate them to real-world situations (Luo et al., 2023). Furthermore, TPACK is considered an effective method to overcome complex challenges when teachers implement technology in the learning process (Sofyan et al., 2023; Wang et al., 2018). Mastering TPACK is key to enhancing the effectiveness of technology-based teaching. In this way, technology is not only used as a support tool but also as a means to enrich students' learning experiences and support their understanding of complex subject matter.

Nevertheless, the literature review shows that most studies related to TPACK focus on secondary, higher, and pre-service education (Krug et al., 2023; Velandar et al., 2023; Zeng, 2022), leaving a significant gap in understanding its application in primary education. Additionally, many previous studies are theoretical and practical (Abu-Hardan et al., 2019; Nilsson, 2022), but they lack a comprehensive view of global trends and publication patterns in this field. This study contributes new insights by using bibliometric analysis to map TPACK research trends in primary education over the past five years (2019-2023), an area that has been underexplored. Bibliometrics is an interdisciplinary method that quantitatively analyzes information sources using mathematical and statistical approaches (Donthu et al., 2021; Jannah et al., 2022; Suprpto et al., 2021). This method allows researchers to analyze research trends by considering citations, co-citations, geographical distribution, and word frequency (Jannah et al., 2022; Zupic & Čater, 2015). Therefore, the researchers are interested in conducting an analysis of TPACK research trends in primary education over the past five years (2019-2023).

This research is important because it not only visualizes trends but also identifies gaps and potential areas for further development, providing crucial insights for academic researchers and policymakers. Understanding these trends is essential, as TPACK plays

a vital role in enhancing teacher competence and facilitating effective technology integration in the classroom. By identifying global research patterns, key publication hubs, and emerging research areas, this study aims to inform the design of teacher training programs, researchers, and teachers to meet the demands of Education 4.0.

The primary objective of this study is to explore global research trends related to TPACK in the context of primary education over the past five years. The specific objectives of this study include:

TPK1: Analyzing publication trends, citations, contributors, and countries contributing to TPACK research.

TPK2: Visualizing TPACK trends in primary education.

TPK3: Exploring research methods used in TPACK studies in primary education.

TPK4: Identifying the top five TPACK articles over the past five years.

Method

Search Design

This study used the Systematic Literature Review (SLR) method with the assistance of Covidence software to review articles based on publication standards, databases, and inclusion and exclusion criteria (Dobrescu et al., 2021; Khan et al., 2023). The data used were articles indexed in Scopus, obtained from the Scopus database and Publish or Perish. This study included publications from 2019 to 2023 to capture the latest trends in educational technology and ensure the relevance of the findings to current challenges. A total of 226 publications related to the keywords used were found in both databases. To maintain quality and reproducibility, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were used as guidelines, following three stages: identification, screening, and eligibility assessment (Nasir et al., 2023; Titus & Muttungal, 2024).

Bibliometric analysis was applied to identify, track, and map the relationships between various fields of knowledge, topics, publications, authors, and the flow of scientific knowledge related to this research (Fajri et al., 2024; Moreno-Guerrero et al., 2020). This analysis enables researchers to understand the development of research in a specific topic, identify the scientific contributions of authors and institutions, and uncover patterns in scientific publications (Muhlis et al., 2023; Suprpto et al., 2021). To produce relevant discussions and conclusions, the researchers used VOSviewer version 1.6.20 as a data processing tool. In summary, this study began by identifying 226 articles from Scopus and Publish or Perish. The articles were then selected using Covidence with PRISMA guidelines. The selected data

were collected and processed using Mendeley and Excel. The results of the data analysis were summarized and visualized using VOSviewer to illustrate patterns and relationships within the data.



Figure 1. Research Procedure

Data Search Strategy

As the initial step in the literature review, the strategy used for literature search was based on online databases (Solimun et al., 2023). The researchers utilized Scopus-indexed articles from two databases, Scopus and Publish or Perish, to search for and collect relevant sources. These databases were selected due to their high quality, wide acceptance, and comprehensive, user-friendly digital libraries for finding information on education and technology online. This is shown in Table 1.

Table 1. Database Search Strategy

Filter	Description
Year	2019-2023
Subject area	Social Science
Search string	"TPACK" OR "TPCK" AND "Elementary School" OR "Primary School"
Source type	Journal
Language	English
Document type	Article (Open access)
Rank type	Indexed by Scopus

The search from these databases yielded 226 articles, consisting of 39 articles sourced from indexed Publish or Perish and 187 from the Scopus database. Subsequently, all articles were identified and analyzed for relevance to the research questions and objectives. This study used Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as a guideline, which included determining selection criteria, extraction methods, removing duplicate articles across databases, and selecting studies based on titles, abstracts, and keywords to reduce researcher bias and errors (Solimun et al., 2023).

Data Selection Criteria

At this stage, the criteria for selecting literature were applied rigorously to obtain documents that matched the specified keywords. Kholid et al. (2023) suggests that the criteria used in document selection involve two stages: inclusion and exclusion. As outlined in Table 2 below, these stages must be followed carefully

to ensure the relevance and quality of the selected documents.

Table 2. Inclusion and exclusion criteria

Criteria	Inclusion	exclusion
Title and content	Related to TPACK in elementary schools	Irrelevant titles
Publication year	Published from 2019 to 2023	Published outside the specified range
Type of publication	Only journal articles	Reviews, editorials, and non-empirical studies
Language	English	Others
Field of study	TPACK	Others
Participants	Elementary school teacher	Others
Accessibility	Full-text or open-access articles	Articles requiring payment
Journal indexing	Only articles indexed in Scopus	Others

Data Selection Process

Data selection is a critical element in a literature review to ensure the validity and reliability of the research (Yang et al., 2020). To ensure the integrity of the data and avoid potential bias, the primary focus is identifying topics that align with the research and seeking input from an independent panel of experts. As stated by Schmitt et al. (2023), any discrepancies found are resolved through in-depth discussions. In the next phase, the data is selected with the assistance of Covidence software to ensure accurate data for use in the data extraction process. This literature mapping was conducted in April 2024 and consisted of three stages.

In the first stage, using the predetermined keywords, the researchers obtained 226 articles sourced from the Scopus and Publish or Perish databases. The keywords used were "Technological Pedagogical And Content Knowledge," with the acronyms "TPACK" and "TPCK." Additionally, the keywords "Elementary School" and "Primary School" were used. During the identification stage, 8 duplicate documents were found and excluded from the total of 226 articles. In the screening stage, 218 articles were filtered based on inclusion and exclusion criteria applied to titles, keywords, and abstracts, resulting in the exclusion of 121 articles. Next, the remaining 97 articles were fully reviewed, and 66 were excluded because they only mentioned "TPACK" without discussing it in the context of elementary education. In the inclusion stage, 31 articles passed the final stage and were deemed to meet the eligibility criteria.

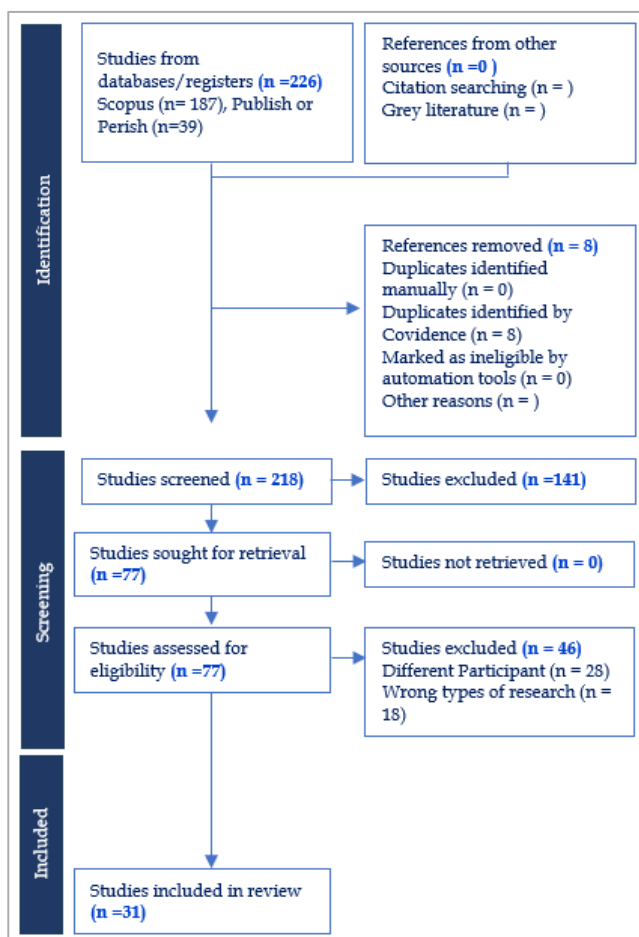


Figure 2. PRISMA flow diagram

Analysis data

All collected articles that met the research criteria were exported in RIS and CSV formats. The data in RIS format was imported into Mendeley to verify and correct the necessary metadata. Subsequently, the data was computationally mapped using the VOSviewer software. Meanwhile, the CSV data was tabulated in Microsoft Excel to facilitate the analysis of trends, gaps, and potential for further development. The factors considered include annual publication trends, citations, author productivity, country productivity, and frequently used research methods. The results of the analysis will be used to identify thematic evolution and current research trends on the topic of TPACK in elementary education (Alka et al., 2023; Lee et al., 2022). The final step of this research is to identify research gaps and propose future research directions on TPACK in elementary education.

Result and Discussion

In recent years, TPACK (Technological Pedagogical and Content Knowledge) has gained increasing attention in the field of education, particularly in

elementary education. This research aims to analyze and explore publication trends, citations, journal contributions, visualize trends, and identify gaps and potential areas for further development related to the advancement of TPACK in elementary education across various countries. The graph below illustrates the research trends on the development of TPACK for elementary school teachers from 2019 to 2023.

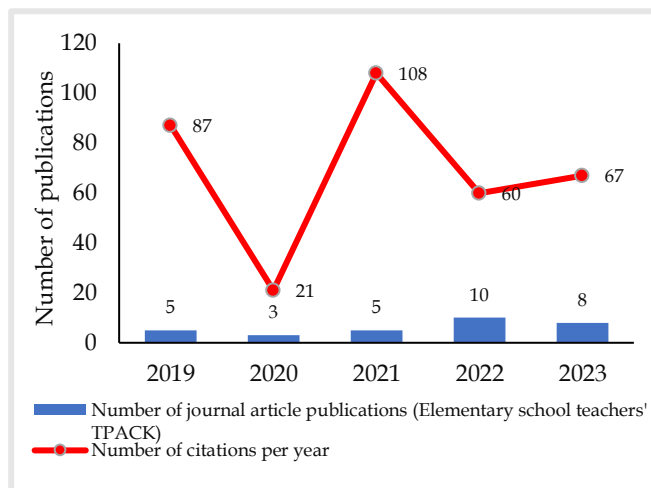


Figure 3. Publication and Citation Trends

Figure 3 illustrates the publication and citation trends of TPACK research in the elementary school context from 2019 to 2023. The clustered column chart depicts the number of journal article publications per year, totaling 31 articles. The number of publications on TPACK in elementary education has shown a generally stable trend with a gradual increase, although a slight decline occurred in 2020 and 2023. The total number of articles rose significantly from 3 in 2019 to 8 in 2023. This trend aligns with previous research findings, which highlight the growing interest of academics and practitioners in elementary education regarding the utilization of TPACK (Boateng et al., 2024; Paidican & Arredondo, 2022). Boateng et al., (2024) noted that the effective integration of technology in teaching has fueled the interest in exploring the TPACK approach, particularly in response to the rapid digital developments in elementary school settings.

On the other hand, citation trends for TPACK articles in the context of elementary school teachers have fluctuated, with the highest citations occurring in 2021, reaching 108, and the lowest in 2020, with only 21 citations. These fluctuations may be associated with specific variables, including the urgent need for technology-based research during the COVID-19 pandemic, which heightened attention on technology-driven teaching methods (Hew et al., 2020). This indicates a period of rapid development. The focus on recent research from 2021 to 2023 highlights active

engagement from researchers and academics in generating new insights. A study by Lee et al., (2022) found that increased international collaboration and technological advancements have accelerated the adoption of TPACK, contributing to the rise in citations in recent years. The rapidly evolving dynamics in this field necessitate ongoing monitoring of the latest research to stay relevant with current developments.

Table 3. The Highest Number of Publication Citations

Authors	Scopus citation
Jang, J; Ko, Y; Shin, W S; Han, I	97
Celik, I	57
Roussinos, D; Jimoyiannis, A	48
Pareto, L & Willermark, S	22
Viberg, O; Mavroudi, A; Khalil, M;	19
Bälter, O	

Table 3 presents the authors with the highest number of citations in TPACK research within the context of elementary education. The most frequently cited authors are considered to be the most influential in this field of study. Among the 31 articles analyzed, there are 84 authors, 29 of whom collaborated on their publications. This collaboration reflects a common pattern in TPACK research, where synergy between various researchers contributes to the broader development and dissemination of the TPACK concept (Nasir et al., 2023). Additionally, the study by Jang et al., (2021) holds the top position with 97 citations, indicating their significant influence in the context of technology-based education. Other authors, such as Ismail Celik and Roussinos-Jimoyiannis, also play a critical role in promoting the adoption of TPACK across different countries.

Table 4. Journals with the Highest Contribution

Journal	Number
Contemporary Educational Technology	2
Eurasia Journal of Mathematics, Science and Technology Education	2
Journal of Pedagogical Research	2

Table 4 highlights the journals that have contributed the most to TPACK publications in elementary education between 2019 and 2023. The three leading journals with the largest contributions are *Contemporary Educational Technology*, *Eurasia Journal of Mathematics, Science and Technology Education*, and the *Journal of Pedagogical Research*, each publishing two articles. The presence of these journals underscores the importance of specialized academic forums in disseminating research related to pedagogical innovation, particularly in rapidly evolving fields such as TPACK (Handayani et al., 2023). The study by García-

Lázaro et al., (2022) also emphasizes that journals specializing in educational technology play a critical role in increasing citation numbers and providing a platform for researchers to share the latest findings.

There are 19 countries with published articles related to TPACK in elementary education in the Scopus database.

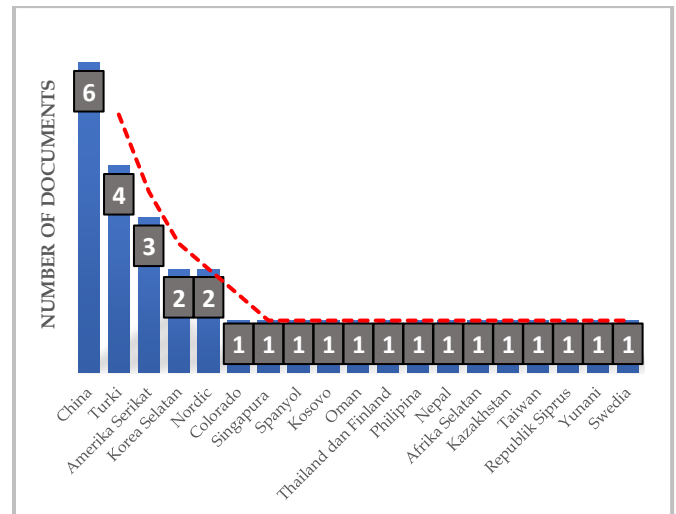


Figure 4. Countries and Number of Article Publications

Figure 4 shows the distribution of TPACK-related article publications in elementary education across various countries based on data from the Scopus database. A total of 19 countries have contributed to the publication of articles on TPACK in elementary education. China stands out as the country with the highest number of publications, followed by Turkey and the United States, each with four and three articles, respectively. South Korea and the Nordic countries each contributed two articles. Collectively, these five countries account for 58.06% of the 31 articles analyzed.

The dominance of Asian countries, particularly China and South Korea, in TPACK research aligns with global trends showing increased interest in technology integration in education across The Asia region (Dewi et al., 2021; Nasir et al., 2023). Dewi et al. (2021) highlight the importance of international collaboration, especially in Asia, in driving technology-based educational innovations. Additionally, Turkey has also emerged as a significant player in this research, as noted by Dikmen & Demirer (2022), where TPACK has become an essential attribute for teachers in the information and technology era, emphasizing the importance of understanding TPACK within the context of smart educational environments in elementary schools.

The active involvement of Asian countries in TPACK research can also be linked to national policies encouraging the use of technology in classrooms. Yang (2019) study observes that the Chinese government,

through various technology-based educational initiatives, has played a major role in fostering interest among academics and education practitioners in adopting the TPACK approach. This cross-national collaboration further strengthens the development of TPACK research, with Asian countries taking a leading role in expanding the application of this concept across various educational contexts.

researchers to the significant shifts in global education caused by the pandemic, which accelerated the adoption of remote learning technologies (Nasri et al., 2020). This highlights the research focus on technology use in uncertain situations, supporting deeper efforts toward technology integration in the context of elementary education.

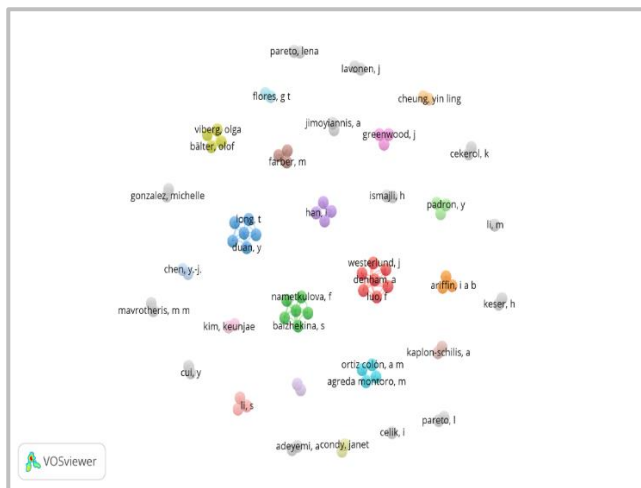


Figure 5. Visualization of collaboration among authors

Figure 5 illustrates the collaboration network among authors in TPACK research over the past five years, generated through VOSviewer with 83 researchers and 202 co-authorship links. Nodes in close proximity with the same color represent groups of authors who frequently collaborate, forming several collaboration clusters. This collaboration reflects a common pattern in academic research, where authors with similar research interests work together, creating focused research groups on specific topics (Alka et al., 2023). Each cluster represents a particular topic, with authors at the center of the cluster, such as Jaehong Jang, Yujung Ko, Won Sug Shin, and Insook Han, who play pivotal roles in the collaboration network. They focus on the topic of 'Augmented Reality and Virtual Reality for Learning,' indicating that teachers' positive attitudes toward AR and VR technology are influenced by ease of use, perceived usefulness, social norms, TPACK competence, and motivational support.

Of the 31 articles analyzed, 139 keywords were identified in TPACK research. To ensure statistical validity, the researchers set a minimum threshold of two occurrences for each term, resulting in 22 eligible keywords. The most common keyword was "TPACK," appearing 19 times, followed by "Technological Pedagogical Content Knowledge" with 6 occurrences, and "Technology integration" and "COVID-19," which appeared 5 and 4 times, respectively. The emergence of the term COVID-19 reflects the swift response of

Table 5. Frequently Occurring Keywords

Keyword	Occurrences	Total link strength
TPACK	19	27
Technological pedagogical content knowledge	6	4
Technology integration	5	13
Covid-19	4	6
Teacher education	3	10
Teacher training	3	10
Content knowledge	3	9
Activity theory	2	12
Didactic design	2	12
Expansive learning	2	12
Integrated approach	2	12
Teaching as design	2	12
Teaching practices	2	12
TPACK in situ	2	12
Education	2	9
Pedagogical knowledge	2	9
Technological knowledge	2	9
Educational technology	2	5
Teaching	2	4
Professional development	2	3
Primary school	2	2
Teacher professional development	2	2

In relation to the theme of professional development, the keywords "Teacher Training" and "Teacher Education" each appeared 3 times. This indicates that improving teachers' competencies in managing and integrating technology into teaching remains a primary focus in TPACK research (Handayani et al., 2023). Professional development for teachers is crucial to ensure effective technology integration in classrooms, particularly in elementary schools. Ortiz Colón et al. (2023) emphasize the importance of continuous and structured training to help teachers effectively combine content, pedagogy, and technology.

Supporting concepts such as "Activity Theory" and "Expansive Learning," each appearing twice, also play a critical role in facilitating the application of TPACK in innovative learning practices. Activity Theory has proven effective in examining how teachers and students interact with technology during the learning process (Pareto & Willermark, 2022). Similarly, "Expansive Learning" focuses on the development of

dynamic learning environments, allowing teachers to explore new technology-based teaching approaches.

Additionally, the terms "Didactic Design" and "Integrated Approach," which also appeared twice, underscore the importance of effective and integrated instructional design within the TPACK framework. Structured teaching with a strong didactic approach can

enhance the effectiveness of technology-based learning in educational settings such as elementary schools, where teachers play a central role in designing instruction (Nilsson & Lund, 2023). These terms highlight that attention to integrated teaching strategies has become a key focus in recent research, particularly in supporting efficient learning in elementary education.

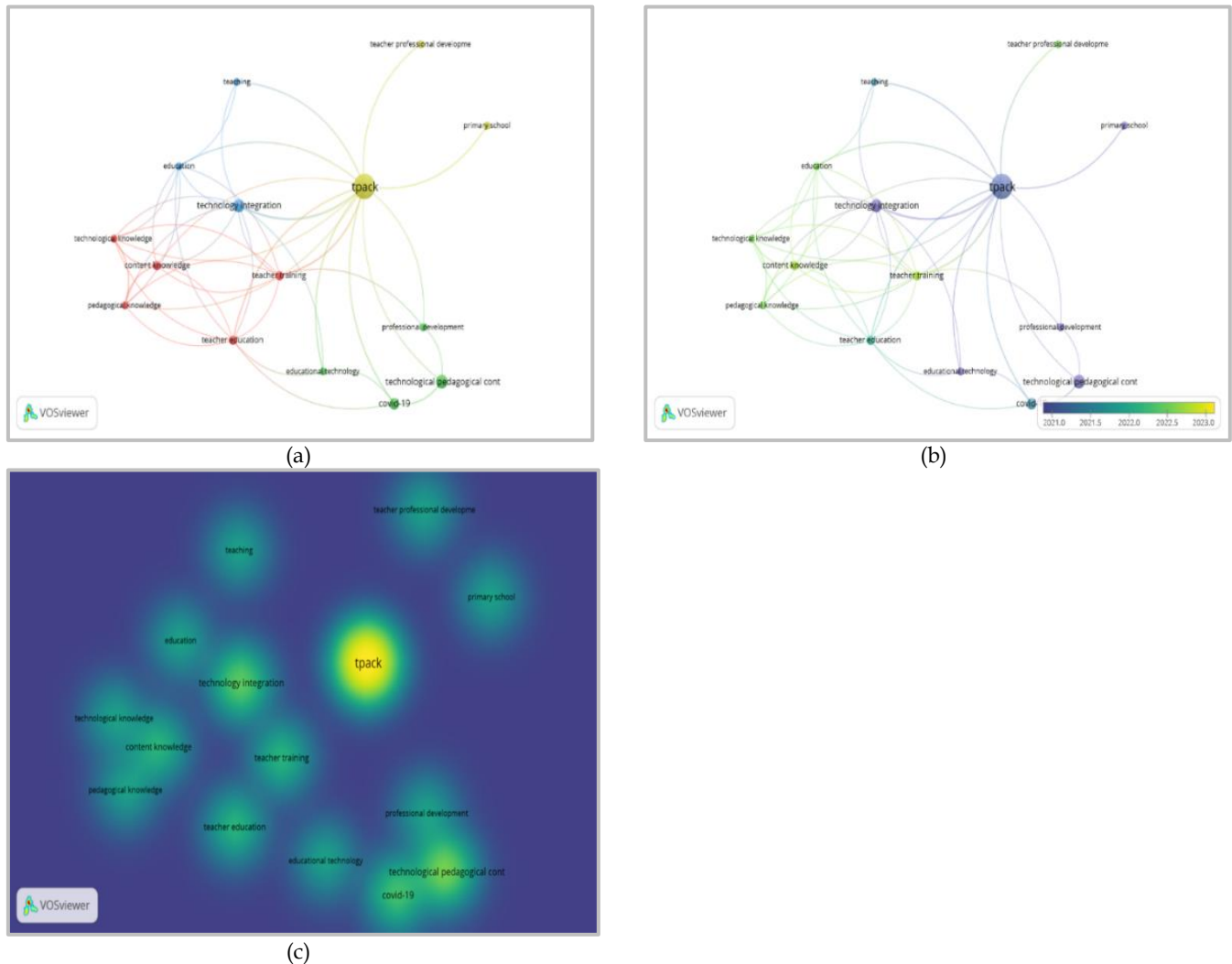


Figure 6. (a) Network visualization co-occurrence, (b) Overlay visualization co-occurrence, (c) Density visualization co-occurrence.

Of the 139 identified keywords, 22 met the minimum occurrence threshold, but only 15 were significantly interconnected. As a result, only these keywords were used in the visualization of the Co-occurrence of Keywords. Figure (a) illustrates how "TPACK" is linked with other concepts such as "technology integration," "teacher training," and "educational technology." The strong connections between TPACK and keywords such as "professional development" and "primary school" highlight the importance of technology integration not only in teacher education but also in the context of elementary education (Wollmann & Lange-Schubert, 2022).

Wollmann & Lange-Schubert (2022) research emphasizes that professional development for teachers is crucial for expanding the adoption of TPACK in elementary education, further reinforced by the connection between "teacher training" and "technology integration" in this visualization.

Figure (b) provides a temporal perspective, highlighting how keyword discussions shifted between 2021 and 2023. The color change from blue to green in the visualization indicates that certain topics, such as "COVID-19," were more dominant at the beginning of the marked period, reflecting the researchers' swift response to the global pandemic (Keser & Sari, 2021;

Sothayapetch & Lavonen, 2022). The pandemic accelerated the adoption of technology in education, prompting research on remote learning and technology integration in elementary classrooms (Sothayapetch & Lavonen, 2022). This aligns with the visualization findings, which show a significant increase in discussions on technology integration and teacher training during this period.

Figure (c) illustrates the frequency and strength of relationships between keywords, with "TPACK" as the central hub. Areas with higher light intensity, such as around the keywords "TPACK," "teacher training," and "technology integration," indicate that these topics are frequently discussed and considered highly relevant in the TPACK literature (Nasir et al., 2023). The connections between TPACK and these topics reflect a strong focus on the importance of developing teachers' abilities to effectively use technology in the classroom, particularly within the context of elementary education. This visualization provides a clearer view of recent research trends, identifying the topics that dominate academic discussions in this field.

In TPACK research, various research methods are employed to collect and analyze data. The choice of research method is critical, as it affects the validity and reliability of research findings (Heale & Twycross, 2015; Noble & Smith, 2015). The 31 selected articles from 2019 to 2023 reveal a range of commonly used research methods in TPACK studies, as well as trends in their usage in recent years.



Figure 7. Proportion of TPACK Research Methods

Figure 7 shows the distribution of research methods used in 31 articles on TPACK from 2019 to 2023. Quantitative methods dominated with 55% (17 articles), followed by qualitative methods comprising 29% (8 articles), while mixed-methods approaches were employed in only 16% (5 articles). This distribution

suggests that quantitative methods are preferred by TPACK researchers, likely due to their ability to generate measurable data and more generalizable conclusions (Franklin, 2023). However, despite being used less frequently, qualitative and mixed-methods approaches still play a vital role in providing deeper insights into the implementation of TPACK.

Quantitative TPACK research, found in 18 articles, demonstrates variation in approaches, including probability sampling, longitudinal studies, self-report, cross-sectional surveys, Delphi design, and the development and validation of the TPACK-TT scale. Surveys were the most commonly used method in quantitative research, as they allow for large-scale data collection and can capture educational phenomena across broad populations (Li, 2023). Additionally, quantitative research was used for descriptive and inferential analysis, measuring attitudes, perceptions, and testing theoretical models, all contributing to a more comprehensive understanding of TPACK implementation in various educational contexts.

On the other hand, qualitative TPACK research, analyzed from 9 articles, revealed that case studies were the dominant approach, used in 5 articles. Qualitative approaches, particularly case studies, are often employed to explore the deep, complex implementation of TPACK in real-life situations, such as classrooms or other educational settings (Cole, 2023; Rana et al., 2022). Systematic literary content analysis, formative interventions, and phenomenological approaches were also found in several articles, all of which help to identify patterns, key themes, and individual subjective experiences in the practice of TPACK. These approaches provide a richer understanding of how technological, pedagogical, and content knowledge is applied in specific contexts.

Table 6 presents the top five articles in TPACK research published between 2019 and 2023, exploring the application of advanced technologies such as Augmented Reality (AR), Virtual Reality (VR), and Artificial Intelligence (AI) in elementary education. These technological advancements highlight the importance of integrating technological, pedagogical, and content knowledge (TPACK) by teachers to optimize their use in teaching (Nuangchalerm, 2020). Jang et al. (2021), found that teachers' positive attitudes towards using AR and VR were influenced by ease of use and motivational support, while Celik (2023) demonstrated a strong connection between TPACK and ethical considerations in the application of AI-based technologies.

Table. 6 Trend of the Top Five Articles in Elementary Education Over the Last Years (2019-2023)

Title	Authors	Findings	Recommendations
Augmented Reality and Virtual Reality for Learning: An Examination Using an Extended Technology Acceptance Model	Jang, J; Ko, Y; Shin, W S; Han, I	Teachers exhibit a positive attitude towards the use of AR and VR, influenced by perceived ease of use and usefulness. Factors such as social norms (SN) within TPACK and motivational support (MS) are key determinants in teachers' acceptance of AR and VR technologies.	The study recommends strong support from school administration and peers in the implementation of AR and VR technology, including more in-depth professional training. Further research combining qualitative data is also suggested to understand teachers' readiness and intentions in using AR and VR in education.
Towards Intelligent-TPACK: An empirical study on teachers' professional knowledge to ethically integrate artificial intelligence (AI)-based tools into education	Celik, I	There is a significant relationship between the components of Intelligent-TPACK and ethical considerations, with technological knowledge (TK) enhancing pedagogical and content knowledge (TPK and TCK) and ethics.	The study recommends future research to use multimodal data, such as interviews or videos, to complement self-reported data in measuring AI-based instructional knowledge from various perspectives. It also suggests collecting data from a larger sample size and recruiting pre-service teachers to enhance the validity and reliability of the results.
Examining Primary Education Teachers' Perceptions of TPACK and the Related Educational Context Factors	Roussinos, D; Jimoyiannis, A	Teachers have a good understanding of content, pedagogical, and technological knowledge but struggle to integrate the three. Factors such as gender, teaching experience, and ICT training affect ICT application.	The study recommends professional development programs focused on lesson plan design and integrating all aspects of TPACK to enhance the effectiveness of ICT use in teaching. For further research, it recommends studying the alignment between teachers' perceptions and practices in integrating technology in the classroom.
TPACK In Situ: A Design-Based Approach Supporting Professional Development in Practice	Pareto, L; Willermark, S	The study shows an improvement in didactic design quality through the use of the TPACK in situ model, with some designs being successful and others facing challenges in implementation.	Researchers recommend a design-based approach for teacher professional development within the TPACK framework. They emphasize the importance of involving teachers in authentic teaching settings and using the TPACK in situ model to plan, implement, and evaluate the quality of didactic design.
Validating an instrument to measure teachers' preparedness to use digital technology in their teaching	Viberg, O; Mavroudi, A; Khalil, M; Bälter, O	The study identifies factors contributing to teachers' readiness to use digital technology, including the ability to use digital technology, social influence and support, intention to use, usability and efficiency, awareness of limitations, pedagogical potential, and awareness of how to get help. The results show high reliability in most factors measured.	Researchers recommend that future research focuses on larger samples and different cultural contexts to further validate the instrument used in measuring teachers' digital readiness. Additionally, it is important for schools to support teachers in enhancing their knowledge, acceptance, and behavior related to technology integration in teaching.

Teachers' readiness to implement these technologies depends not only on their individual technological competencies but also on strong administrative support and comprehensive professional development programs (Spiteri & Chang Rundgren, 2020; Wohlfart & Wagner, 2023). This

research underscores that the implementation of advanced technologies requires support from various educational stakeholders, including school administrators and peers, to enhance the effectiveness of technology use in classrooms (Wohlfart & Wagner, 2023). This is reflected in Viberg et al. (2020) who

emphasized the importance of social support and teachers' preparedness to use digital technology, and Pareto & Willermark (2022), who highlighted the challenges in implementing the TPACK model in situ, even though some designs succeeded in improving the quality of didactic design.

Furthermore, research indicates that successful technology integration in teaching requires carefully designed professional development programs to help teachers effectively combine technological, pedagogical, and content knowledge (Kasim et al., 2024; Mavrotheris & Papanastasi, 2024). Roussinos & Jimoyiannis (2019) stressed the need for TPACK training that focuses on designing lesson plans integrating TPACK aspects. This approach can assist teachers in overcoming challenges in incorporating technology into their teaching practices.

Thus, the increasing use of innovative technologies such as AR, VR, and AI in elementary education must be supported by ongoing research focused on adapting teaching practices to technological advancements. Collaboration among teachers, administrators, and researchers is crucial to address the challenges in integrating these technologies while ensuring that the pedagogical approaches used remain ethical and effective in meeting the educational needs of the digital era.

Based on previous studies, integrating technology and teachers' TPACK competencies in managing instruction is a relevant and compelling topic to explore. Research by Suprpto et al. (2021) revealed a significant increase in interest in TPACK research and the importance of TPACK in developing teachers' competencies for integrating technology into instruction. (Kadioğlu-Akbulut et al., 2023) also noted that the TPACK concept has become a major discussion point over the past two decades, particularly for in-service and pre-service teacher development. Five TPACK research trend clusters were identified: TPACK-based learning methods, TPACK models, TPACK applications, learning media, and TPACK usage goals. Each cluster highlights specific areas essential for the development and implementation of TPACK, ranging from learning methods to the goals of technology use in education. Thus, TPACK covers various dimensions that complement each other to enhance learning quality through technology. (Drajati et al., 2023) further demonstrated that TPACK-based Teacher Professional Development (TPD) programs positively impact English teachers' confidence and belief in integrating technology into their teaching. This shows that TPACK plays a crucial role in enhancing teacher

professionalism by improving their competencies in technological, pedagogical, and content knowledge.

Conclusion

The trend of journal article publications indexed in Scopus regarding TPACK in elementary education during the 2019-2023 period did not show significant fluctuations. The number of journal articles on TPACK in elementary education remained relatively stable and tended to increase gradually, despite a slight decline in 2020 and 2023. "Augmented Reality and Virtual Reality for Learning: An Examination Using an Extended Technology Acceptance Model" is one of the most cited articles on TPACK in teaching and learning in elementary schools. Most publications originated from China, Turkey, and the United States. The most commonly used research methods in the analyzed documents were quantitative and qualitative methods. The main themes frequently researched include technology integration, teacher training, professional development, and educational technology. Density mapping analysis indicates that content, pedagogical, and technological knowledge has not been thoroughly explored. These findings recommend further research to broaden and deepen the understanding of TPACK implementation in elementary education.

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Author Contribution

Qonita Shabira (Q.S): Conceptualization, methodology, writing—original draft preparation, results and discussion; Baharudin (B): Validation, methodology, writing—reviewing; Yuli Yanti (Y.Y): Supervision, conclusion, and review.

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