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Research Trend on Technological Pedagogical and Content Knowledge (TPACK): A Bibliometric Analysis

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Abstract

TPACK is a framework that serves as a guide for educators in utilizing technological advancements in learning activities. TPACK has now become a popular topic in both educational circles and research domains. Previous studies have examined the development of TPACK research through various methods, including literature reviews and bibliometric analyses. Research trends in this field have shown consistent growth up to 2023, highlighting sustained scholarly interest and the importance of conducting comprehensive and up-to-date studies to better understand the framework's nuances. This study utilized bibliometric analysis to review 1,634 English-language articles from the Scopus, covering TPACK research trends from 2006 to September 2024. It focused on keywords such as "TPACK," "TPACK framework," "technological pedagogical content knowledge," and "technological pedagogical and content knowledge." The analysis revealed a consistent annual increase in TPACK-related publications between 2006 and 2024, with an average growth rate of 30.13%. Additionally, the study identified the most prolific authors, leading journals, active countries, and influential institutions in TPACK research, along with the most frequently used keywords. These findings offer valuable insights for future researchers, helping them pinpoint key contributors, resources, and regions central to TPACK-related studies.

Introduction

The swift progress of science and technology in the 21st century has profoundly influenced the education sector (Yılmaz & Aydın, 2019). The presence and accessibility of technology alone do not guarantee its effective use in learning activities (Tondeur et al., 2016). Teachers' abilities are pivotal, not only in utilizing technology but also in optimizing its potential to enhance student learning in the classroom (Drossel & Eickelmann, 2017). Because of this, teachers must acquire the knowledge and abilities known as Technological Pedagogical Content Knowledge (TPACK), which is the ability to smoothly integrate technology with pedagogy and content (Mishra & Koehler, 2006). As more studies use the TPACK framework to assess teachers' proficiency in incorporating technology into the classroom, it has becoming increasingly popular among researchers and educators (Hew et al., 2019). This emphasizes how useful TPACK is as a framework for comprehending successful technology

integration in teaching methods. It is crucial to carry out a systematic review of TPACK research trends as interest in this area is growing. This kind of study offers important information about how TPACK research has evolved and where it is headed (Pigott & Polanin, 2020).

TPACK Framework

Shulman's (1986) fundamental model, which emphasized the significance of instructors possessing expertise in three crucial areas—content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK)—is the basis for the TPACK framework. Although these areas were highlighted in Shulman's framework, the use of technology in the classroom and its effects on student learning outcomes were not particularly covered. This model was then expanded by Mishra and Koehler, who added technological knowledge (TK), leading to the creation of the TPACK framework. According to Thompson and Mishra (2007), this updated approach emphasizes the use of technology to improve instruction.

The TPACK framework encompasses seven interconnected domains: technological knowledge (TK), which refers to a teacher's understanding of various technologies, both traditional and digital; content knowledge (CK), which involves the teacher's grasp of the subject matter; pedagogical knowledge (PK), which reflects the teacher's expertise in designing instructional activities, classroom management, and assessment methods; pedagogical content knowledge (PCK), which highlights the teacher's ability to use effective strategies to teach specific content; technological content knowledge (TCK), which focuses on how digital technology can be used to present subject matter; technological pedagogical knowledge (TPK), which examines how technology can enhance teaching practices and motivate students; and finally, technological pedagogical content knowledge (TPACK), which integrates technology, pedagogy, and content into a cohesive approach to create meaningful and effective learning experiences (Mishra & Koehler, 2006).

The TPACK framework serves as a conceptual model that aids educators in understanding, evaluating, and integrating the connections among technology, pedagogy, and content to guarantee that technology is successfully integrated into the learning process (Koehler et al., 2014; Schmidt et al., 2009). It is frequently used as a foundational reference for educational technology research, to guide the integration of technology in classroom settings, to build teacher education courses, and to analyze technology-based teaching approaches (Polly et al., 2010).

Since its introduction, TPACK has significantly influenced the development of teacher education programs, with many embracing it as a foundational framework to enhance the competencies of pre-service and in-service teachers (Chai et al., 2017; Niess, 2007). This highlights how crucial it is to provide educators with the resources they need to properly integrate technology into their lessons, as this will improve students' comprehension of the material and its real-world applications (Bowers & Stephens, 2011). Research has demonstrated that TPACK is an essential tool for addressing the challenges teachers face when integrating technology into their lesson plans (Chai et al., 2013; Sahin, 2011).

Previous Research on TPACK

Initial studies on TPACK largely concentrated on clarifying and interpreting the model (Lee et al., 2022). Over time, however, research on TPACK has broadened to encompass various dimensions, including the creation of specialized adaptations of the framework. For instance, G-TPACK was designed to incorporate geospatial technology knowledge into TPACK (Doering et al., 2014), while TPACK-W was developed to integrate web knowledge (Lee & Tsai, 2010). Researchers have also introduced other frameworks, such as TPACK-SAMR, which acts as a reflective tool to evaluate the role of technology in educational activities (Tunjera & Chigona, 2020). Moreover, TPACK research has explored key themes, such as its impact on teachers' ability to create effective technology-integrated lessons, its relevance to specific academic disciplines, and its relationship with factors like teacher beliefs and self-efficacy (Abbitt, 2011; Chai et al., 2011; Jang & Tsai, 2012). Additionally, various tools to measure TPACK, including questionnaires and assessments, have been developed, tested, and validated (Lachner et al., 2019; Schmid et al., 2020; Schmidt et al., 2009).

As highlighted above, TPACK has become a rapidly expanding field of research. Consequently, analyzing recent research trends is crucial to better understand the progress and direction of studies in this area. Insights into these trends can help researchers and educators build a foundation for future investigations (Irwanto, 2021). Several prior studies have explored TPACK research trends, revealing growing interest among academics and researchers. This has been demonstrated through an increasing number of publications related to TPACK. For example, Voogt et al. (2013) conducted a literature review of one book chapter and 55 journal articles on TPACK published between 2005 and 2011, emphasizing the growing interest in TPACK and the need for systematic and up-to-date research to enhance understanding of its complexities. In another study, Willermark (2018) analyzed 107 articles on the application of the TPACK framework in educational research published between 2011 and 2016. The study revealed diverse approaches and tools for assessing teachers' TPACK competencies but also pointed out that direct evaluations of teachers' teaching effectiveness remained relatively rare.

Bibliometric Analysis

With the growing number of publications in the TPACK domain, researchers are encountering challenges in identifying and understanding the latest research trends (Briner & Denyer, 2012). Bibliometric analysis has proven to be an efficient and precise technique for analyzing scientific data in large sets (Cobo et al., 2011). Bibliometric analysis allows researchers to trace the development of a field while pinpointing emerging areas within it (Donthu et al., 2021). Furthermore, it helps identify publications from authors across various countries and affiliations, the most influential journals, and the methodologies used along with the findings from prior scientific studies (Durán-Sánchez et al., 2014). Bibliometrix has become a critical component of research methodology for uncovering trends in specific fields.

Previous studies have utilized bibliometric analysis to analyze research trends in the TPACK field. For example, Lee et al. (2022) analyzed publications from 2011 to 2020 indexed in the Scopus database. Their study, which included 700 English-language articles, revealed a steady annual increase in TPACK-related publications. The

findings identified the USA and Turkey as the most prolific countries in publishing research on TPACK. Similarly, Vallespin and Prudente (2023) conducted a bibliometric analysis of 1,303 English-language documents from the Scopus database published between 2006 and 2023. Their findings also indicated a growth in TPACK-related publications, with the USA and Australia emerging as the leading contributors to research in this area. These studies underscore the growing relevance of bibliometric analysis as a tool for tracking the progression of research and understanding global contributions in the TPACK domain.

Research Objectives

This study aims to analyze and identify trends in TPACK research from 2006 to 2024 using bibliometric analysis. To the best of our knowledge, no recent bibliometric analysis has been conducted to identify research trends in the field of TPACK up until 2024. The findings from this analysis can be used to highlight current trends in TPACK research and provide insights into the future direction of studies in this area. Therefore, the research questions for this study are:

1. What are the key insights regarding the development of TPACK research?
2. Who are the most productive researchers and sources in publishing TPACK research?
3. Which countries and affiliations have been the most productive in publishing TPACK research?
4. What are the most common keywords found in TPACK publications?
5. What does the map of international collaboration look like in TPACK publications?

Method

This research employs a bibliometric method to examine trends in TPACK research. Bibliometric analysis, a key aspect of scient metrics, generates quantitative data from academic publications, providing statistical insights for examining trends in a specific research area (Aparicio et al., 2019). This approach enables researchers to explore trends and frequencies of authors, countries, keywords, and institutions involved in the area of interest (De las Heras et al., 2021).

This study utilized the Scopus database due to its distinction as the largest repository of academic documents, comprising over 1.8 billion cited references, 87 million records from more than 7,000 publishers, and 94,000 institutions (Bhuiyan & Hammad, 2024). Compared to the Web of Science, Scopus provides broader journal coverage for keyword searches and citation analysis (Falagas et al., 2008). Furthermore, utilizing the Scopus database enables researchers to track publication trends, identify leading authors and institutions, and gain a comprehensive view of the developments within a particular research field (Martín-Martín et al., 2021).

Article Selection Process and Method

The articles included in this analysis were retrieved from the Scopus database, with publications up to September 25, 2024. The search used keywords such as (“TPACK” OR “TPACK framework” OR “technological pedagogical content knowledge” OR “technological pedagogical and content knowledge”). A total of 2,697 documents were

found between 2006 and 2024 based on these terms. The search was then narrowed to include only articles, as this format is the most common and offers high-quality research with more significant impact (Hosseini et al., 2018). From this, 1,719 articles were found, and the focus was then limited to English-language publications, resulting in 1,658 articles for analysis. These articles were processed through Bibliometrix and underwent further filtering, leading to a final set of 1,634 articles. The filtering process for these articles is summarized in Figure 1 (Moher et al., 2009).

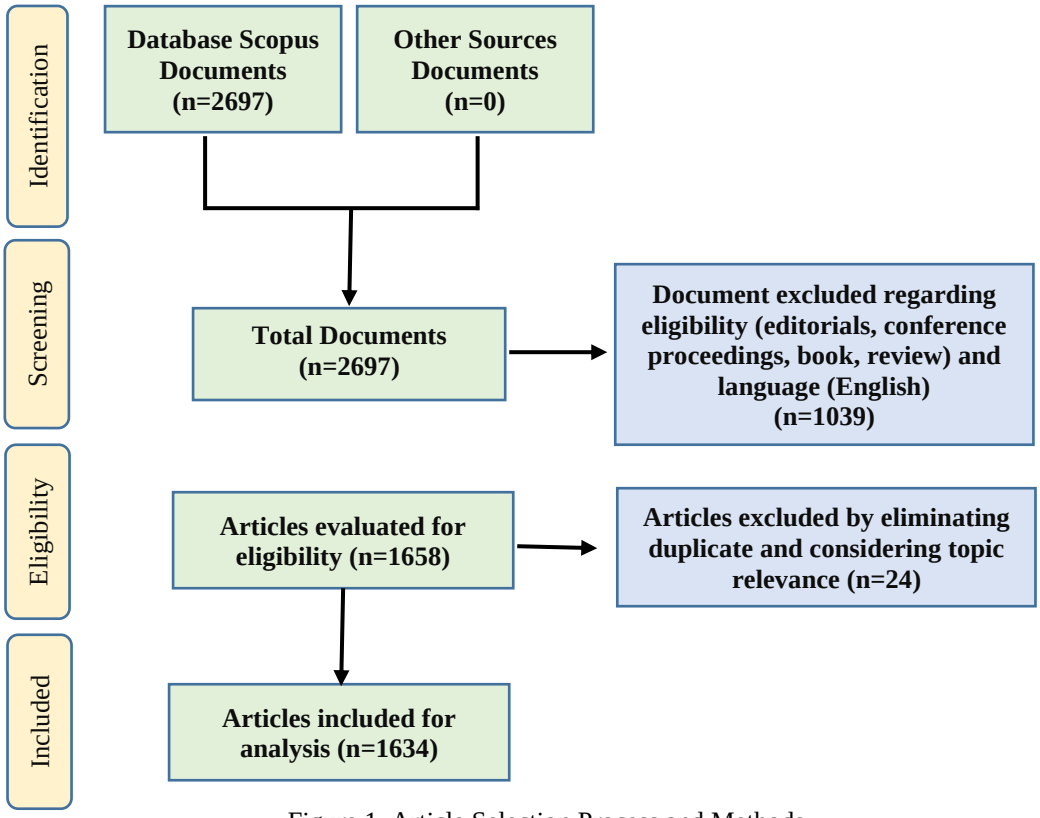

Figure 1. Article Selection Process and Methods

Data Analysis

The article database obtained from Scopus was extracted in BIB (BibTeX) format and analyzed using R-Studio software (version 4.4.1) to visualize the data, enabling comprehensive analysis of all the information (Wen et al., 2023). This software enables the analysis of different bibliometric metrics, including publication counts, co-authorship networks, citation numbers, and keyword co-occurrence patterns, by utilizing various data analysis tools (Aria & Cuccurullo, 2017).

Results and Discussion

Key Information

Table 1 provides key details of research related to TPACK from its introduction in 2006 through to 2024. During this period, 1,634 documents were recorded from 486 sources within the Scopus database. A total of 3,507 authors

contributed to TPACK-related publications, with 275 authors publishing a single article each. Furthermore, 305 articles were authored by a single individual. International collaborations, involving authors from different countries, accounted for 19.77%, underscoring the global cooperation to expand knowledge in the TPACK field. The annual publication growth rate was 30.13%, with an average of 22.5 citations per document, reflecting the significant impact these articles have had on the development of TPACK research.

Table 1. Main Information of Bibliometric Data

Description	Results
Main Information About Data	
Timespan	2006:2024
Sources	486
Documents	1634
Annual Growth Rate %	30.13
Document Average Age	4.59
Average Citattions Per Document	22.5
Keywords Plus (ID)	1361
Author's Keywords (DE)	3121
Authors	
Authors	3507
Authors of Single-Authored Documents	275
Authors Collaboration	
Single-Authored Documents	305
Co-Authors Per Documents	2.87
International Co-Authorships %	19.77

Publication Trends

Figure 2 depicts the trends in TPACK research over time, showing a consistent annual growth rate of 30.13% from 2006 to 2024. Overall, the research trend in TPACK has seen a steady increase, except in 2014, when there was a notable decline in publications, dropping by nearly 40% or 34 articles compared to the previous year. A slight decline in TPACK publications occurred in 2016, with a drop of 7 articles, representing an 8.5% decrease from the previous year. However, a notable increase was observed in 2021, with publications rising by 50% compared to 2018. This surge was largely attributed to the global COVID-19 pandemic, which accelerated the adoption of online learning and prompted educators to adapt to digital tools. Consequently, numerous studies emerged focusing on educators' readiness and profiles for online teaching, their technological competencies, and the creation of new instruments to evaluate teachers' TPACK (Scherer et al., 2021; Schmid et al., 2020).

The highest number of publications occurred in 2023, with 239 articles published. As of September 2024, there were 229 articles on TPACK published. Previous research has also shown a growing trend in TPACK-related studies. Lee et al. (2022) identified a rise in publications between 2011–2020, while Vallespin and Prudente (2023)

conducted a similar analysis for the period 2006 and 2023, also revealing an increase in TPACK-related research. This upward trend shows that TPACK has become a vital framework for guiding teachers in enhancing their skills to effectively integrate pedagogy, technology, and content into the educational process. This integration is essential for fully leveraging technology in education (Scherer et al., 2019). Furthermore, incorporating technology is necessary for creating interactive and adaptive learning activities that meet the demands of the 21st century (Murithi & Yoo, 2021). As shown in Figure 2, the R-squared value of 0.9051 indicates a consistent increase in TPACK research from 2006 to 2024, making it a promising area for continued investigation, with expectations of further growth in the coming years (Irwanto et al., 2023).

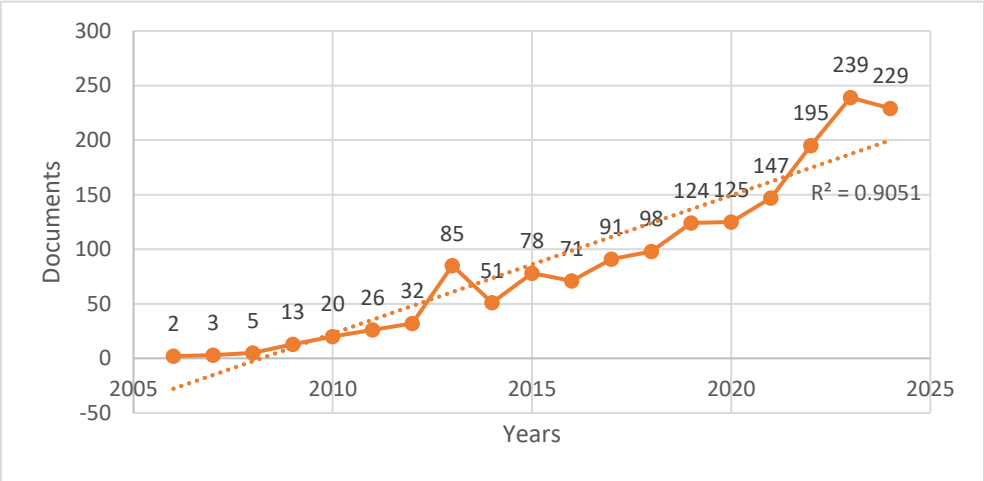

Figure 2. Annual Scientific Production of TPACK

According to Figure 3, since 2006 there has been an increasing impact on TPACK research, evident from the growing citation counts. The highest citation rate was recorded in 2009, with 16.39 citations per year. Publications during the COVID-19 period, particularly in 2020, also had a marked effect on the integration of technology in education. In 2020, the number of citations per publication was 5.27. While the citation rates for TPACK publications in 2023 and 2024 are lower, this is a common trend, as newly published articles typically receive fewer citations in the early years (Prahani et al., 2024).

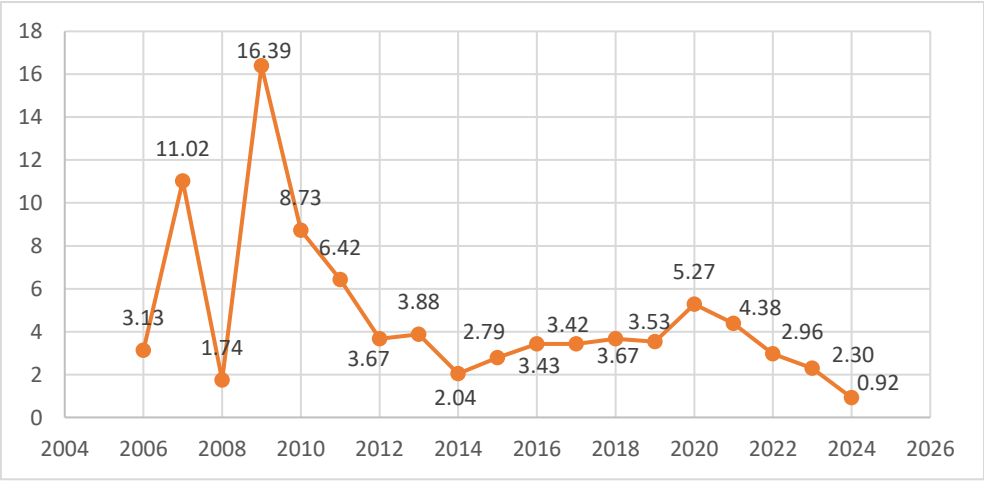

Figure 3. Average citations per year in TPACK literature (2006-2024)

Thematic Development

Figure 4 displays a Sankey diagram that visualizes the process of exploring relationships and communication patterns (Riehmann et al., 2005).

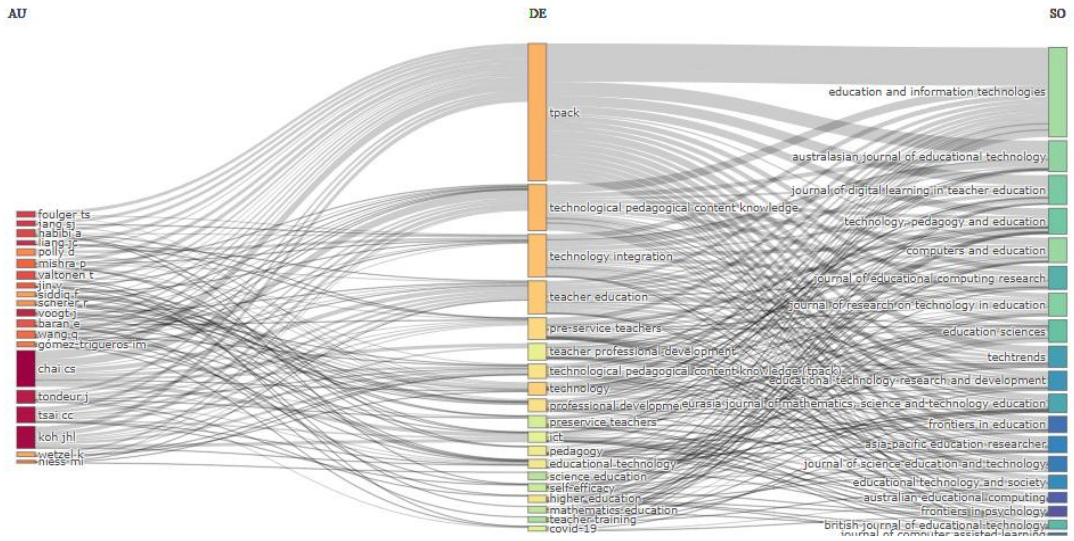

Figure 4. Thematic Development of TPACK Research using Sankey Diagram

In Bibliometrix, a three-field plot is used as a tool to examine connections between several factors, such as authors, keywords, journal sources, and others. This plot provides a comprehensive view of how these factors are interrelated (Yaqoub et al., 2023). The data analysis in this study connects authors, keywords, and journal sources. Keywords are positioned in the center, with author names placed on the left and sources on the right. Authors are linked to keywords, showing the productivity of authors in publishing articles related to those keywords. Meanwhile, keywords are connected to sources on the right, indicating the journals that publish the most articles related to those keywords.

Based on Figure 4, the keywords “TPACK” or “technological pedagogical content knowledge”, and “technology integration” are the three largest boxes, indicating that these keywords are the most frequently used compared to other keywords in articles published on the same subject. The keyword “TPACK” has 18 inbound connections, meaning 18 of the top 20 authors have used this term in their publications. Meanwhile, “technological pedagogical content knowledge” has 14 inbound connections, and “technology integration” has 9 inbound connections.

Chai CS is the author with the widest box, signifying the highest productivity in publishing articles related to this field. The thickest lines connect Chai CS to the keywords "TPACK" and "technology integration". Chai CS’s most recent publication focuses on developing TPACK competencies to promote Virtual Reality (VR) use in independent learning for a Mandarin L1 writing program (Jiang et al., 2024). The journal *Education and Information Technologies* also stands out, with 20 incoming flows and the keywords "TPACK" and "technology integration" being most closely associated with it. This shows that *Education and Information Technologies* is the key publication source for research on these keywords.

Top Author

Table 2 highlights the seven most prolific authors in TPACK research, detailing their contributions based on h-index scores and total article citations. The fractionalized article value represents an author's specific contribution to a publication when collaborating with others (Waltman & van Eck, 2015). Among these authors, Chai Ching Sing and Koh Joyce Hwee Ling are the most published. Chai, affiliated with the Chinese University of Hong Kong, leads with 47 publications and 3,483 citations, underscoring the extensive influence of his work. Chai's research primarily focuses on assessing TPACK competencies in teachers and teacher candidates, AI-driven learning, and STEM education (Chai et al., 2024; Cheah et al., 2019; Lin et al., 2022).

Table 2. List of Top Authors in TPACK Research and their Impact

Authors	Articles	Articles Fractionalized	h-index	Total Citation
Chai CS	47	13.73	33	3483
Koh JHL	25	10.77	23	2319
Tsai CC	19	5.33	16	2394
Tondeur J	15	3.48	13	1657
Voogt J	13	3.79	13	1373
Liang JC	12	3.72	9	264
Jang SJ	11	5.50	10	694

Koh Joyce Hwee Ling, from the National Institute of Education, is another leading author with 25 published articles and a total of 2,319 citations. His research primarily explores topics such as teachers' beliefs about designing constructivist-based lessons through the TPACK framework, enhancing teachers' TPACK skills, and improving university faculty's ability to integrate technology in teaching (Dong et al., 2015; Koh, 2019, 2020). Both Chai and Koh have frequently collaborated with other researchers to publish studies focused on developing teachers' TPACK and designing lessons that incorporate technology in teaching (Chai et al., 2013; Koh et al., 2013, 2017).

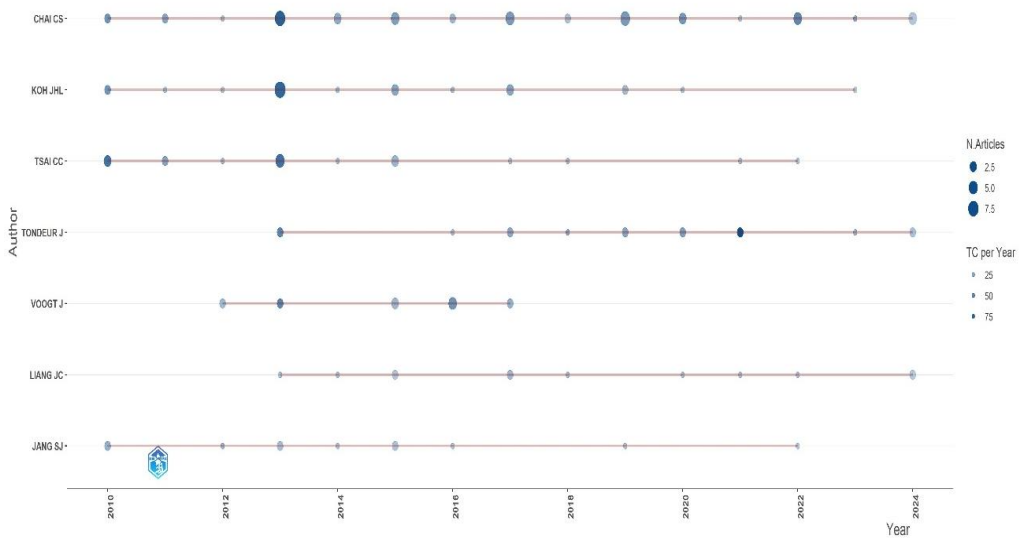

Figure 5. Top Author Production over Time

Figure 5 shows the yearly publication output of the most prolific authors in the TPACK field. Chai CS has consistently published articles on TPACK from 2010 through 2024. His first article, published in 2010, discussed the profiles of prospective teachers in Singapore within the TPACK framework (Koh et al., 2010). This article, co-authored with Koh JHL and Tsai CC, has had a significant impact on related research, averaging 14.8 citations per year. The highest number of publications by a single author in one year occurred in 2013, with Koh JHL leading the field by publishing 9 articles in that year alone.

The most cited article is one published by Voogt et al. (2013), titled "Technological pedagogical content knowledge – a review of literature", which has received 514 citations. This paper reviews 55 articles on TPACK, aiming to outline the theoretical foundations and application of TPACK in educational settings. Another highly cited article is by Lee & Tsai (2010), titled "Exploring teachers' perceived self-efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web", which has 368 citations. This study examines the creation of a questionnaire designed to assess teachers' self-efficacy concerning TPCK-Web and their perspectives on web-based learning (Lee & Tsai, 2010).

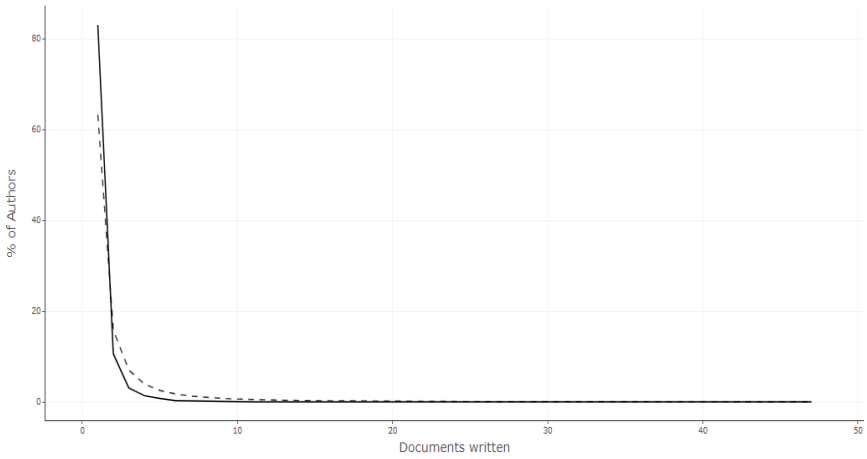

Figure 6. Author Productivity through Lotka's Law

According to Brew et al. (2016), Lotka's Law describes the trend of publication frequency among authors in a certain discipline, like TPACK. The number of authors who contribute a large number of articles tends to decrease as the volume of publications increases, according to the law. In contrast to four writers (0.01%) who have authored ten or more works in the subject, 2,910 authors (83%) have only published one TPACK-related article, as seen in Figure 6.

Top Sources

The top ten sources with the most publications on TPACK and their impact on the field are displayed in Table 3. Research on TPACK may be accessed primarily through these journals. With 95 articles about TPACK, the USA based source, *Education and Information Technologies* tops the list. Published by Kluwer Academic Publisher,

this journal covers topics in education and e-learning. Since its first publication in 2014, this journal has accumulated 1,274 citations and holds an h-index of 20. The h-index is a measure that evaluates an author's productivity and the impact of their most frequently cited works (Hirsch & Buela-Casal, 2014).

Table 3. Top Sources in TPACK Research and their Impact

Source Name	**N**	**Cite Score (2023)**	**h_index**	**g_index**	**m_index**	**TC**	**PY_start**
Education and Information Technologies	95	10.00	20	31	1.82	1274	2014
Computers and Education	53	27.10	35	53	1.94	5232	2007
Australasian Journal of Educational Technology	42	7.60	28	42	1.75	1992	2009
Journal of Research on Technology in Education	42	11.70	19	41	1.12	3167	2008
Journal of Digital Learning in Teacher Education	39	4.90	17	37	1.13	1384	2010
Technology, Pedagogy, and Education	33	9.50	15	24	1.25	621	2013
Education Sciences	31	4.80	11	18	1.00	348	2014
British Journal of Educational Technology	29	15.60	18	27	0.95	767	2006
Journal of Educational Computing Research	29	11.90	21	29	1.31	1646	2009
Eurasia Journal of Mathematics, Science and Technology Education	26	4.30	10	14	0.67	245	2010

Computers and Education stands out as the source with the most citations, totaling 5,232, and the highest CiteScore of 27.1. Citescore is a measure that assesses a journal's impact by comparing the total citations it receives to the number of articles it publishes over a specific period (Croft & Sack, 2022). This journal, also based in the USA and focusing on computer science and social sciences, holds the highest h-index among the sources listed at 35. This indicates that *Computers and Education*, published by Elsevier Ltd, has the greatest impact on TPACK research. Meanwhile, the *British Journal of Educational Technology*, also from the USA and published by Wiley-Blackwell Publishing Ltd, is the longest-running source for TPACK-related research, having been publishing articles since 2006.

Figure 7 illustrates the journals that belong to the core zone for TPACK-related publications, based on Bradford's Law, which posits that journal articles on a specific topic tend to follow a pattern where the majority of articles are concentrated in a few major journals (core zone), while many other journals contribute only one or two articles

on the topic (Drott et al., 1979). This suggests that only a small number of journals serve as the primary sources for relevant papers, while most journals contribute fewer articles.

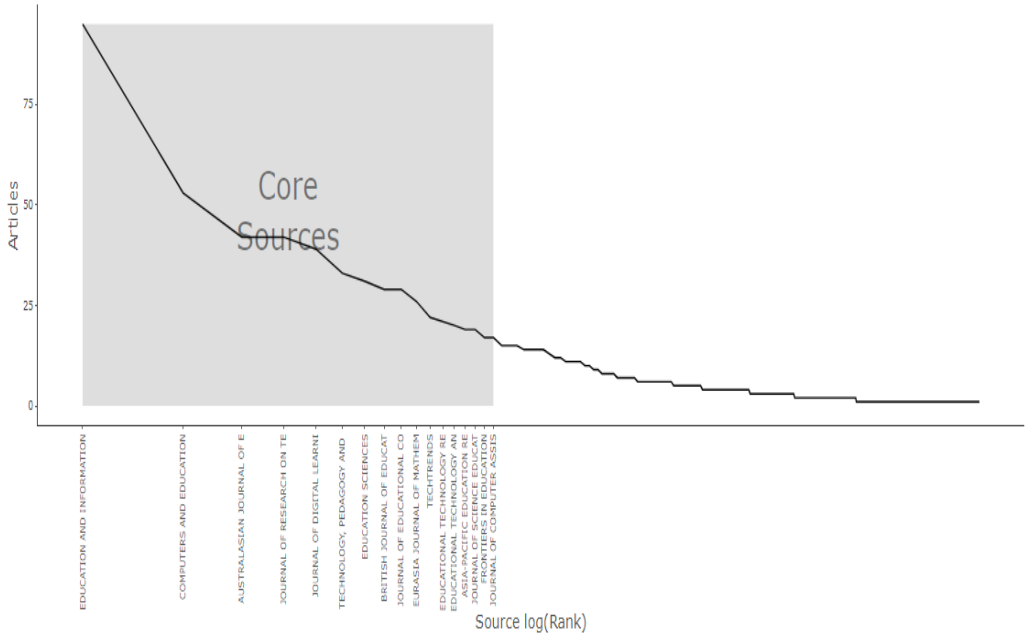

Figure 7. Core Sources through Bradford's Law

Figure 8 illustrates that the 10 most productive sources have consistently published articles related to TPACK each year. *Education and Information Technologies* and *Computers and Education* are two journals that have remained dedicated to advancing research in the field of TPACK. Since first publishing articles on TPACK in 2014, *Education and Information Technologies* has grown to become the journal with the highest number of TPACK-related publications by 2024. In contrast, *Computers and Education* began publishing articles on TPACK as early as 2007 and has consistently released articles each year, making it the second most prolific journal in TPACK publications by 2024, with a total of 53 articles published.

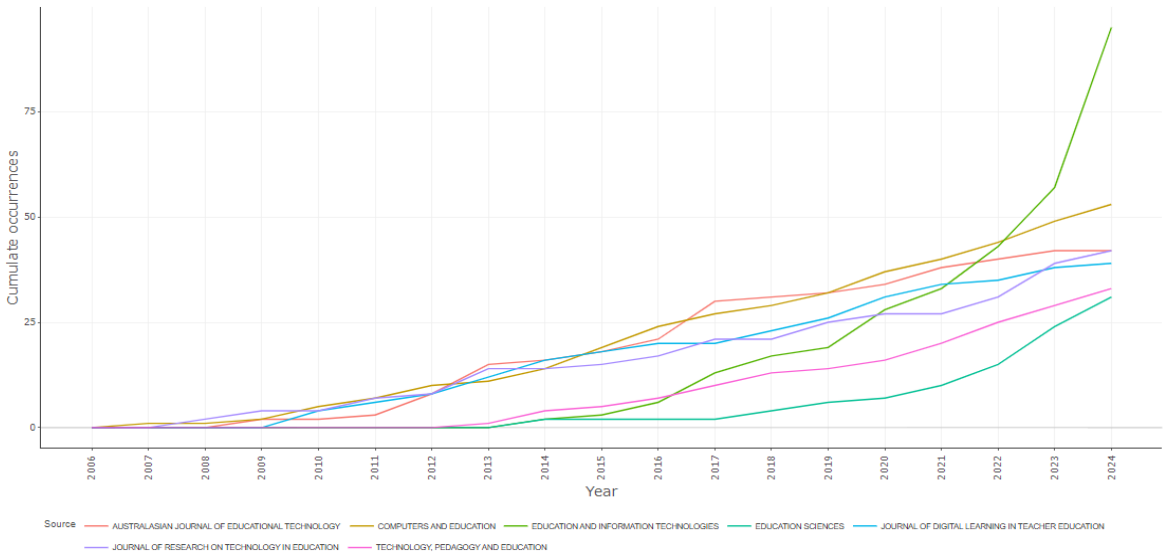

Figure 8. Top Sources Publication Growth

Most Influential Literature

Table 4 lists the ten most frequently cited TPACK research articles, which have significantly influenced the trajectory of TPACK studies in subsequent years. The most frequently cited work is by Schmidt et al. (2009), which introduced a tool for evaluating pre-service teachers' TPACK competencies. This instrument has profoundly influenced subsequent research aimed at assessing and understanding the TPACK knowledge of teachers and pre-service educators. The second most cited article, authored by Angeli and Valanides (2009), explores the epistemological foundations of TPACK and introduces the ICT-TPCK framework. This framework provides a structured approach to integrating technology into teaching, including methods for evaluating teachers' use of the concept and its effects on student outcomes.

Table 4. Most Highly Cited TPACK Paper from 2006 to 2024

Rank	Total Citation	TC per Year	Author(s)/years	DOI	Source
1	992	62.00	(Schmidt DA, 2009)	10.1080/15391523.2009.10782544	J Res Technolog Educ
2	750	46.88	(Angeli C, 2009)	10.1016/j.compedu.2008.07.006	Comput Educ World J Gastroenterol
3	548	34.25	(Harris J, 2009)	10.1080/15391523.2009.10782536	J Res Technolog Educ
4	514	42.83	(Voogt J, 2013)	10.1111/j.1365-2729.2012.00487.x	J Comput Assisted Learn
5	512	28.44	(Koehler MJ, 2007)	10.1016/j.compedu.2005.11.012	J Educ Comput Res
6	399	79.80	(Falloon G, 2020)	10.1007/s11423-020-09767-4	Educ Technol Res Dev
7	389	27.79	(Graham CR, 2011)	10.1016/j.compedu.2011.04.010	Comput Educ
8	369	24.60	(Lee MH, 2010)	10.1007/s11251-008-9075-4	Instr Sci
9	353	23.53	(Archambault, LM, 2010)	10.1016/j.compedu.2010.07.009	Comput Educ
10	347	23.13	(Chai CS, 2010)	NA	Educ Technol Soc

Meanwhile, the article by Fallon (2020) has the highest annual citation rate, at 79.80. This article presents a conceptual framework for digital competence, which supports teachers in integrating the latest technologies into teaching activities to enhance students' skills and learning outcomes. These articles have played a pivotal role in enhancing the understanding of TPACK and have significantly shaped the progress of research in this domain.

Top Countries and Affiliations

The countries with the highest number of published articles on TPACK are presented in Table 5. USA leads with the most articles at 608 and the highest total citations, reaching 6,804. China ranks second with 399 articles, followed by Turkey in third place with 294 articles. Meanwhile, Netherlands has the third-highest average citations per article overall, at 63.2. Singapore and Cyprus, which do not rank in the top 10 for total publications, have the highest and second-highest average citations per article, with averages of 104 and 90.7, respectively.

Table 5. Countries with the Highest Number of Documents and Citations in TPACK Research

Country	Frequency	Total Citation	Average Article Citations
USA	608	6804	32.10
China	399	3527	22.20
Turkey	294	2078	17.20
Indonesia	267	844	8.70
Australia	186	1537	22.60
Germany	108	520	11.30
Malaysia	96	368	10.80
South Africa	85	322	7.00
Spain	69	615	18.10
Netherlands	54	1011	63.20

According to Table 5, when assessing the top ten countries by continent, Asia leads in TPACK-related research output with 948 published articles. North America, primarily through contributions from the USA, ranks as the second most productive continent with 608 articles. Europe follows closely with 525 articles, while Africa has contributed a total of 85 articles to TPACK research.

Figure 9 depicts the trajectory of TPACK-related publications among the top 10 most active countries in the field. Since 2006, USA has consistently led in publishing research articles on TPACK. The country's emphasis on technology integration in both curricula and teaching practices has contributed to this trend, as American educational institutions have heavily invested in technological tools for educational improvement. These efforts are intended to enhance teaching quality and positively impact student achievement (Selingo, 2013). As a result, there is a substantial amount of research on teachers' and teacher candidates' skills in embedding technology into education, framed by the TPACK model. China has remained the second most productive country since 2008, while Turkey, which began publishing TPACK-related research in 2009, has consistently ranked third in the number of publications through 2024. Indonesia entered the fourth spot in 2020, surpassing the Netherlands, which had maintained stable publication numbers since 2017 and, by 2024, ranked tenth.

Figure 10 highlights the affiliations with the highest output in TPACK publications. Nanyang Technological University in Singapore leads with 39 articles, making it the most prolific affiliations in this field. Chinese

universities notably dominate the top 10, with four affiliations represented. Beijing Normal University takes third place with 36 articles, followed by The Chinese University of Hong Kong in fourth place with 28 articles. The Education University of Hong Kong ranks sixth with 22 articles, while Central China Normal University is in eighth place with 21 articles. Although the USA has the highest overall publication count, it contributes only two affiliations to the top 10. Arizona State University ranks seventh with 21 articles, and Iowa State University is tenth with 19 articles. These two affiliations are the top contributors from the USA in the field of TPACK research.

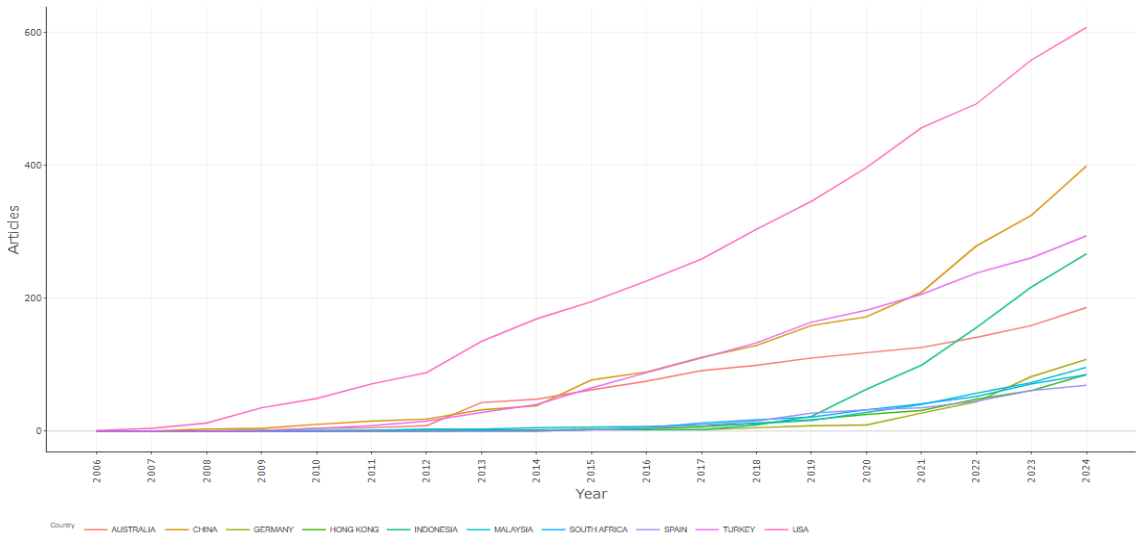

Figure 9. Document Growth of TPACK by Country

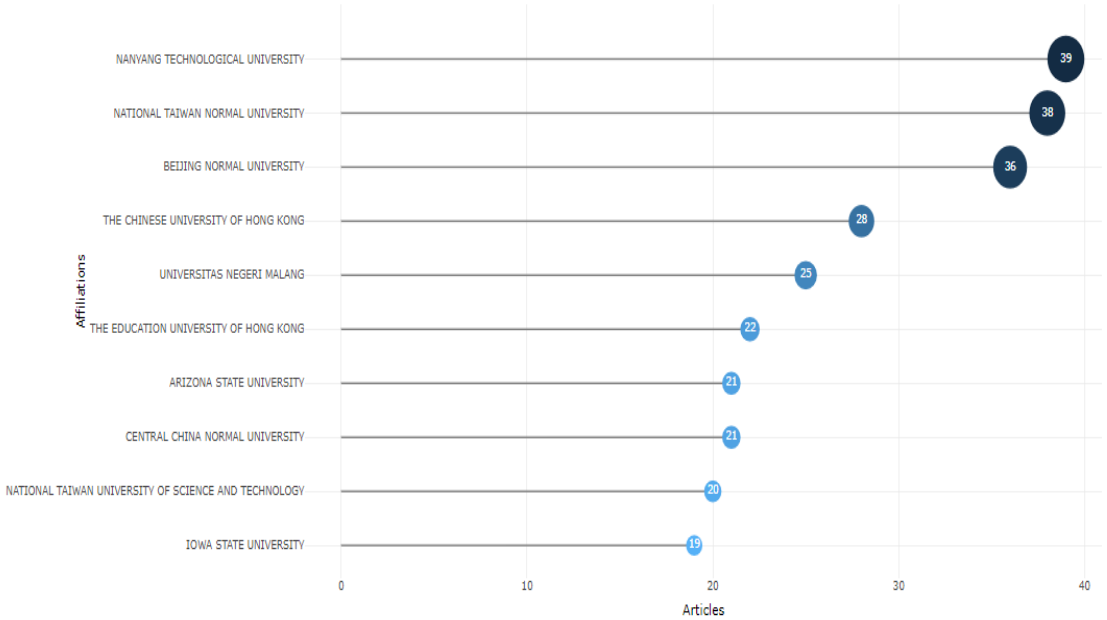

Figure 10. Top Affiliations

Keyword Trend

Figure 11 highlights the most commonly used keywords in TPACK research. With 706 instances, the keyword "TPACK" comes in first, demonstrating its prevalence throughout the research field. With 178 references,

"technology integration" comes next, highlighting the close relationship between the TPACK framework and successful technology integration in instructional strategies. Aumann et al. (2024) emphasizes that teachers must utilize their TPACK skills to maximize the benefits of technology in instructional activities. Furthermore, "pre-service teacher" is mentioned 76 times, suggesting a strong focus in TPACK research on building competencies among future teachers. For instance, Öztürk et al. (2024) explore how pre-service teachers' TPACK levels impact their readiness to engage in blended learning.

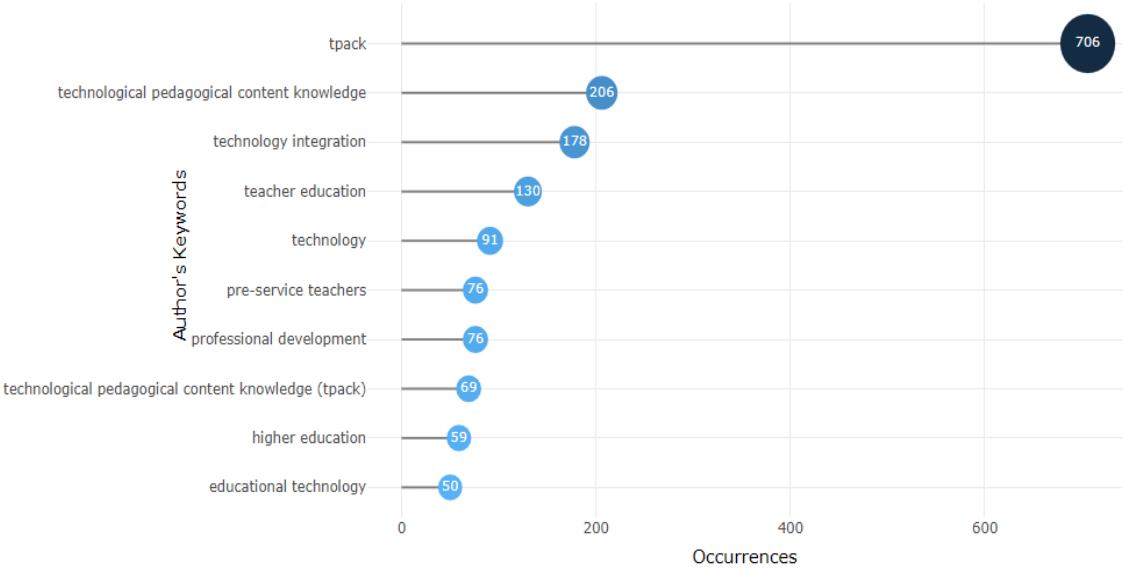

Figure 11. Most frequent Words

Figure 12 illustrates the evolution of keywords from 2006 to 2024. The term "TPACK" saw a notable surge in usage starting in 2015. "Higher education" first appeared in 2012 and has shown consistent growth through 2024, reflecting the increasing number of TPACK studies within this context. Similarly, "technology integration," which emerged in 2008, has experienced steady growth, with a significant increase in 2024. Other keywords related to TPACK have also grown annually, signifying the expanding interest in this field of research.

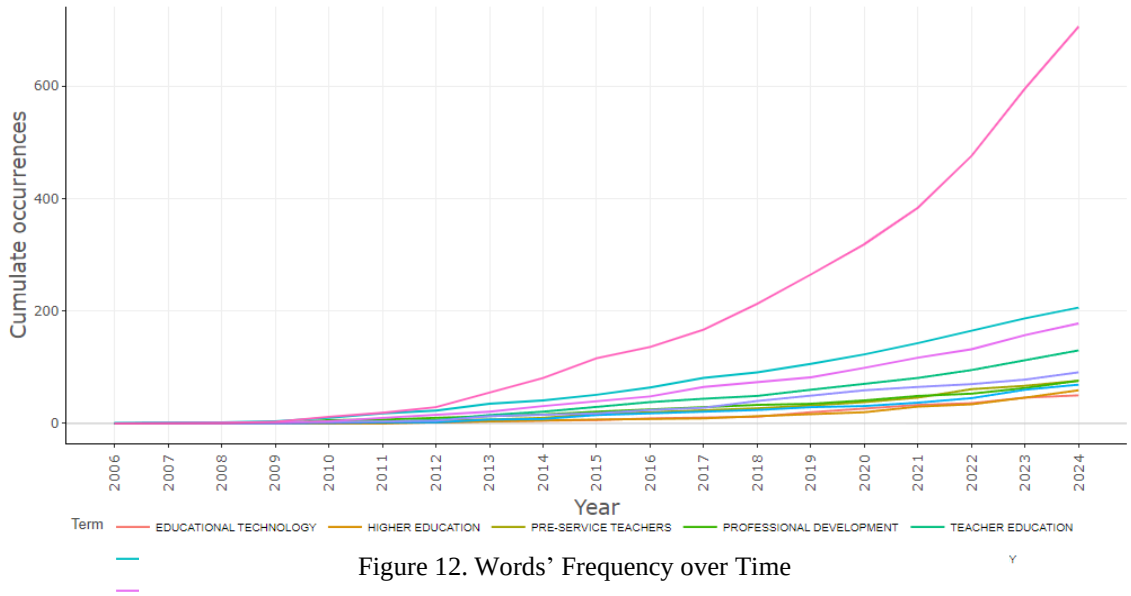

Figure 12. Words' Frequency over Time

Conceptual Structure

Figure 13 displays the co-occurrence network of keywords, illustrating the connections among terms found in articles within the TPACK domain. Each keyword is depicted as a circle, with larger circles representing higher relevance. The keywords are organized into four clusters, distinguished by red, blue, green, and purple colors. Proximity between circles reflects the strength of the relationships between keywords (Kut & Pietrucha-Urbanik, 2022). Furthermore, the figure shows lines linking the keywords, where thicker lines indicate a higher frequency of co-occurrence in publications.

The division of keyword clusters into four groups is as follows:

Cluster 1 (Red): Technology Integration

This cluster examines the connection between TPACK competencies and the use of technology in teaching and learning processes. Central terms associated with this group include "TPACK," "technology integration," "teacher education," and "pre-service teachers." The most frequently referenced work in this cluster is Harris et al. (2009), which presented TPACK as a powerful framework to support educators in effectively integrating technology. Likewise, Abbitt (2011) emphasized how the TPACK model serves as a practical guide for pre-service teachers to incorporate technology into their instructional methods

Cluster 2 (Blue): Learning Strategies

Keywords in this cluster include “improving classroom teaching”, “pedagogical issues”, and “teaching learning strategies”. The focus of this group is on how TPACK relates to strategies that can improve teaching practices within the classroom. Hsu et al. (2020) highlighted that in game-based learning (GBL), it is crucial for teachers to have solid pedagogical knowledge about using games to boost student engagement in learning. Additionally, Jang (2010) found that the use of interactive whiteboards (IWB) can help enhance science teachers' TPACK, as well as improve student motivation and performance during lessons.

Cluster 3 (Green): Educator Competence

The significance of TPACK (technological, pedagogical, and content knowledge) components as essential skills for teachers is emphasized by the green cluster. Bowers and Stephens (2011) investigated how to use technology to create effective lesson plans for math teachers. Similar to this, Mohammadpour and Maroofi (2023) created a performance-based instrument to assess math and science teachers' pedagogical and content understanding, providing a useful tool for furthering this field of study.

Cluster 4 (Purple): Teacher Professional Development

TPACK is emphasized in this cluster as a fundamental framework for promoting professional teacher

development. Two of the main themes are "teacher professional development" and "technological pedagogical and content knowledge." An online training program developed by Rienties et al. (2013) greatly improved the TPACK proficiency of 33 participants. The association between TPACK abilities and online teaching expertise was also examined by Aquino et al. (2022), who provided a structured framework to direct teacher development in contemporary educational environments.

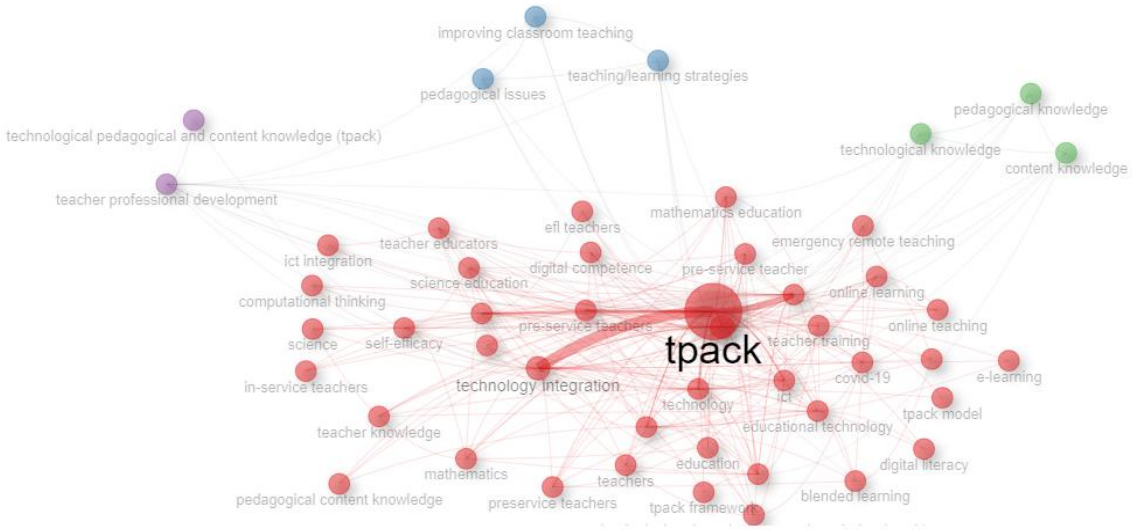

Figure 13. Co-occurrence Network

The analysis above highlights the connection between the identified keywords and education. The presence of "technology integration" underscores the need for teachers to optimize technological advancements in education to create learning activities aligned with 21st-century demands. Keywords such as "pre-service teachers", "teacher education", and "teacher professional development" emphasize the importance of designing programs focused on professional growth for teachers and teacher candidates, enhancing their TPACK knowledge to develop frameworks that align with evolving educational trends.

In bibliometric studies, another conceptual tool that provides valuable insights is the thematic map. This type of map visualizes key themes within a field of study (Cobo et al., 2011). For this analysis, thematic maps were created using author keywords, limited to 100 terms to enhance the visualization of these themes. These maps categorize keywords into clusters that reveal significant research themes. The two dimensions used in thematic maps are centrality, which is represented on the x-axis and indicates the significance of a topic, and density, which is represented on the y-axis and indicates the theme's degree of development (Madsen et al., 2023).

There are four main categories of topics identified by the thematic map. Motor themes, which represent the most frequently discussed topics in the field, are highlighted in the upper-right quadrant. "TPACK", "technology integration", "COVID-19", "online learning", and "online teaching" are some of these major themes, as seen in Figure 14. In the upper-left quadrant, *niche themes* appear as specialized but relatively isolated topics. Themes such as "technological", "pedagogical" and "secondary education" are prominent here, suggesting various connections between TPACK and these specific areas. The lower-right quadrant presents *basic themes* which includes foundational themes with low development but high centrality and relevance to TPACK. These themes,

including "technology", "pedagogy", "mathematics", "mathematics education", and "teacher professional development", are integral to TPACK research. Lastly, motifs that are emerging or declining are represented by the lower-left quadrant, which has low centrality and density. These cover topics including "teaching/learning strategies", "pedagogical issues", "motivation", and "improving classroom teaching" (Madsen et al., 2023; Mühl & de Oliveira, 2022). These categories provide a comprehensive view of the thematic trends and their significance within TPACK research.

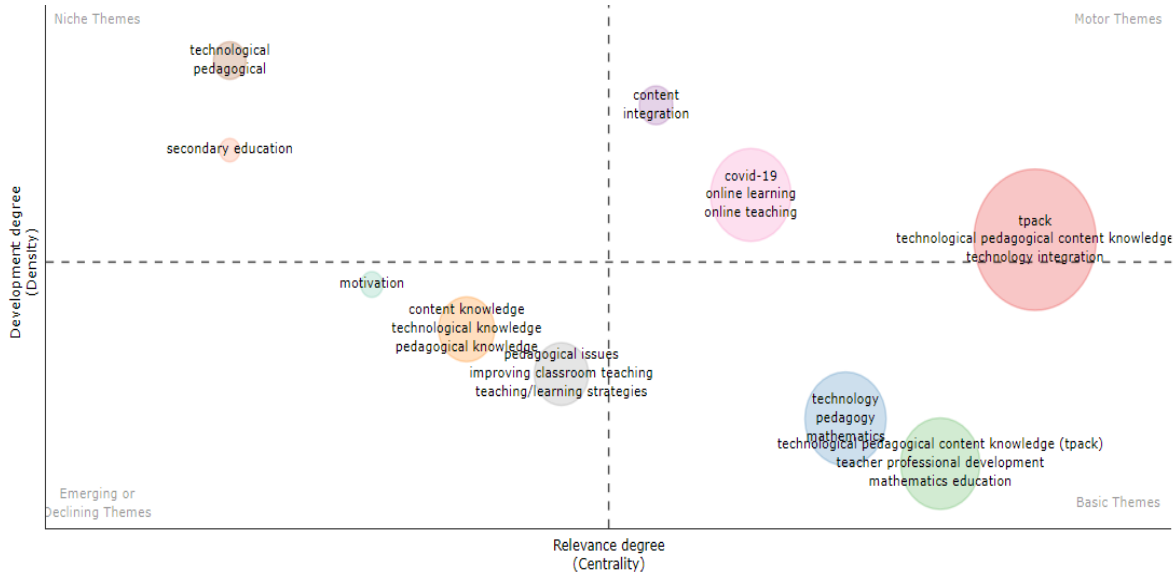

Figure 14. Thematic Map

Figure 15 illustrates the thematic evolution within the research field based on author keywords. This evolution is represented using a flow diagram, providing a visual depiction of how themes within a research area have developed over time (Madsen et al., 2023).

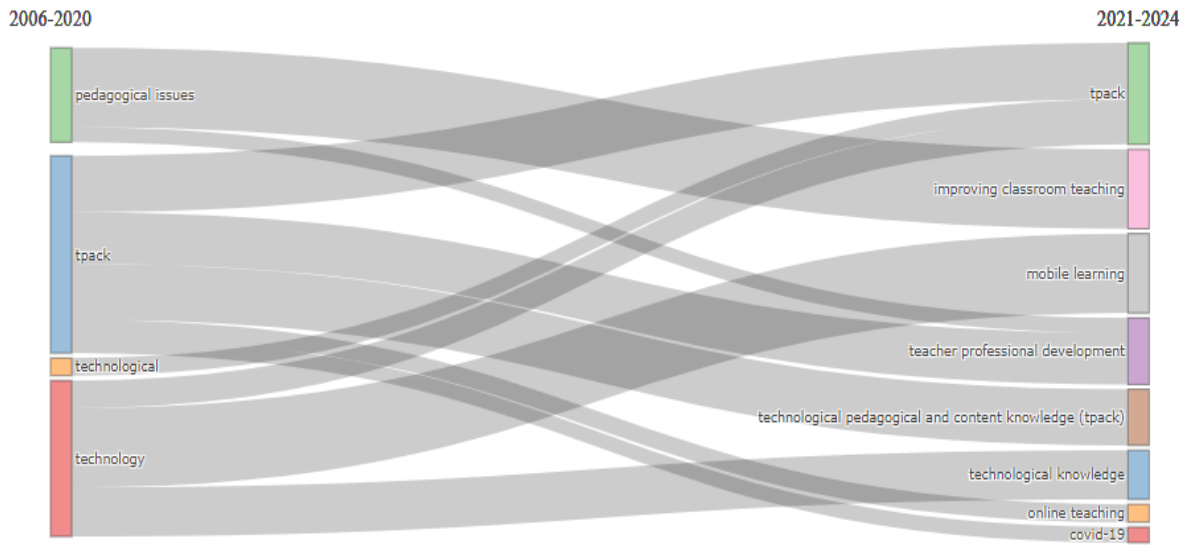

Figure 15. Thematic Evolution

The diagram highlights the progression of themes in TPACK research, divided into two distinct periods: 2006–2020 and 2021–2024. "TPACK" and "technology" emerged as key themes throughout the first phase, which ran from 2006 to 2020. This underscored the early adoption of the TPACK framework as a fundamental model for incorporating technology into teaching methods. During this time, TPACK was developed as a methodical strategy for using technology to improve teaching methods. In the subsequent phase, spanning 2021 to 2024, the evolution of TPACK research themes became apparent. Emerging topics such as "mobile learning", "improving classroom teaching", and "teacher professional development" signified the continued expansion and refinement of the TPACK framework.

These themes underscore the growing focus on enhancing teaching quality through professional development and leveraging advancements in technology. Today, TPACK and technology integration remain closely linked, emphasizing their importance in supporting teacher professional growth. This alignment is critical for improving classroom learning experiences and ensuring that educational practices keep pace with rapid technological advancements.

Multiple Correspondence Analysis (MCA) is a method used to examine relationships among three or more variables by employing geometric techniques to clearly illustrate patterns (Ayele et al., 2014). By utilizing MCA, researchers can explore connections between various concepts within a research field (Wang et al., 2022). Figure 16 presents an MCA analysis divided into two clusters: red cluster and blue cluster. In the red cluster, keywords such as "online learning" and "COVID-19" appear close together, indicating a strong relationship between online learning and the COVID-19 pandemic. Additionally, keywords like "TPACK", "higher education", "technology integration", "professional development", and "teacher training" are also closely positioned, reflecting a strong interconnectedness among these terms in TPACK research. In contrast, the blue cluster includes keywords such as "mathematics education", "technology", "pedagogy", and "ICT". These terms are spaced farther apart, suggesting weaker associations among them in the context of this research.

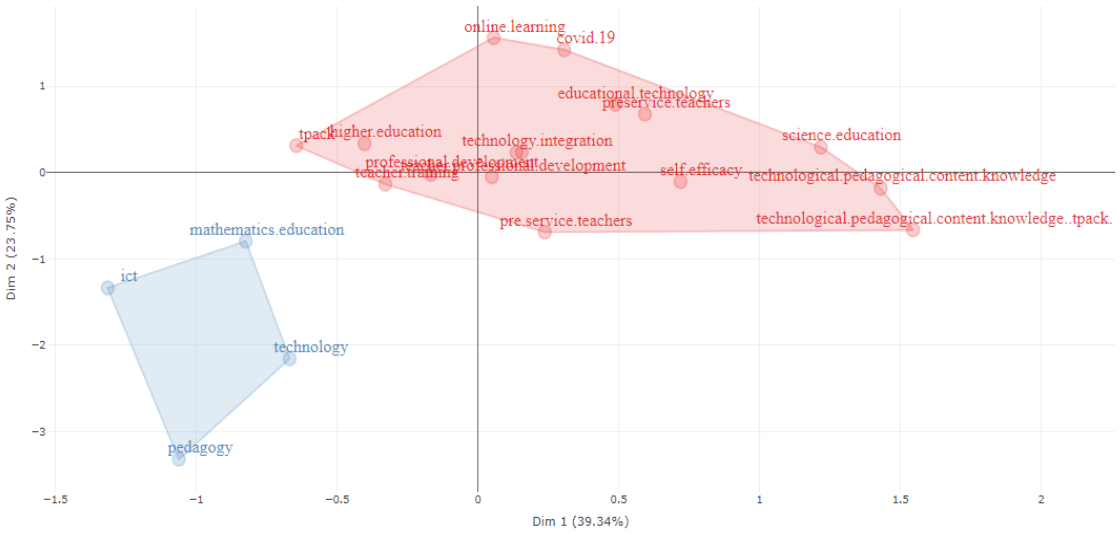

Figure 16. Factorial Analysis using MCA

The thematic dendrogram in Figure 17 illustrates the hierarchical order and relationships among author keywords, organized into two hierarchical clusters (Wei & Jiang, 2023). The blue and green clusters represent two distinct thematic groups within the TPACK field, indicating relatively distant relationships between these groups. The blue cluster focuses on themes related to keywords such as "technology integration", "teacher education", "professional development", "pre-service teachers", and "online learning". Within this cluster, the terms "online learning" and "COVID-19" are closely associated, as shown in the dendrogram. Additionally, "pre-service teachers" is linked to "professional development" reflecting a thematic connection between these concepts. In contrast, the green cluster centers on keywords like "pedagogy", "technology", "ICT", and "mathematics education". This implies that themes pertaining to the incorporation of technology into mathematics education methods are the focus of the green cluster.

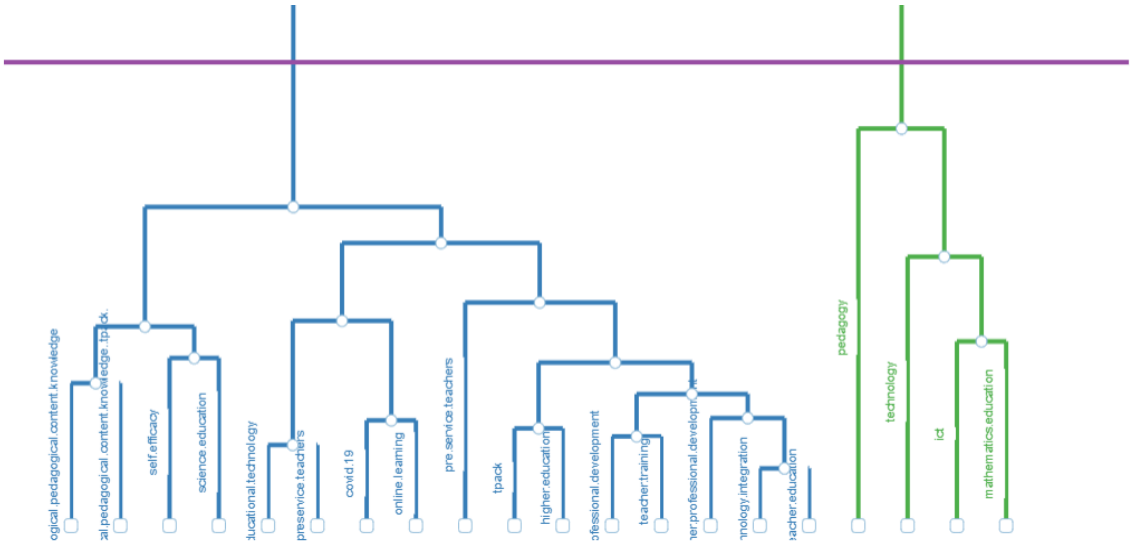

Figure 17. Thematic Dendrogram

Social Structure

Bibliometric also allows for social structure analysis, which examines collaboration among authors, institutions, and countries. The collaboration map is illustrated using nodes and links. Larger nodes indicate a more significant contribution from authors, countries, or institutions, while thicker lines connecting two nodes reflect more frequent collaboration between them (Wei & Jiang, 2023).

Figure 18 presents a collaboration map that highlights active networks of co-authorship in TPACK research. The map identifies ten distinct groups of authors who regularly collaborate. The first group is led by Chai CS, who works with authors such as Koh JHL, Tsai CC, Jong MSY, and Drajati NA. In 2017, Chai CS and Koh JHL co-authored three papers, one of which focused on the importance of developing TPACK in pre-service teachers to boost their confidence in creating effective learning activities (Chai & Koh, 2017). In 2019, Chai CS teamed up with Drajati NA and others to explore key factors in applying the TPACK framework to teaching multimodal literacy to English language learners (Tan et al., 2019). In 2020, Chai CS and Tsai CC, along with other co-authors, studied elementary school teachers' views on TPACK-Games, investigating their attitudes towards

integrating games into teaching (Hsu et al., 2021). By 2023, Chai CS and Jong MSY examined how TPACK influences the effectiveness of video-based virtual reality in educational settings (Chen et al., 2023).

The second prominent group comprises Koehler MJ, Baran E, Siddiq F, Tondeur J, Fisser P, Voogt J, and Angeli C. This team has contributed extensively to the TPACK framework, focusing on its development for pre-service science teachers, evaluating their readiness to integrate technology into teaching, and exploring how teacher education programs foster TPACK development to equip future educators for classroom technology integration (Alayyar et al., 2012; Tondeur et al., 2013, 2017). In collaboration with Schmidt and others, Baran E and Koehler MJ created an instrument to measure pre-service teachers' TPACK levels, which has since been widely utilized in related studies (Schmidt et al., 2009).

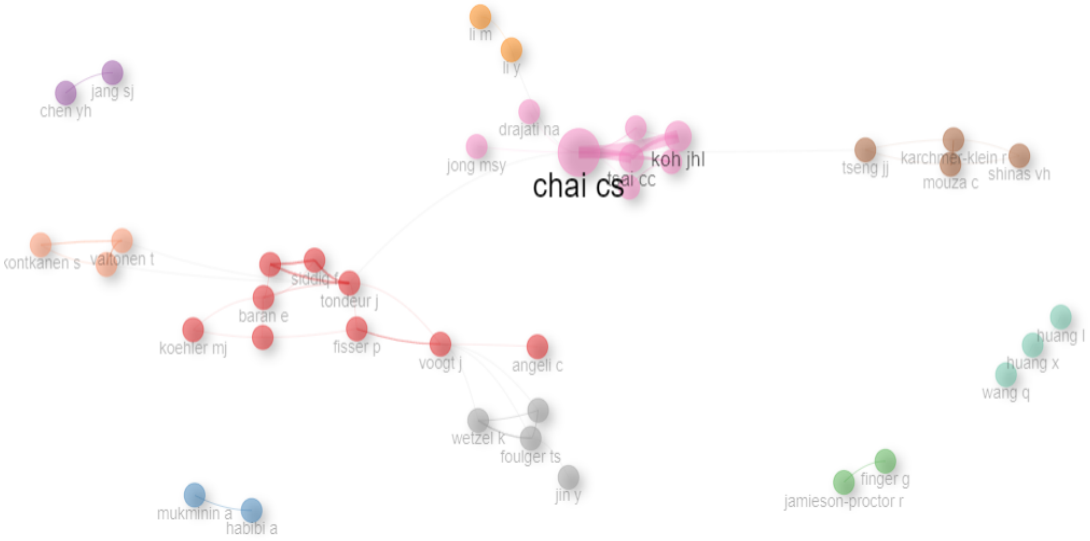

Figure 18. Authors Collaboration Network

Figure 19 displays the collaboration between institutions in TPACK research. The analysis shows four main collaborative groups. The first, led by Nanyang Technological University, is the most prominent, with active partnerships with institutions such as Central China Normal University, National Taiwan Normal University, Universitas Negeri Malang, Northeast Normal University, and others. The strongest collaboration is indicated by the thick line connecting Nanyang Technological University and National Taiwan Normal University, highlighting their active research partnerships on TPACK. The second major cluster includes universities like Arizona State University, the University of Florida, the University of Eastern Finland, Monash University, and Middle East Technical University. The third cluster features collaboration among three Turkish universities: Gazi University, Necmettin Erbakan University, and Mersin University along with Purdue University in the USA. Additionally, two Australian universities, Curtin University and Griffith University, are also significant contributors to the TPACK research field.

The collaboration between countries is depicted in Figure 20, highlighting nations actively engaged in joint research efforts. China and Hong Kong stand out as the most collaborative countries, with a total of 32 TPACK-related articles published. USA also demonstrates significant productivity in collaboration, particularly with

China, Turkey, and Canada. USA and China collaborations have resulted in 24 articles, USA and Turkey collaborations in 15 articles, and USA and Canada collaborations in 9 articles. Additionally, a productive partnership between two Southeast Asian countries, Indonesia and Malaysia, is notable, with a total of 14 articles published through their collaboration.

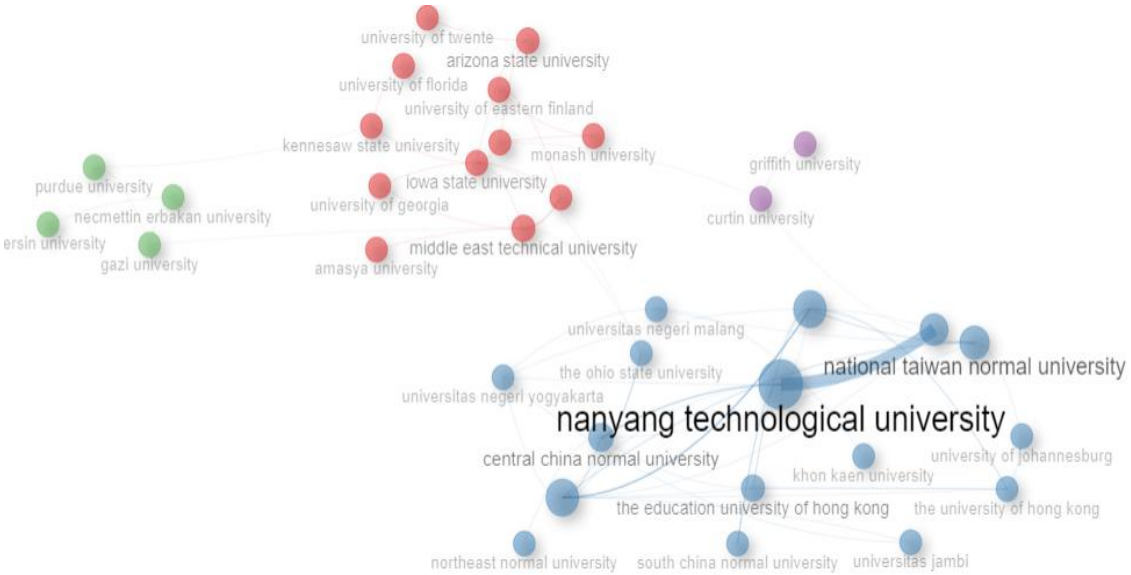

Figure 19. Institution Collaboration Network.

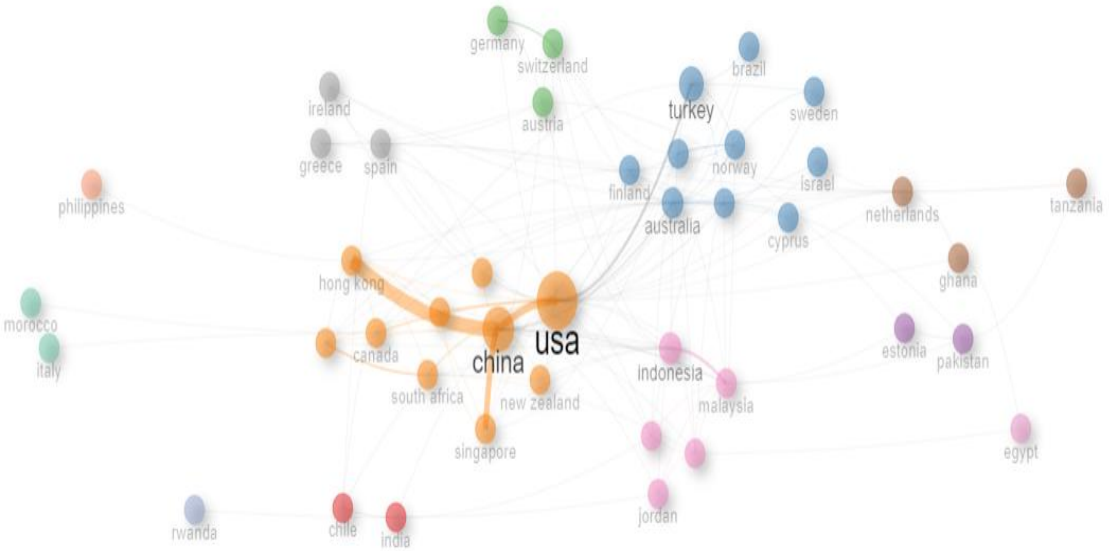

Figure 20. Countries Collaboration Network

Conclusion

Table 6 summarizes the trends in TPACK research from 2006 to 2024 based on bibliometric analysis. The analysis, which includes 1,634 documents authored by 3,507 researchers, highlights a notable increase in TPACK-related publications over the years, with an annual growth rate of 30.13% and an R-square value of 0.9051. These figures reflect a steady rise in interest and research activity in this area. Additionally, the analysis identifies the

most prolific authors, journals, countries, and institutions contributing to TPACK research, offering valuable insights for pinpointing key contributors and resources in the field.

Table 6. Summary of the Findings

Parameters	Information
Total documents	1634
Annual growth rate (%)	30,13
Total authors	3507
Top Author	Chai CS (47 articles)
Total sources	486
The most productive source	Education and Information Technologies (95 articles)
Top-cited article (DOI)	10.1080/15391523.2009.10782544
The most productive country	USA (608 articles)
The most productive affiliation	Nanyang Technological University (39 articles)
The most favourite keyword	TPACK, technology integration, teacher education, pre-service teacher.
Emerging research directions	Pedagogical issues, improving classroom teaching, teaching/learning strategies

Chai Ching Sing emerges as the most prolific author, with a total of 47 articles published from 2010 to 2024, maintaining consistent output during this period. The international co-authorship rate of 19.77% highlights the global nature of TPACK research collaborations. Chai Ching Sing is also recognized for frequently collaborating with other researchers, significantly expanding the scope of TPACK studies. TPACK-related research has been published across 486 sources, with *Education and Information Technologies*, a U.S.-based journal, leading as the most productive source with 95 articles. USA is the most productive country in TPACK research, contributing 608 publications, emphasizing the integration of technology through the TPACK framework as a key focus in U.S. higher education. Singapore's Nanyang Technological University is identified as the most productive affiliation, with 39 articles published in this field.

The article by Schmidt et al. (2009) on developing an instrument to assess educators' TPACK competencies is the most frequently cited publication, highlighting its significant influence on subsequent research in this field. This reflects the strong emphasis within TPACK studies on evaluating the TPACK knowledge of both current and future teachers across various subject areas. Keywords like "teacher education" and "technology integration" highlight the link between teacher preparation and the objective of improving TPACK knowledge to facilitate the efficient use of technology in the classroom. Additionally, the phrase "pre-service teachers" highlights the importance of teacher preparation programs in higher education by guaranteeing that aspiring teachers are prepared to successfully incorporate technology into 21st-century learning environments (Kirschner, 2015).

These results can help higher education institutions and teacher preparation programs tailor their curricula to focus on developing TPACK competencies. This approach will equip both current educators and future teachers with the skills needed to integrate technology effectively in line with the requirements of 21st-century education. In

the long run, this bibliometric analysis provides a basis for future studies to identify key authors, sources, affiliations, and countries that are making significant contributions to the field of TPACK.

Recommendations

One of the limitations of this study is the narrow scope of data used, as it was exclusively sourced from the Scopus database. To gain a more thorough understanding of TPACK research, future studies should consider broadening the analysis by incorporating additional databases, like Web of Science, alongside Scopus. Moreover, the bibliometric thematic analysis relies on the researcher's criteria for selecting keywords to extract articles from the database. If these keywords are not carefully chosen, there is a risk of including irrelevant articles or excluding pertinent ones. Therefore, future research should implement stricter data selection criteria, utilizing more precise keywords that are directly connected to the TPACK framework and its role in education.

While bibliometric analysis provides valuable quantitative insights, such as keyword frequencies, author trends, and institutional and national contributions, it falls short in delivering qualitative data. This qualitative dimension is crucial for a more holistic understanding of the research processes and outcomes. Consequently, future research should consider combining bibliometric analysis with other methodologies, such as a Systematic Literature Review (SLR), to gain a more in-depth and nuanced perspective on the field.

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