

A Bibliometric Analysis of Research on Technological Pedagogical Content Knowledge on In-Service Teachers in Higher Education

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Abstract

Technological Pedagogical Content Knowledge illustrates the interconnected nature of knowledge required to effectively integrate technology in enhancing student learning. While numerous review studies on Technological Pedagogical Content Knowledge exist, those that employ a bibliometric analysis are limited. In this comprehensive bibliometric review, we analyzed 209 Technological Pedagogical Content Knowledge studies focusing on in-service teachers in higher education, sourced from the Scopus database from 2012 through April 2023. The significance of this study lies in its effort to map the research landscape of Technological Pedagogical Content Knowledge by addressing the main question: What are the primary trends, key contributors, thematic areas, and keyword co-occurrence networks in Technological Pedagogical Content Knowledge research on in-service teachers in higher education? We adopted PRISMA guidelines into the standard bibliometric workflow and used VOSviewer as the visualization tool. Publication trends, major contributors, research areas, and keyword co-occurrence networks were identified. The analysis indicated an increasing trend in the number of publications on in-service teachers' Technological Pedagogical Content Knowledge in higher education, with the highest number recorded in 2022. We also identified representative articles, institutions, the most contributing journals, and funding agencies, most from developed countries/regions. The analysis highlights prolific researchers, key research areas, and keyword co-occurrence networks. Overall, this analysis has provided a comprehensive overview of the current research in higher education. Based on these findings, we recommend that future research focus on Technological Pedagogical Content Knowledge training modules and AI-based Technological Pedagogical Content Knowledge frameworks for teachers in higher education.

Keywords: bibliometric analysis, higher education, in-service teachers, technological pedagogical content knowledge

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Introduction

The integration of technology in education has become increasingly essential, particularly in higher education, where the demand for innovative teaching approaches is growing. This necessity has led to the development of various frameworks to guide educators in effectively incorporating technology into their teaching practices. Among these frameworks, Technological Pedagogical Content Knowledge (TPACK) stands out as a comprehensive model that outlines the interconnected knowledge areas required by teachers. Technological Pedagogical Content Knowledge, or TPACK, is a comprehensive framework proposed by Mishra and Koehler (2006). It encompasses Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK), along with their various intersections, such as Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Pedagogical Content Knowledge (PCK) (Mishra & Koehler, 2006; Rosenberg & Koehler, 2015).

Despite the numerous TPACK studies, there is a lack of literature reviews of bibliometric analyses focusing on TPACK research conducted over the past decade, specifically on in-service teachers in higher education (Rosenberg & Koehler, 2015; Yeh et al., 2021). In the context of higher education, this study aims to provide a detailed examination of TPACK research specifically focused on in-service teachers in higher education. The research is conducted with the understanding that TPACK offers teachers a knowledge map, guiding teaching effectively in technology integration into teaching practices (Saubern et al., 2020). Given the increasing importance of educational technology in today's classrooms, possessing technological knowledge is essential for teachers to leverage educational tools effectively and enhance student learning (Cheok et al., 2017).

Hence, this paper aims to map the research landscape of Technological Pedagogical Content Knowledge and identifies key trends, contributors, and research areas, to address this research gap by conducting a comprehensive bibliometric analysis of journal publications on TPACK research on in-service teachers in higher education, utilizing the Scopus databases and VOSviewer. Generally, this comprehensive bibliometric analysis will shed light on the current state of TPACK research on in-service teachers in higher education, providing valuable insights for researchers, educators, and policymakers in higher education.

The analysis aims to identify fruitful publication sources, authors, journals, organizations, and countries associated with TPACK research, providing insights into collaborations, journal preferences, funding agencies, and suggestions for future studies. Five research inquiries guide this analysis, focusing on the period from 2012 to April 2023:

RQ1: What are the major trends in TPACK research conducted on in-service teachers in higher education ?

RQ2: Which articles, journals, nations/regions, institutions, and funding institutions are the primary contributors to TPACK research in in-service teachers in higher education ?

RQ3: Who are the most frequent publishers of TPACK research among in-service teachers in higher education?

RQ4: In which areas has the issue of TPACK research among in-service teachers in higher education been addressed?

RQ5: What are the all keyword co-occurrence networks of in-service teachers' TPACK research in higher education?

Literature Review

Technological Pedagogical Content Knowledge (TPACK) is a complicated and comprehensive framework that guides educators in integrating technology into their teaching practices. It emphasizes the need for a balanced understanding of three core components: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). TPACK ensures that technology is not used in isolation but as an integrated tool to enhance student learning and engagement, making it a valuable model for modern education.

Over the past decade, Technological Pedagogical Content Knowledge (TPACK) has garnered widespread attention as a framework for teacher education. Existing research has primarily focused on the definition, measurement, and how to enhance this capability through teacher training (Rosenberg & Koehler, 2015; Yeh et al., 2021). However, despite the substantial amount of research on TPACK, particularly in the context of pre-service teachers, studies on TPACK for in-service teachers remain relatively scarce, especially in higher education settings. This scarcity is particularly concerning because in-service teachers are facing increasing demands to integrate rapidly evolving educational technologies into their teaching practices. As higher education institutions continue to adopt digital tools, it is necessary to equip in-service teachers with the required skills to effectively incorporate these technologies into their teaching methods (Williams, 2017). The lack of research focused on in-service teachers in higher education highlights a notable gap in the existing literature that requires further investigation to support the ongoing professional development of these teachers.

With the rapid development and proliferation of educational technology, many studies have explored the application of TPACK in higher education (Saubern et al., 2020). These studies not only focus on teachers' technological knowledge but also on effectively integrating this knowledge into the teaching practice to improve student learning outcomes. For example, Cheok et al. (2017) pointed out that having technological knowledge is crucial for teachers to effectively utilize educational tools. Similarly, Santos and Castro (2020) evaluated the application of TPACK among teachers in public schools, finding that while these teachers possessed strong knowledge across the seven TPACK elements, their ability to apply technology in teaching varied significantly. This variation was largely influenced by their Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK), emphasizing the need for more structured approaches to integrating technology in teacher training programs. Additionally, these studies underscore the significance of continuous professional development in helping teachers keep pace with technological advancements and enhance their TPACK-related skills (Adipat et al., 2023). However, most existing studies are concentrated on case studies or small-scale experiments, lacking a systematic bibliometric review, which has led to a gap in the systematic understanding of the main trends, key contributors, and research hotspots within the field of TPACK research.

Although some literature reviews on TPACK research have been conducted, studies using bibliometric analysis remain limited (Hudha et al., 2020; Novia et al., 2023). For instance, Rodríguez Moreno et al. (2019) systematically reviewed publications from 2014 to 2017, highlighting the emphasis on basic and higher education while pointing out the lack of longitudinal studies that explore the practical application of TPACK by teachers in their daily routines. Similarly, Othman & Maat (2020) provided a systematic review of TPACK research in mathematics education from 2015 to 2020, revealing that qualitative research methods were predominantly used to explore technology integration in mathematics teaching.

While there is a substantial body of literature on TPACK, the bibliometric analysis of this field remains limited. Besides, bibliometric analysis helps researchers quantify and assess academic output and reveals research hotspots and development trends (Abdullah & Naved Khan, 2021). In education, while a few studies have employed VOSviewer for bibliometric analysis of TPACK, these studies are mostly concentrated in the health sciences or medical fields. The lack of comprehensive bibliometric studies in the field of education, particularly those focused on in-service teachers, limits our understanding of how TPACK research has evolved and where future studies should focus (Soler-Costa et al., 2021). Research on TPACK for in-service teachers in higher education, particularly studies using VOSviewer for keyword co-occurrence analysis, remains relatively scarce. This type of analysis is crucial because it not only maps the existing literature but also uncovers patterns and trends that are not easily detected through traditional literature reviews (Donthu et al., 2021). Therefore, this study aims to fill this gap through bibliometric analysis, providing a comprehensive understanding of the current state of TPACK research for in-service teachers.

Bibliometric Analysis

Bibliometric analysis is a methodology that uses statistical techniques to quantify, monitor, and evaluate academic papers (Roemer & Borchardt, 2015). The bibliometric analysis provides researchers with quantitative analysis, helps discover research directions, facilitates a better understanding of research fields and trends, and provides support and reference for research management, policy-making, and decision-making (Abdullah & Naved Khan, 2021). VOSviewer is an outstanding software used to construct and visualize bibliometric networks, initially popularized within the health science/medicine field. Many review studies within educational studies have now begun to utilize bibliometric analyses using VOSviewer (Hudha et al., 2020; Novia et al., 2023). Hence, the bibliometric analysis software VOSviewer was used in this investigation.

The analysis also examines the research trends in the most widely referenced journal publications in Scopus-indexed papers regarding in-service teachers' TPACK in higher education. This topic has received insufficient attention in academic circles. Overall, a bibliometric analysis of in-service teachers' TPACK research in higher education is valuable for understanding the research landscape, assessing impact, recognizing key contributors, and informing evidence-based practices and policies in teacher education and technology integration (Putri et al., 2022).

Methods

Article Selection Process

PRISMA, known as The Preferred Reporting Items for Systematic Reviews and Meta-Analyses, a comprehensive 27-item checklist set of guidelines, was used to guide this study, from establishing research questions, developing a search strategy, screening the titles, and data extraction. In higher education, in-service teachers refer to individuals currently employed as educators in colleges, universities, or other higher education institutions. The Scopus database was searched for academic literature on in-service teachers in higher education TPACK. Numerous review articles (e.g., Malanski et al., 2021; Pham et al., 2021) have emphasized that Scopus is a suitable database for bibliometric analysis due to its higher accuracy and data quality. It also offers more advanced analysis tools and features, such as author and affiliation searches, collaboration networks, and trend analyses (e.g., Alryalat et al., 2019; Montoya et al., 2018). It is one of the most

frequently employed databases in many scientific fields, typically for literature searches (Harzing, 2019; Herrera-Franco et al., 2020).

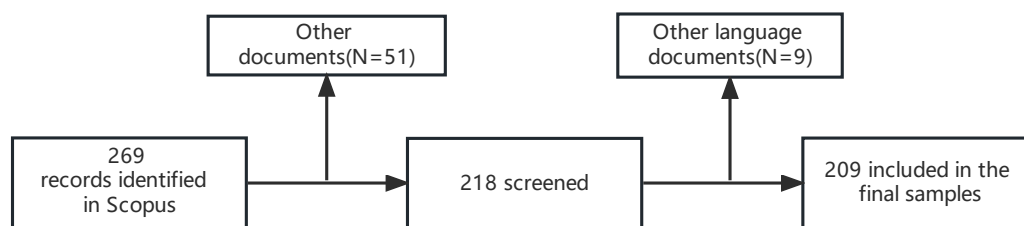


Figure 1. PRISMA diagram of included journals

We formulated a search query informed by understanding the TPACK domain while drawing upon previously employed TPACK education search queries, such as those utilized in the study by Jiménez Sierra et al. (2023). The search criteria encompass the terms "technological pedagogical content knowledge" and its acronyms "TPACK" or "TPCK", as well as in-service teachers and higher education. The present investigation utilized the content analysis method of keywords as its analytical approach. Only publications and journal articles written in English are included in the investigation. Consequently, a total of 209 articles were found.

Exclusion Criteria

The final journal samples involved two exclusion criteria to remove irrelevant papers. To ensure reliability, solely journal articles ($n = 209$) were incorporated (including review articles), while conference proceedings, book series, and books were excluded. Subsequently, nine articles were excluded from the study due to their composition in languages like Spanish, German, Korean, and Turkish ($n=9$).

Analysis

A total of 209 studies were selected based on the criteria mentioned above. The search procedure is succinctly summarized in Figure One. The initial examination of the articles focused on the frequency of publication every year, notable academic journals, geographical locations, academic institutions, and frequently researched keywords. Subsequently, the analysis of the co-occurrence of keywords was conducted utilizing VOSviewer.

To answer RQ1, the keywords mentioned above were searched in Scopus first, and then the years, literature categories, and language filters were applied. Lastly, the numbers of publications of each year were presented in the right column. Figure three, annual article publication counts were obtained by making the number of papers published each year as the horizontal axis (years) and the vertical axis (number of publications). To answer RQ2, citation and co-citation analysis were run via VOSviewer by loading the CSV file downloaded from Scopus. RQ3 and RQ4 were also answered based on the search result of research question one. The most contributed journals, nations/regions, institutions, funding institutions, and subject areas were just below the publication years, and the most cited articles were also listed according to their citation ranking. To answer RQ5, all the search result publication information of RQ1 was exported as CSV format, which was imported and loaded through VOSviewer to see all the keywords co-occurrence in this field. The VOSviewer result can be saved as a keyword network map and an original data CSV, where you can see all the detailed information, including key keyword clusters,

the weight value of all keyword occurrences, the score of average keyword citations, and the weight value of keyword total link strength.

Results

This section presents the findings of a comprehensive analysis of in-service teachers' TPACK in higher education.

RQ1: What are the major trends in TPACK research conducted on in-service teachers?

The findings show that the number of indexed articles increasingly grew annually; in 2022, it peaked (58 articles). One possible reason for this could be due to the high number of online classes during the Covid-19 pandemic (Cheng et al., 2022). Although there were only 12 articles in April 2023, this growing trend is expected to continue throughout 2023. Figure Two presents the number of articles published during the review period (2012 -April 2023).

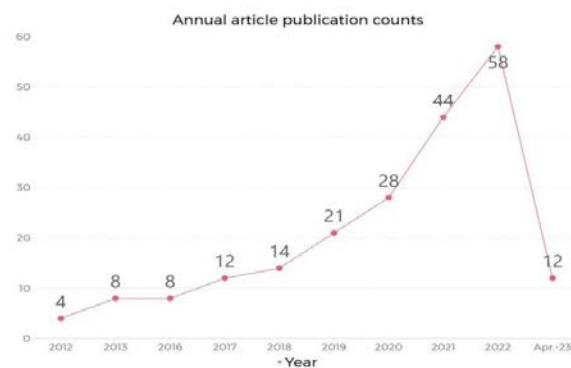


Figure 2. Annual article publication counts

RQ2: Which articles, journals, nations/regions, institutions, and funding institutions are the primary contributors to TPACK research in in-service teachers in higher education ?

Representative journal articles

We found it important to identify representative journal articles and the number of Scopus citations they received because they indicate the importance of a particular study (Aksnes et al., 2019). We found five top representative articles, which focused on online higher education, teacher education, and TPACK, which are shown in Figure three.

Rank	The representative articles	Authors	Source	Keywords	Scopus citation
1	Profiling teachers' readiness for online teaching and learning in higher education: Who's ready?	Ronny Scherer , Sarah K. Howard , Jo Tondeur , Fazilat Siddiq	Computers in Human Behavior	COVID-19 pandemic, Higher education , Online teaching and learning, Teacher readiness, TPACK	169
2	Identifying science teachers' perceptions of technological pedagogical and content knowledge (tpack)	lin tc tsai c.-c; chais: lee m.-h.	Journal of science education and technology	TPACK, Science teacher _x0002_ Teacher education, Teacher knowledge, Gender difference	132
3	Mediating factors that influence the technology integration practices of teacher educators	Michael J. Nelson , Rick Voithofer , Sheng-Lun Cheng	Computers and Education	Improving classroom teaching , pedagogical issues ,teacher education ,teacher educators, TPACK	64
4	Factors affecting Nigerian teacher educators' technology integration: Considering characteristics, knowledge constructs, ICT practices and beliefs	Eloho Ifinedo , Jenni Rikala , Timo Hämäläinen	Computers & Education	ICT in education; technology integration; teacher educators; partial least square – sequential equation modelling (PLS-SEM)	61
5	Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games	Chung-Yuan, Hsu; Meng-Jung, Tsai; Yu-Hsuan, Chang; Jyh-Chong Liang.	Educational Technology & Society	Game-based learning, TPACK, Games, Teacher, Teaching beliefs	56

Figure 3. The most cited publications for in-service teachers' TPACK in higher education

As shown in Figure Three, the Scopus journal articles with the most citations were written by eminent researchers in the TPACK field. For example, the article "Profiling Teachers' Readiness for Online Teaching and Learning in Higher Education: Who's Ready?" by Scherer et al. (2021) received 169 citations in Scopus. The second most prominent researcher was Lin et al. (2013), who gained 132 citations in Scopus.

From this analysis, it is interesting to note that the article that received the most citations is from as recent as 2021, while the article that comes in second place is from a decade ago. A possible reason for the high number of citations of Scherer et al.'s (2021) article may be attributed to the need for more online classes, specifically during the COVID-19 pandemic, which began in 2020. Scherer's et al. (2021) article is timely and specifically deals with teacher readiness within this context.

The Most Contributing Journals

According to the Scopus databases, a comprehensive total of 137 journals have disseminated research about TPACK research among in-service teachers in higher education. Furthermore, it is noteworthy that 11 scholarly journals have published no less than five articles on this particular subject matter. These journals include Education and Information Technologies (13 publications), Computers and Education (12 publications), Computers in Human Behavior (7 publications), Technology, Pedagogy and Education (7 publications), and Frontiers in Psychology (7 publications), as shown in Figure Four.

Journals	Number	Citation
Education and Information Technologies	13	9.4615
Computers and Education	12	46.5
Computers in Human Behavior	7	56.2857
Technology, Pedagogy and Education	7	12.5714
Frontiers in Psychology	7	3.5714

Figure 4. Most contributing journals

Among all, three out of four journals belong to SSCI in social studies, namely, Education and Information Technologies, Computers and Education, Computers in Human Behavior, and Frontiers in Psychology. Only Technology, Pedagogy, and Education is not an indexed journal, but its CiteScore ranked 29 out of 493 in the field of communication in Scopus.

Countries/regions

In the Scopus database, TPACK research among in-service teachers in higher education has been conducted in 57 countries/regions. Nine countries/regions, namely the United States, Indonesia, Turkey, Taiwan (China), China, Hong Kong (China), Malaysia, Australia, and Germany, are the most productive, with more than ten articles. The United States contributed to 31 publications, representing 18% of the total. The findings suggest that the United States exhibits a higher level of involvement in this specific subject matter (Figure Five).

Countries/regions	Publications
United States	31
Indonesia	26
Turkey	26
Taiwan	25
China	23
Hong Kong	16
Malaysia	12
Australia	10
Germany	8

Figure 5. Countries/regions

Institutions

Scholars from four hundred eighty-eight academic institutions have made contributions to 209 publications that focus on in-service teachers' TPACK in higher education. The institutions that made the highest number of contributions were The Ohio State University (8 publications), The Education University of Hong Kong (7 publications), The University of Hong Kong (6 publications), Beijing Normal University (6 publications), Huazhong Normal University (5 publications), as presented in Figure Six.

Institutions	Publications
The Ohio State University	8
The Education University of Hong Kong	7
The University of Hong Kong	6
Beijing Normal University	6
Huazhong Normal University	5

Figure 6. Institutions

Funding agencies

There was significant interest from 85 funding agencies to support research on in-service teachers' TPACK in higher education. Three of these organizations stood out for supporting the most research initiatives on this subject, namely, the Ministry of Science and Technology in Taiwan (15 publications), Bundesministerium für Bildung und Forschung in Germany (4 publications), and the European Commission in Brussels (4 publications) as indicated in Figure Seven. Notably, research on TPACK among in-service teachers in higher education has gained more attention in Taiwan. Before 2019, the total of articles published by the three organizations was 4, and from 2019 to now, the cumulative number of articles published has reached 19. That funding increased during the Covid, possibly because of the rise in online teaching and learning.

Funding sponsor	Countries /Regions	Major articles	Authors	Journals	Publications
Ministry of Science and Technology, Taiwan	Taiwan	Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games Examining teachers' technological pedagogical an	Hsu, C.-Y., Tsai, M.-J., Chang, Y.-H., Liang, J.-C. Hsu, L.W., Chen, Y.-J.	Educational Technology and Society South African Journal of Education	15
Bundesministerium für Bildung und Forschung	Germany	Teachers' role in digitalizing education: an umbrella review Using technology to promote student learning? An analysis of pre- and in-service teachers' lesson plans	Wohlfart, O., Wagner, I. Wekerle, C., Kollar, I.	Educational Technology Research and Development Technology, Pedagogy and Education	4
European Commission	Brussels	Learning design as a vehicle for developing TPACK in blended teacher training on technology enhanced learning TPACK of prospective mathematics teachers at an early stage of training	Papanikolaou, K., Makri, K., Roussos, P. Morales-López, Y., Chacón-Camacho, Y., Vargas-Delgado, W.	International Journal of Educational Technology in Higher Education Mathematics	4

Figure 7. Funding agencies

RQ3: Who are the most frequent publishers of TPACK research among in-service teachers in higher education?

Authors	Institutions	Countries/Regions	Publications
Chai C.S.	Nanyang Technological University	Singapore	9
Tsai C.-C.	National Taiwan University of Science and Technology	Taiwan	6
Jang S.-J.	Chung-Yuan Christian University	Taiwan	5
Liang J.-C.	National Taiwan University of Science and Technology	Taiwan	5

Figure 8. The authors who have the most contributions to in-service teachers' TPACK research

Figure Eight displays the most prolific researchers in the field of in-service teachers' TPACK in higher education, along with their affiliated institutions and nations. This assistance may make finding the right institutions and research partners easier. Among 631 authors, the most fruitful scholars on this topic are Chai C.S. (9 publications) from Singapore, Tsai C.-C. (6 publications) from Taiwan, Jang S.-J. (5 publications) from Taiwan, and Liang J.-C. (5 publications) from Taiwan.

From this list of top researchers in TPACK, it is evident that three are affiliated with universities that focus on Science and Technology: Nanyang Technological University, National Taiwan University of Science and Technology, and Chung-Yuan Christian University. This may explain why TPACK was an area of interest among researchers from these institutions. Additionally, while Chai C.S. (from Singapore) has the most publications, Singapore is not listed as one of the top countries with research surrounding TPACK.

RQ4: In which areas has the issue of TPACK research among in-service teachers in higher education been addressed?

The topics that are most often researched and discussed are social sciences (185 publications), computer science (78 publications), psychology (24 publications), arts and humanities (21 publications), and engineering (14 publications), as shown in Figure Nine.

Research areas	Publications
Social Sciences	185
Computer Science	78
Psychology	24
Arts and Humanities	21
Engineering	14

Figure 9. Research areas

RQ5: What are the all keyword co-occurrence networks of in-service teachers' TPACK research in higher education?

Using keywords can aid researchers in locating the most pertinent and useful data. (Darko et al., 2019). In this Scopus database, 15 keywords appeared more than ten times in studies on TPACK among in-service teachers in higher education, including "TPACK," "Technological Pedagogical Content Knowledge," "Technology Integration," "Teaching," "Teacher Education," "Engineering Education," "Professional Development," "Education," "Teachers'," "E-learning," "Educational Technology," "Teacher training," "Technological Pedagogical Content Knowledge (TPACK)", "Technology," and "Higher Education" as shown in Figure 10.

Keywords	Publications
TPACK	125
Technological Pedagogical Content Knowledge	47
Technology Integration	39
Teaching	32
Teacher Education	26
Engineering Education	20
Professional Development	19
Education	15
Teachers'	15
E-learning	14
Educational Technology	13
Teacher training	11
Technological Pedagogical Content Knowledge (TPACK)	11
Technology	11
Higher Education	10

Figure 10. Keywords

The analysis of keyword co-occurrence in VOSviewer exhibited the occurrence of 41 keywords more than five times, as depicted in Figure 11. The acronym TPACK holds significant importance in teacher education, pedagogy, and professional growth. Figure 11 illustrates the principal topics, participants, and data analysis methods. Quantitative research approaches, like factor analysis and structural equation modeling, dominated TPACK research on in-service teachers. Most of these investigations employed a survey design. For example, Schmid et al. (2020) developed a short assessment instrument for TPACK.

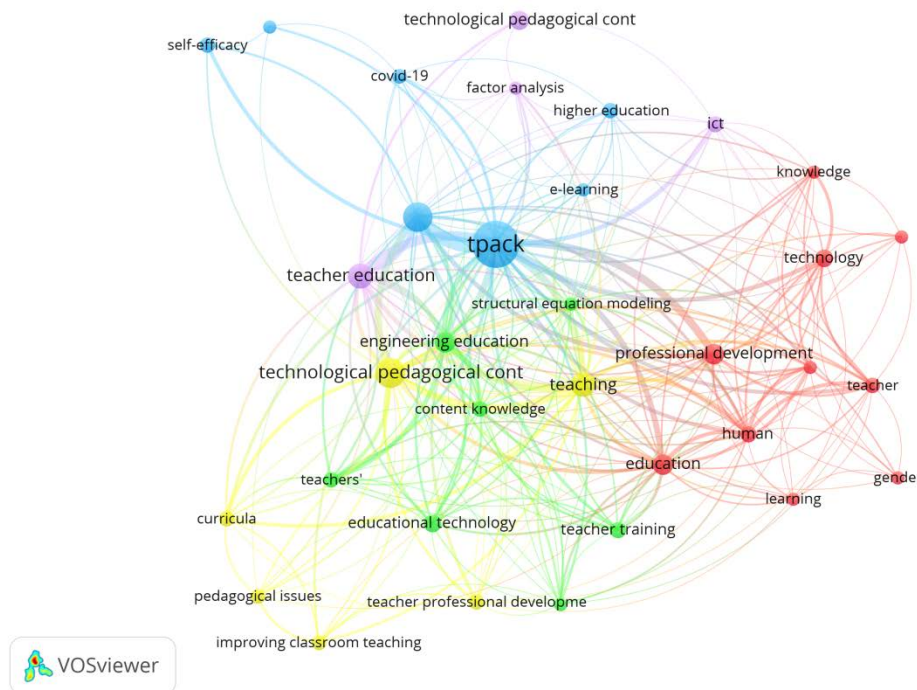


Figure 11. Keywords in VOSviewer

Co-occurrence

Keyword Clustering

The clustering of keywords is displayed in Figure 12 to facilitate comprehension of their significance. In VOSviewer's keyword centrality, TPACK was the most influential keyword. It was discovered that TPACK surveys administered to in-service teachers were employed in many disciplines, for example, mathematics education, technology, science, and engineering (e.g., Chai et al., 2019; Muhtadi et al., 2017). For example, DeCoito & Estaiteyeh (2022) investigated the perspectives and attitudes of STEM (science, technology, engineering, and mathematics) teachers towards online teaching, as well as the successes and difficulties encountered with online teaching through the lens of self-efficacy theory and the TPACK framework. Koh (2019) interviewed three mathematics teachers and analyzed the data using content and thematic analysis. The findings revealed that mathematics teachers face challenges in supporting mathematical inquiry with authentic problems when designing technology-integrated lessons, arguing that teachers need to acquire TPACK knowledge to integrate technology. Most of these studies employed 'TPACK' and 'teachers' the most in their keywords.

	Keywords	Occurrences	Total link strength
Cluster 1 (10 items)	Education	14	67
	Professional Development	14	45
	Technology	10	37
	Human	8	62
	Teacher	7	38
	Digital Competence	5	12
	Gender	5	10
	Human Experiment	5	41
	Knowledge	5	25
	Learning	5	15
Cluster 2 (7 items)	Engineering Education	14	71
	Educational Technology	10	33
	Teacher Training	8	32
	Content Knowledge	7	41
	Teachers'	7	35
	Structural Equation Modeling	5	31
	Technological Knowledge	5	27
Cluster 3 (7 items)	TPACK	111	163
	Technology Integration	35	91
	Higher Education	7	16
	Self-Efficacy	7	11
	Covid-19	6	14
	E-Learning	5	16
	Information And Communication Technology	5	6
Cluster 4 (6 items)	Technological Pedagogical Content Knowledge	36	92
	Teaching	21	97
	Curricula	7	30
	Teacher Professional Development	7	24
	Improving Classroom Teaching	6	19
	Pedagogical Issues	6	17
Cluster 5 (4 items)	Teacher Education	23	71
	Technological Pedagogical Content Knowledge (TPACK)	12	6
	ICT	8	22
	Factor Analysis	5	17

Figure 12. Keywords clustering

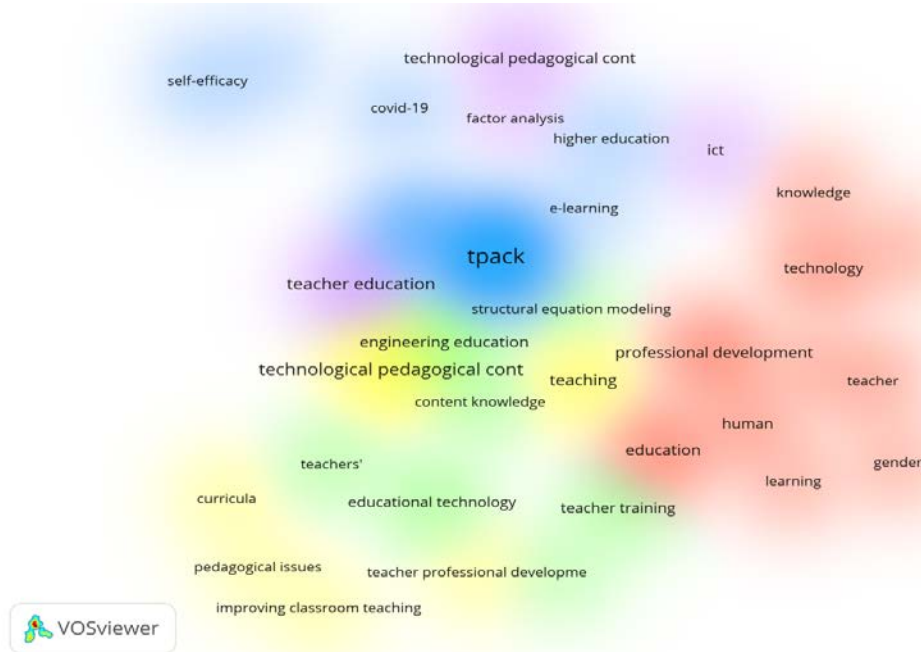


Figure 13. Keyword density visualization in VOSviewer

Figure 12 presents a full list of five clusters. In Figure 13, the keyword density visualization, each node is a keyword, and the node size shows how often the term is used. The red cluster on the right (cluster 1) is strongly related to education, as indicated by the terms education and professional development. The green cluster (cluster 2) is strongly linked with engineering education, educational technology, and teacher training. The research method is primarily quantitative, as indicated by the term structural equation modeling. The blue cluster (cluster 3) above the green cluster is strongly associated with the TPACK framework, technology integration in the classes and higher education level, as indicated in Figure 13, TPACK with the highest occurrence (111), total link strength (163), and technology integration with the second highest total link strength (91). The yellow cluster (cluster 4) on the left is related to technological pedagogical content knowledge and its classroom teaching, in which all the keyword connections with teaching are the strongest because teaching shares the highest total link strength (97) among all. The purple cluster (cluster 5) is also strongly linked to teacher education and technological pedagogical content knowledge (TPACK), which is similar to cluster 3 and cluster 4. In cluster 5, ICT tools and factor analysis are the major concerns in the research.

Discussion

The present investigation examines a collection of articles from 2012 to April 2023 from the Scopus database. Based on these articles, we identified trends in research on in-service teachers' TPACK in higher education. The study used bibliometric analysis to investigate these publications, concentrating on various factors, including the number of publications, the most productive countries or regions, funding organizations, institutions, journals, publishers, and the keyword co-occurrence networks.

The outcomes of this study aid scholars in recognizing potential areas of research, partners, institutions, and financial backing opportunities. Currently, limited review studies employ a

bibliometric analysis to investigate TPACK among in-service teachers in higher education. Additionally, the existing studies there have not been recent similar introspections since the COVID-19 pandemic. Therefore, this bibliometric analysis fills this gap within the TPACK and higher education field.

First, the findings show that an increasing number of review studies on TPACK have appeared in recent years (see Aleman-Saravia & Deroncela-Acosta, 2021; Brianza et al., 2022; Irwanto, 2021). This trend is consistent with some of the researchers' key findings (e.g., Suprpto et al., 2021; Zou et al., 2022). The reasons behind this trend are complex, but the rapid transition to online learning during and after the COVID-19 pandemic (Lemay et al., 2021), the rapid emergence of new educational technologies (DeSantis, 2016), and the increasingly demanding teaching quality from teachers (Ammade et al., 2020), may play a significant proportion in this trend. Moreover, this trend highlights the evolving nature of TPACK research, where the integration of technology into pedagogical practices has become a critical component of professional development for in-service teachers. This evolution aligns with earlier discussions in the literature review regarding the necessity for ongoing professional development in higher education to keep pace with technological advancements (Williams, 2017). The findings further support the assertion that effective integration of educational technology requires a deep understanding of both technological and pedagogical knowledge (Cheok et al., 2017).

Second, generally, the majority (66%) of literature was published by researchers from developed countries/regions, including the United States (31 publications), Turkey (26 publications), Taiwan (China) (25 publications), Hong Kong (China) (16 publications), Australia (10 publications). 34% of the literature has been written in developing countries/regions: Indonesia (26 publications), China (23 publications), and Malaysia (12 publications). These results are consistent with Su's (2023) findings. Moreover, we have also observed that the number of literature from developing countries/regions is gradually rising. This new finding may indicate that higher education in developing countries/regions increasingly focuses on teachers' knowledge and integrating technology into teaching. Additionally, among all these research, the high-quality educational journals favor more on quantitative TPACK research more than qualitative ones, such as *Computers in Human Behavior* (7 publications, 162 citations), *Journal of Science Education and Technology* (6 publications, 129 citations), *Computers and Education* (12 publications, 123 citations), and *Journal of Educational Technology and Society* (2 publications, 56 citations). In contrast, Suprpto et al.'s (2021) findings show that most TPACK studies are qualitative. The reason why the high-quality educational journals favor more quantitative might be the accuracy of the statistical analysis, which tends to have a higher impact in terms of peer review and citation.

Third, the ability of bibliometric analysis to locate significant researchers and articles through empirical literature analysis is one of its strengths (White & McCain, 1998). The citation and co-citation of this bibliometric analysis identified that Chai C.S, Tsai C.-C, Jang S.-J, and Liang J.-C. contributed the most to the TPACK research of in-service teachers. Singapore (Chai C.S.) and Taiwan (China) (Tsai C.-C, Jang S.-J, Liang J.-C.) are developed countries/regions from which the authors mentioned above originate. This finding indicates that developed countries/regions may possess more experience, resources, and expertise in educational technology and teaching practices, allowing other regions to draw inspiration and learn from them. As the highest funding region, Taiwan might set a good example for the less developed regions to learn from. This is particularly relevant given the literature review's emphasis on the importance of structured approaches to integrating technology in teacher training programs (Santos & Castro,

2020). The identification of these key contributors underscores the role of well-resourced institutions and researchers in advancing TPACK research, further highlighting the disparities between developed and developing regions in educational technology integration.

Fourth, the findings highlight the multidisciplinary nature of TPACK research among in-service teachers in higher education, with common areas of focus including social sciences, computer science, psychology, arts and humanities, and engineering. This demonstrates the diverse range of disciplines involved in investigating TPACK, which is consistent with the findings of Ammade et al. (2020). Fifth, the VOSviewer keyword analysis revealed keyword clusters related to the TPACK framework most followed by education and technology integration, such as engineering education and teacher professional development. This finding is consistent with Su's (2023) TPACK research among pre-service teachers and Suprpto et al.'s (2021) findings from bibliometric analysis on TPACK during 2015-2019.

The present literature review is subject to three limitations. To attain a more comprehensive comprehension of the research about in-service teachers' TPACK in higher education, it is necessary to conduct a systematic review or meta-analysis review, which was not incorporated in the present study. Secondly, it could be contended that utilizing only two keywords, namely "TPACK" and "TPACK," may not adequately narrow the scope of research topics. Finally, it should be noted that the extent of the gathered data was limited to the Scopus database exclusively, without incorporating other databases (such as Google Scholar Web of Sciences or CNKI).

Potential Research Topics

One of the potential research topics is the TPACK training module for teachers. Among 253 studies, only 10 studies focused on teachers' TPACK training modules in higher education contexts (Alas & Kriisa, 2022; Chaipidech et al., 2022; Spyros et al., 2013). Alas and Kriisa (2022) designed an online training program for Estonian examiners and raters of the English as a Foreign Language National Examination. The resulting online program included trainer input in the form of videos and interactive tasks for managing interviews and assessing student performance. The implementation of this program showed significant benefits for training, including an increase in learner autonomy and trainee satisfaction with the training quality. Chaipidech et al. (2022) looked into the effects of a TPD design with an embedded personalized learning system on the TPACK of in-service teachers. Findings indicated that TPACK research among in-service teachers in higher education improved significantly (Chaipidech et al., 2022; Kapici & Akcay, 2020; Spyros et al., 2013).

Another potential topic is the AI-based TPACK framework. Among 209 studies, only one study focused on the interplay between AI and TPACK. Celik (2023) created a TPACK-based scale to assess teachers' knowledge of how to use AI-based tools in a pedagogically and ethically appropriate way, as no previous studies had explored this topic, which he developed a model to investigate how the components of TPACK interact with ethics. In the study, Celik (2023) suggested an Intelligent-TPACK framework.

This review of the literature makes several contributions to the TPACK domain. Initially, the study thoroughly examines the current state and expansion of in-service teachers' TPACK in higher education. Furthermore, this review helps to identify researchers, funding agencies, and nations or regions with good potential to conduct research in this area and find prospective collaborators. Additionally, the usage of relevant keywords aids researchers in locating important

material and comprehending research centers in this field. It is also critical for scholars to identify the most prominent publications in this discipline.

Conclusion

The primary aim of this bibliometric review is to map the research landscape of Technological Pedagogical Content Knowledge (TPACK), specifically focusing on in-service teachers in higher education. The study examined 209 articles from the Scopus database published between 2012 and April 2023. The analysis has revealed several important findings and suggested potential future research topics.

First, there has been a significant increase in publications on in-service teachers' TPACK in higher education. Second, the study identified representative articles with significant citations, indicating their impact on the field. The top journals that have published research on in-service teachers' TPACK in higher education are highlighted, including *Education and Information Technologies*, *Computers and Education*, and *Computers in Human Behavior*. The countries/regions with the highest contributions to TPACK research are also identified. Furthermore, the institutions that have significantly contributed to TPACK research in higher education are also revealed, such as Ohio State University, The Education University of Hong Kong, and Beijing Normal University. Besides, the study identified the funding agencies that have supported research on TPACK among in-service teachers in higher education, including the Ministry of Science and Technology in Taiwan (China), Bundesministerium für Bildung und Forschung in Germany, and the European Commission in Brussels.

Third, the TPACK researchers publishing the most frequently in this area are Chai C.S. (9 publications), Tsai C.-C. (6 publications), and Jang S.-J. (5 publications), and Liang J.-C. (5 publications). Fourth, the analysis explored the research areas addressed in the context of in-service teachers' TPACK in higher education, including social sciences, computer science, psychology, arts and humanities, and engineering. With visualization of keyword density, education, engineering education, and educational technology, ICT tools, and factor analysis are found to be strongly linked to in-service teachers' TPACK research in higher education.

Overall, it can be derived from the findings that there is growing recognition of the importance of integrating technology into teaching practices, and the significant portion of high-quality literature in this field originates from developed regions or countries, which may suggest a strong connection between in-service teachers' TPACK in higher education and economic development. It also can be derived from keyword co-occurrence network analysis that a substantial amount of research still focuses on teacher education and development. Hence, this study suggests that future in-service teachers' TPACK research in higher education should focus on developing TPACK training modules and AI-based TPACK frameworks to assist teachers in successfully incorporating technology into their instructional practices. In general, this bibliometric review provides valuable insights into the current state of research on in-service teachers' TPACK in higher education, helping researchers and policymakers understand the research landscape, identify key contributors, and inform evidence-based practices and policies in teacher education and technology integration.

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