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Research Hotspots and Future Prospects of TPACK in Early Childhood Education: An Analysis Based on CiteSpace Knowledge Mapping

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Abstract:
With the rapid development of educational technology, the ability of early childhood educators to integrate technology and content knowledge (TPACK, Technological Pedagogical Content Knowledge) has gained increasing attention. This study aims to comprehensively analyze the research trends and development of TPACK in early childhood education, revealing the current state and future directions in this field. By adopting bibliometric methods and content analysis, we examine academic papers published from 2012 to 2022, focusing on the volume of publications, publishing countries, research institutions and authors, co-citation of literature, keywords, and research frontiers. The results show a significant increase in the volume of publications related to early childhood educators' TPACK, with a peak in 2021. The United States, China, and Turkey are leading the research in this field. Institutions such as Nanyang Technological University and National Taiwan University of Science and Technology have made outstanding contributions to TPACK research. Highly cited literature emphasizes the core theories and methodologies of the TPACK framework. Keyword analysis reveals that "beliefs," "perceptions," and "skills" are the current research hotspots. This study provides valuable insights into the current status and future development of early childhood educators' TPACK, emphasizing that research into TPACK will continue to play a crucial role in supporting educators to effectively integrate technology and pedagogy in a rapidly changing educational environment.

Keywords: early childhood educators; tpack; citespace; technology; knowledge

INTRODUCTION

With the continuous development and widespread adoption of information technology, its impact on learning and daily life has penetrated every corner, especially in the field of education. The integration of information technology with education is becoming increasingly widespread, and its influence on education is growing. In particular, in the field of early childhood education, with the increasing emphasis on preschool education and the popularization of technology, early childhood education has inevitably been deeply impacted by information technology [1]. Therefore, the development of early childhood educators' competencies in information technology has become particularly important.

In the transition from Education 2.0 to Education 3.0, the explosion of information and knowledge brought about by the internet, along with trends in digitalization and artificial intelligence in teaching, have not only covered higher education and basic education, but have also gradually spread to younger learners, such as elementary school students and preschool education [2]. The introduction of computers, multimedia teaching, and artificial intelligence devices in early childhood education institutions has become a common phenomenon, providing significant opportunities for the informatization of early childhood education. The traditional competencies of early childhood educators can no longer meet the demands of the new era. Therefore, it is urgent to increase attention to the professional development of early childhood educators and develop new competencies that are suited to the information-age educational environment.

Recent studies have shown that after participating in technology-enriched courses, early childhood educators have significantly improved their attitudes toward educational technology and pedagogical technology. Their teaching knowledge, technological content knowledge, technological pedagogical knowledge, and overall TPACK scores have all significantly increased [3]. This emphasizes the importance of technology in early childhood education and the necessity of professional development for educators in this field. Another study also pointed out that early childhood educators' TPACK abilities are closely related to their digital literacy skills, technology attitudes, and usage, further confirming the importance of integrating technology into early childhood education [4].

Therefore, this study aims to explore the improvement of early childhood educators' abilities within the TPACK framework and how to effectively integrate technology with pedagogy. By gaining an in-depth understanding of the current status of TPACK in the field of early childhood education, this study can provide strategies for enhancing early childhood educators' teaching abilities, thus better adapting to the demands of the information-age education era.

LITERATURE REVIEW

The TPACK (Technological Pedagogical and Content Knowledge) framework, proposed by Koehler and Mishra in 2005, has become an essential knowledge structure for teachers in the age of information technology [5]. This framework emphasizes the interaction and organic integration of technology, pedagogy, and content knowledge, providing a new theoretical basis for the development of teachers' technological teaching abilities. TPACK includes three core elements: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK); four compound elements: Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and Technological Pedagogical Content Knowledge (TPACK); and one contextual element: Context. With the widespread application of new educational models such as mobile learning, flipped classrooms, and MOOCs, the TPACK ability of teachers has become particularly important. Lim et al. (2023) showed that after participating in technology-rich courses, early childhood educators' TPACK abilities significantly improved [3]. Furthermore, Altun (2019) found that the TPACK abilities of pre-service early childhood educators are closely related to their digital literacy skills and technology attitudes [4].

These studies highlight the importance of integrating technological pedagogical content knowledge in the age of information technology. However, the practical application of the TPACK framework faces various challenges. Koehler and Mishra (2005) argued that due to the diversity of educational contexts, there is no universal "perfect solution" to address all educational issues [5]. Teaching should be personalized according to specific contexts, learners, and subjects. Therefore, teachers need to fundamentally understand the dynamic and complex relationship between technology, pedagogy, and content, and integrate them to develop teaching methods and strategies suited to specific educational contexts. In the field of early childhood educators' TPACK, research by Siu-Man, and Gonzalez (2013) indicates that having a certain level of technological teaching ability plays a crucial role in improving the professional competence of early childhood educators and developing children's digital abilities [6]. Other studies have found that preschool educators demonstrate satisfactory self-efficacy in integrating technology across all seven domains of TPACK [7]. Luo et al. pointed out that preschool educators with higher academic qualifications have more knowledge of technology use and ICT integration in teaching environments, whereas more experienced preschool educators may show some resistance to the integration of technology in teaching environments [8].

Although these studies contribute to the understanding of early childhood educators' TPACK development, few attempts have been made to use bibliometric methods to collect data and summarize the scientific achievements in the field of early childhood educators' TPACK research. Bibliometric analysis, based on the application of mathematical and statistical methods, can objectively measure the research productivity and contribution of a discipline to knowledge advancement [9]. Therefore, this study will conduct a bibliometric analysis of early childhood educators' TPACK research in terms of countries/regions, journals, authors, and keywords. This will help scholars track the development trends of research topics at different stages.

RESEARCH METHODOLOGY

CiteSpace is a free visualization software developed by Professor Chaomei Chen from the College of Information Science and Technology at Drexel University [10]. CiteSpace knowledge mapping visualization analysis software is capable of analyzing publication volume, authors, publishing institutions, keyword co-occurrence, and co-citation of literature. The software can be used to identify and discover the latest research hotspots and trends, making them visually represented in knowledge maps [11]. The analysis principle of the software is based on the time-slicing method, which divides the time intervals evenly and then constructs a co-occurrence network based on the co-occurrence relationships in each period. These smaller networks are then combined in chronological order to form a systematic and progressive visualization network [12]. By analyzing

quantitative data from literature, it is possible to reflect the basic situation and development trends of a research field, thus avoiding the qualitative induction and overly subjective issues that may arise in previous studies [13].

In this study, CiteSpace knowledge mapping visualization analysis software was used as the research tool. The documents for analysis were extracted from the WOS (SCI, SSCI, SCIE, ESCI, A&HCI) database. The research used "early childhood educator / preschool teacher / TPACK" as the search terms for the topic/title/abstract, with the time span set from 2012 to 2022. After systematic reading and screening, 1485 valid articles were obtained. A bibliometric method was employed to analyze the 1485 retrieved documents. First, the selected bibliographic data from the WOS database (in Refworks format) were imported into CiteSpace, where deduplication was performed. Then, threshold settings were applied, with a time partition of 1 year, resulting in 10 time intervals. Authors, institutions, topics, keywords, publication times, and sources of literature were analyzed, while other settings were left as default. The analysis produced clear and intuitive visual knowledge maps. Based on these knowledge maps, combined with the literature, the study identifies the hotspots in early childhood educators' TPACK research over the past decade and reveals the development trends in this field.

RESEARCH RESULTS

Analysis of Publication Volume

The publication volume is shown in Figure 1. Figure 1 illustrates the annual number of publications on early childhood educators' TPACK research from 2012 to 2022. The number of papers published in each year is as follows: 44 papers in 2012, 64 papers in 2013, 88 papers in 2014, 119 papers in 2015, 90 papers in 2016, 183 papers in 2017, 163 papers in 2018, 199 papers in 2019, 200 papers in 2020, 215 papers in 2021, and 120 papers in 2022. The changes in the number of scientific publications within a certain time interval can highlight the accumulation of knowledge in a particular research field and provide important parameters for understanding the development of that field from a "quantitative" perspective. From the overall trend in Figure 1, the annual publication volume shows a fluctuating development trend, which can roughly be divided into two periods: 2012-2016 and 2016-2022.

From 2012 to 2016, the publication volume related to early childhood educators' TPACK research grew year by year, especially reaching its peak in 2015. This growth trend may be related to the global increase in the emphasis on early childhood education. For example, UNESCO’s "Education 2030 Agenda," released in 2013, emphasized the importance of early childhood education, which likely stimulated interest in research on early childhood educators' TPACK abilities [14]. From 2016 to 2022, the peak of research occurred in 2021. The increase in research during this period may have been influenced by educational policies in several countries and regions. For instance, the EU's "Digital Education Action Plan" released in 2017 highlighted the importance of digital skills and educational technology, which likely spurred research on early childhood educators' TPACK abilities [15]. Furthermore, the research peaks in 2020 and 2021 might be linked to the COVID-19 pandemic. During the pandemic, the closure of schools worldwide and the increased demand for remote teaching forced educators and researchers to focus on early childhood educators' TPACK abilities, particularly in the context of remote teaching [16]. Therefore, the global emphasis on remote teaching and digital education by governments and educational institutions during the COVID-19 pandemic likely played a significant role in the substantial increase in research literature during this period.

In summary, the changes in the publication volume of early childhood educators' TPACK research reflect the impact of global educational policy shifts and significant events, such as the COVID-19 pandemic. These studies provide valuable insights into the capabilities of early childhood educators in integrating technology, pedagogy, and content knowledge, and have important implications for the future development of the early childhood education field.

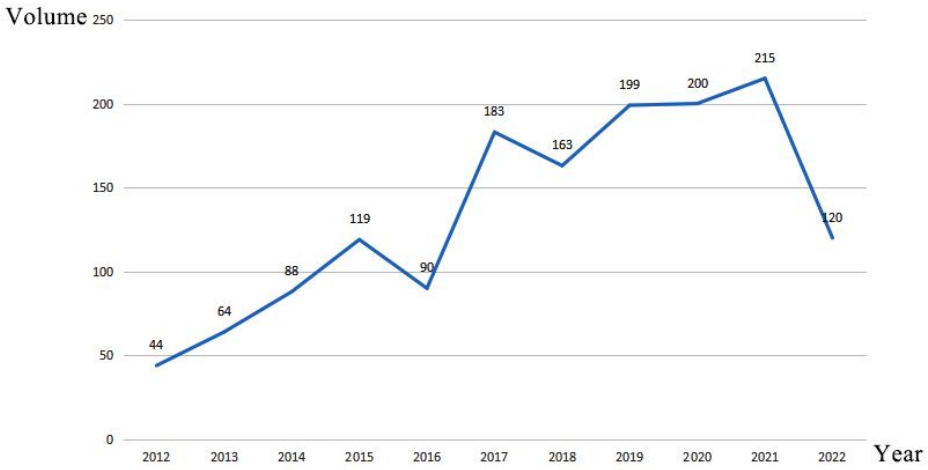

Figure 1. Distribution of Publication Volume Over Time

Overview of Publication by Country

Using a threshold of 20 papers published annually, the top 10 countries or regions that have contributed to early childhood educators' TPACK research are identified. Figure 2 shows that the United States (214 papers, accounting for 14.4% of the total output), China (120 papers, 8%), Turkey (120 papers, 8%), Sweden (54 papers, 3.6%), Taiwan (51 papers, 3.4%), Spain (45 papers, 3%), Germany (36 papers, 2.4%), Indonesia (32 papers, 2.1%), Australia (29 papers, 1.9%), and Singapore (20 papers, 1.3%) are the top 10 contributing countries/regions. Figure 3 shows the countries/regions with the highest research productivity in early childhood educators' TPACK over the past decade.

In terms of geographical distribution, TPACK theory has attracted broad attention from researchers worldwide. The countries with the highest research output and citation rates include the United States, and many Asian countries and regions have also made significant achievements in this field. The United States, ranking first in publication volume, has long maintained a leadership position in educational technology and early childhood education research. Higher education institutions and research centers in the United States have invested heavily in educational technology research, particularly in the field of early childhood education. Furthermore, the U.S. government and private foundations have funded educational research, promoting the development of this research area.

China and Turkey also hold advantageous positions in early childhood educators' TPACK research. The high publication volume in these two countries may be attributed to their recent emphasis on educational reform and technology integration. Both China and Turkey are actively promoting educational modernization, especially in early childhood education, with governments and educational institutions working to improve teachers' technological skills and teaching quality.

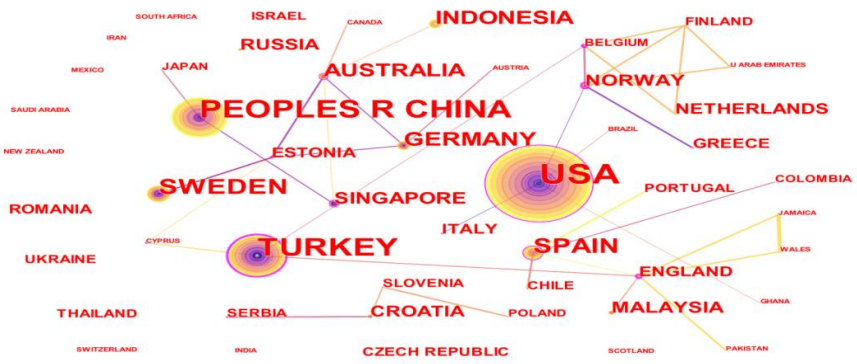

Figure 2. Countries or Regions of Publication

Analysis of Research Institutions and Collaboration

By analyzing the data obtained from CiteSpace and setting the threshold to Top N=50 for institutions, a knowledge map of high-output institutions in early childhood educators' TPACK research is generated. Nodes represent publishing institutions, and the larger the node, the higher the publication frequency of the institution. The analysis reveals that the institution with the highest publication volume is Nanyang Technological University (18 papers). Nanyang Technological University has strong research capabilities in educational technology and teacher education, and its high publication volume likely reflects its leading position in TPACK research. The institutions with the next highest publication volumes, in descending order, are National Taiwan University of Science and Technology (11 papers), University of Gothenburg (11 papers), University of Virginia (11 papers), Ohio State University (10 papers), Chinese University of Hong Kong (7 papers), National Taiwan Normal University (7 papers), Middle East Technical University (6 papers), Tallinn University (6 papers), and Beijing Normal University (5 papers).

In addition, the collaboration between research institutions is represented by co-occurrence relationships (i.e., collaborations between institutions), where the thickness of the connecting lines indicates the strength of the collaboration. Figure 3 shows the research institutions with larger nodes in early childhood educators' TPACK research, with 12 connecting lines indicating collaborations between the following institutions. The five strongest collaborations are as follows: Nanyang Technological University (NTU), National Taiwan University of Science and Technology (NTUST), and National Chengchi University (NCCU) are collaborating. University of Nottingham, Yuzuncu Yil University, and Middle East Technical University (METU) are collaborating. Uppsala University and Karolinska Institutet are collaborating.Ohio State University, University of Washington, Louisiana Tech University, and University of Virginia are collaborating.National Taiwan Normal University (NTNU), Chinese University of Hong Kong (CUHK), Beijing Normal University (BNU), and Universitas Negeri Jakarta (UNJ) are collaborating.

These significant collaboration relationships between research institutions indicate that different institutions are simultaneously researching the same topic, forming an influential collaborative network. Such cross-institution collaboration not only promotes knowledge sharing and innovation but also strengthens international cooperation and academic exchange in the field of early childhood educators' TPACK research.

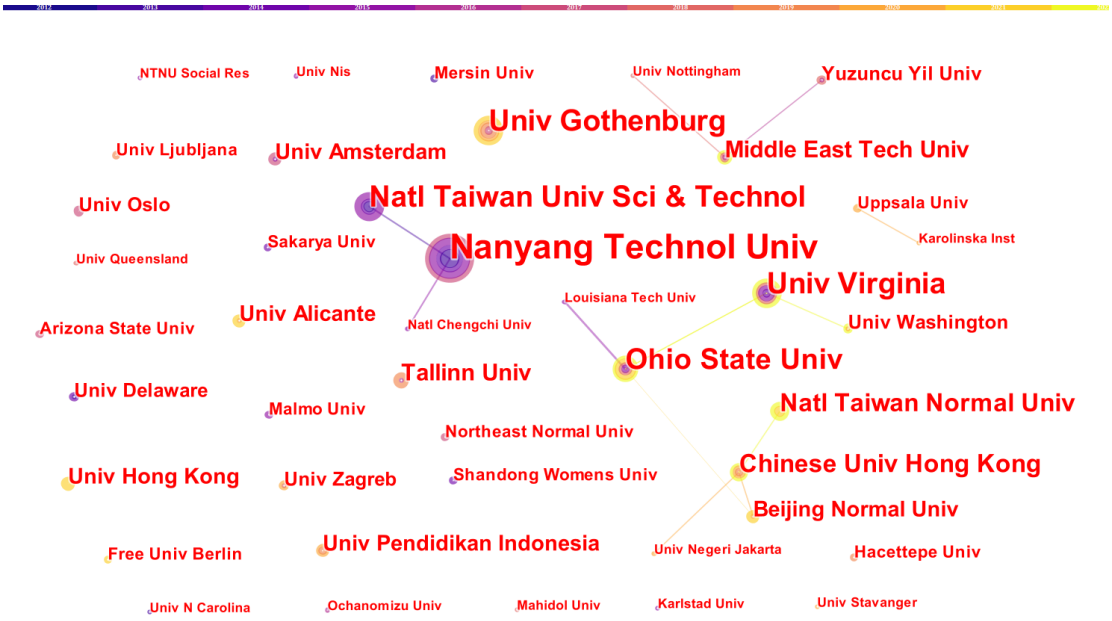

Figure 3. Co-occurrence Map of Research Institutions

Author Analysis

By constructing an author collaboration co-occurrence map, the major researchers in this field can be clearly identified, providing accurate information for future research or collaboration and contributing to the

development of the field of early childhood educators' TPACK. Clustering analysis of authors was conducted by selecting the "Author" node type, resulting in 78 nodes and 60 connections. From the map, high-output authors and their collaboration relationships in this field can be clearly identified. In Figure 4, the size of the nodes represents the volume of publications, and this can also be seen in the font size—larger fonts correspond to higher publication volumes.

From Figure 4 and Table 1, the scholars with the highest co-occurrence frequency in the past decade on early childhood educators' TPACK research are: CHING SING CHAI (18 papers), JOYCE HWEE LING KOH (12 papers), CHINCHUNG TSAI (10 papers), and JYHCHONG LIANG (6 papers). The other authors have published 2 papers each. These authors are the top ten with the highest publication counts in the past decade. The map also shows that there is a visible collaborative pattern in the field of early childhood educators' TPACK, with authors such as CHING SING CHAI, JOYCE HWEE LING KOH, CHINCHUNG TSAI, and JYHCHONG LIANG, as well as ILARIA SOTTIMANO, DANIELA CONVERSO, SARA VIOTTI, VINCENZA CASCIO, and GLORIA GUIDETTI, having notable collaborations.

Based on the overall analysis of the map, it can be concluded that there is no trend of "academic oligarchs" in the field of early childhood educators' TPACK research in the past ten years. This indicates that numerous scholars have conducted research on early childhood educators' TPACK and shared their results.

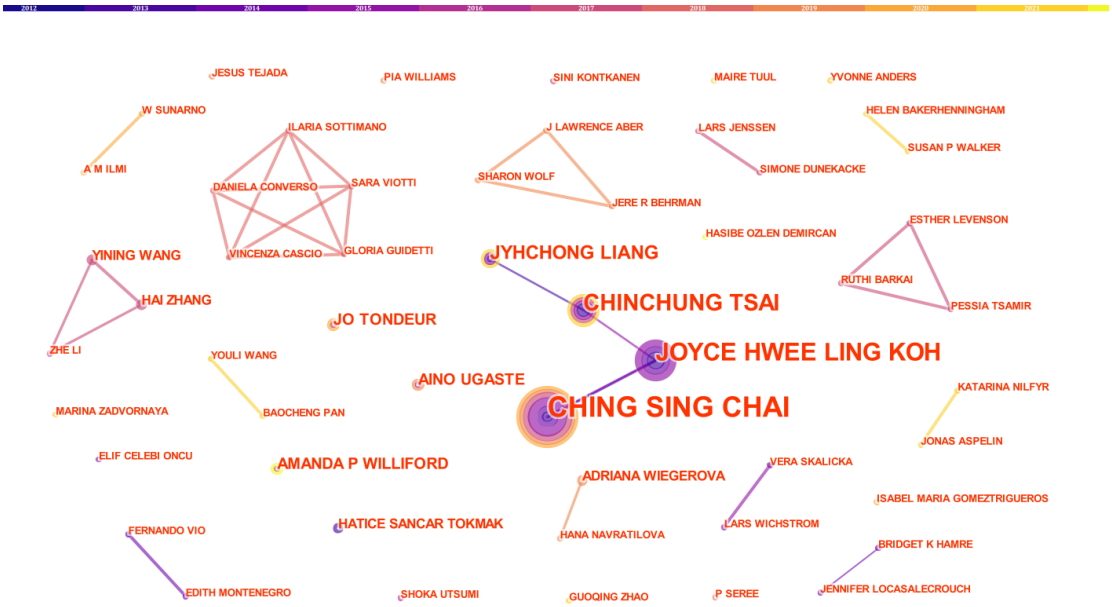

Figure 4. Co-occurrence Knowledge Map of Authors

Table 1. Top Ten Authors by Publication Volume

NO.	Authors	Amounts
1	CHING SING CHAI	18
2	JOYCE HWEE LING KOH	12
3	CHINCHUNG TSAI	10
4	JYHCHONG LIANG	6
5	AMANDA P WILLIFORD	4
6	JO TONDEUR	4
7	AINO UGASTE	4
8	ADRIANA WIEGEROVA	3
9	HATICE SANCAR TOKMAK	3
10	HAI ZHANG	3

Co-citation Analysis

As shown in Figure 5, the larger the node in the graph, the higher the frequency of co-citations. In the exploration of research related to early childhood teachers' TPACK (Technological Pedagogical Content Knowledge), some key papers have made significant contributions to the development and understanding of the theory. These papers have not only deepened the researcher's understanding of the TPACK framework but also greatly advanced the academic progress in this field by providing new theoretical perspectives and empirical research results. Specifically, the five most frequently cited papers have provided valuable theoretical support and practical guidance for early childhood teachers' technological education content knowledge.

For example, Schmidt et al.'s 2009 study discussed the epistemological issues of TPACK and proposed the ICT-TPACK model. Through empirical research, the impact of this model on student learning was tested, providing deep insights into the construction and practical application of the TPACK theory, particularly in pre-service teacher education [17]. In Voogt & Tondeur(2015) literature review, 55 peer-reviewed journal articles and one book chapter were analyzed to explore the theoretical foundations and practical applications of TPACK, revealing different understandings of TPACK and technological knowledge, as well as how these perspectives influence the measurement of TPACK [18]. The study of Angeli & Valanide (2009) discussed the epistemological and methodological issues of TPCK and proposed the concept of ICT-TPCK. They explored models for its development and assessment, offering new insights into TPCK theory and methods, and demonstrated through empirical research the positive effects of these theoretical models on developing ICT-TPCK [19]. Cox et al.'s 2009 research conducted an in-depth analysis of the TPACK model. While they did not provide specific contributions, their work helped to understand the complexity of TPACK and its impact in the field of educational technology [20]. Finally, Graham's 2011 study used Whetten's criteria for theory building to evaluate the TPACK framework, identified specific weaknesses in TPACK research, and proposed directions for theoretical development. The study provided an in-depth analysis of the theoretical foundation of the TPACK framework and called for researchers to use research findings to collaboratively construct a common definition and understanding of the TPACK construct [21]. These studies collectively form an important foundation for understanding and developing early childhood teachers' TPACK abilities.

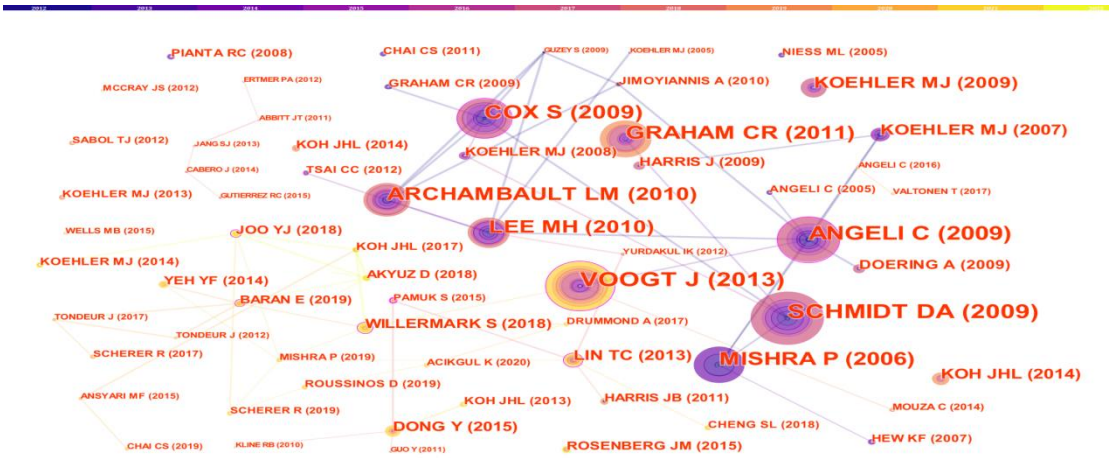

Figure 5. Co-citation of Literature

Keyword Analysis

Keywords are a crucial component of academic papers, representing the core and essence of the research topic. High-frequency keywords are often used to identify the hot topics within a specific research field. In this study, a statistical analysis was conducted on the high-frequency keywords from research on early childhood teachers' TPACK from 2012 to 2022. A time slice of one year was set, and the keywords were selected based on their prominence, with other settings kept as defaults. The result was a co-occurrence knowledge map of keywords.

As shown in Figure 6, the top ten high-frequency keywords in early childhood teacher TPACK research are as follows:TPACK (181 occurrences, centrality 0.20), Pedagogical content knowledge (177 occurrences, centrality 0.00), Preschool teacher (139 occurrences, centrality 0.43), Education (132 occurrences, centrality 0.49),

Preschool (119 occurrences, centrality 0.44), Framework (114 occurrences, centrality 0.39), Teacher (81 occurrences, centrality 0.13), Belief (80 occurrences, centrality 0.20), Children (75 occurrences, centrality 0.21), Perception (64 occurrences, centrality 0.32).

Since this study focuses on documents related to “preschool teachers” and "TPACK," the keywords "preschool," "teacher," and "TPACK" are common across most of the samples and do not provide distinguishing features when identifying research trends. Therefore, these keywords are not discussed in detail.

In early childhood teacher TPACK research, the importance of keywords like "belief" and "perception" has been supported by multiple studies. Liang et al. (2017) highlighted that teachers' beliefs about the use of information technology can influence their TPACK levels. This suggests that a preschool teacher's beliefs are crucial in how they integrate technology into teaching [22]. Chai et al. (2019) found that preschool teachers' design beliefs are a significant predictor of their TPACK effectiveness, emphasizing the role of beliefs in forming effective TPACK practices [23]. Furthermore, in research on teachers' perceptions, Koh et al. (2013) explored teachers' perceptions of the TPACK framework, finding that teachers perceive TPACK as consisting of the direct effects of technological knowledge and pedagogical knowledge, which are critical for developing technological pedagogical knowledge and technological content knowledge [24]. These studies show that teachers' beliefs and perceptions play a pivotal role in the development and application of TPACK. Understanding teachers' beliefs and perceptions can aid in designing more effective teacher training and professional development programs, thus supporting teachers' growth in integrating technology and content knowledge.

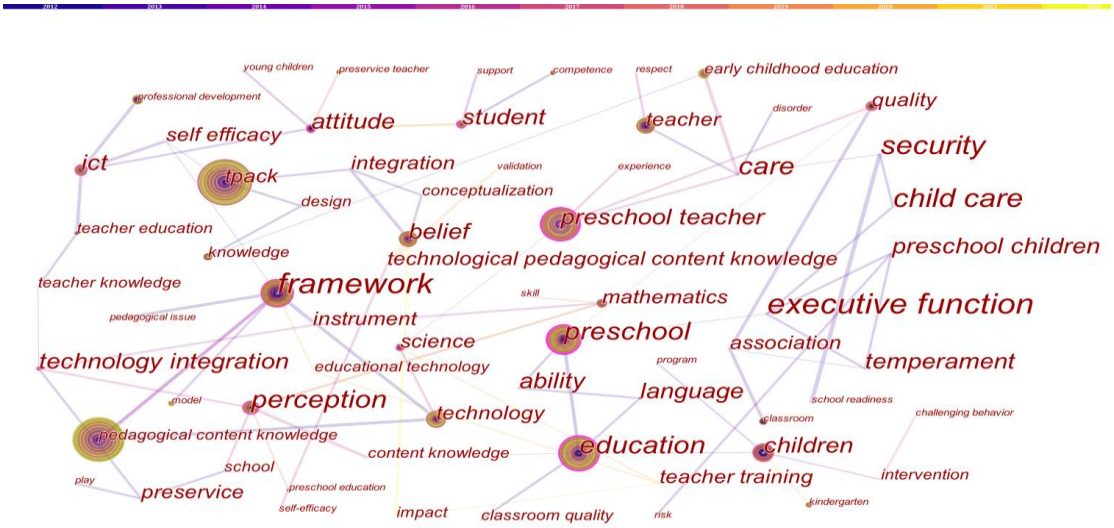

Figure 6. Co-occurrence Knowledge Map of Keywords

Research Frontier Analysis

A sharp increase in the frequency of keywords in cited articles can reveal emerging research trends and frontiers. Through keyword burst analysis from 2012 to 2022, we can identify the cutting-edge trends in early childhood teacher TPACK research. In terms of burst duration, "skill" is the keyword with the longest burst duration. Regarding burst intensity, "impact" ranks first with a burst intensity of 5.6159, and its burst duration lasted from 2020 to 2022. "Validation," with a burst intensity of 5.1249, ranks second, with its burst period spanning from 2019 to 2020. The citation burst intensity and duration highlight the dynamic shifts in research focus, which may be influenced by technological advancements, policy changes, and societal demands in the education field. The start and end times of citation bursts may correspond to the introduction of new teaching theories, technological tools, or changes in education policies.

In Figure 7, the keywords that have emerged strongly over the past five years include "validation," "skill," "teacher training," and "impact." "Validation" and "skill" emphasize research interest in validating teacher skills, which connects to the empirical foundations of TPACK in early childhood education. This indicates that researchers are exploring how teachers can effectively use the TPACK framework to support language and skills development in young children.

On the other hand, "teacher training" and "impact" have high burst intensities (5.6159), which underscores the growing importance of quantitative studies evaluating educational interventions in recent years. This trend is likely tied to the direct impact of teacher training quality on educational outcomes, emphasizing the necessity of assessing and improving educational practices. In the context of the TPACK framework, these trends suggest that researchers and policymakers have increasingly focused on teacher skill development and the evaluation of its impact on early childhood education.

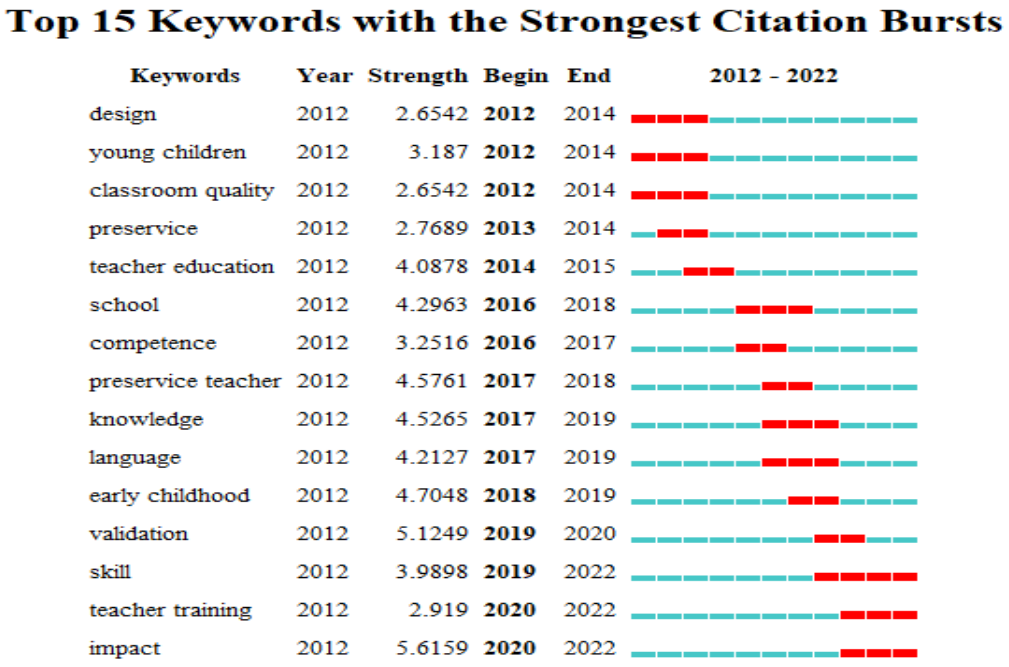

Figure 7. Trend of Keyword Burst

DISCUSSION

This study offers a comprehensive analysis of research related to early childhood teacher TPACK (Technological Pedagogical Content Knowledge) across seven key aspects: publication volume, countries/regions contributing to research, research institutions and collaborations, authors, co-citation analysis, keyword analysis, and research frontiers.

Specifically, the significant increase in the number of publications reveals the growing importance of early childhood teacher TPACK research. This growth trend is likely linked to global shifts in educational policies, particularly the release of major policy documents such as UNESCO's "Education 2030 Agenda" and the EU's "Digital Education Action Plan," which highlight the importance of early childhood education and the integration of technology. These policy changes have not only increased the application of educational technology in early education but also stimulated deeper academic interest in researching TPACK competency among early childhood educators.

The leading roles of the United States, China, and Turkey in early childhood teacher TPACK research may reflect the high regard these countries place on educational technology and teacher education. Their education systems emphasize the integration of technology and innovative teaching methods, fostering the development of TPACK-related research. Additionally, the educational policies and funding investments in these countries may provide a conducive environment for advancing TPACK research.

Furthermore, the increase in cross-institutional collaboration underscores the importance of academic cooperation in a globalized context. The prominent performance of institutions such as Nanyang Technological University and National Taiwan University of Science and Technology, as well as international collaborations, shows that sharing resources and knowledge is vital to driving the development of TPACK research. This collaboration not only facilitates knowledge exchange across different cultural and educational contexts but also provides broader perspectives and deeper insights for the field.

Authors such as Chai and Koh have made significant contributions to the development and practical application of the TPACK framework. Their research has not only deepened the understanding of TPACK but also provided practical guidance for the professional development of teachers in integrating technology, pedagogy, and content knowledge.

The high citation frequency of key works such as Schmidt et al. (2009) and Voogt & Tondeur (2015) underscores their pivotal role in shaping the core theoretical and methodological foundations of TPACK research. The widespread citation of these works reflects their influence and their role in inspiring subsequent studies in the field.

More importantly, the emergence of keywords such as "belief" and "perception" highlights the challenges teachers face when adopting and applying the TPACK framework. These challenges involve not only enhancing technological skills but also understanding and supporting teachers' personal beliefs and perceptions, which play a crucial role in the effective integration of technology.

Finally, the trends associated with keywords like "validation," "skill," "teacher training," and "impact" signal an increasing focus on validating teacher TPACK competencies and evaluating the effectiveness of educational interventions. These trends reflect a growing demand for quantitative research and evidence-based approaches in education, emphasizing the importance of assessing teacher professional development and educational outcomes.

These findings provide valuable perspectives for understanding the current state and future directions of early childhood teacher TPACK research. They not only reveal the dynamics and trends in the field but also offer important insights for policymakers, teacher trainers, and researchers.

CONCLUSION

This study provides a comprehensive analysis of early childhood teacher TPACK research, offering an in-depth understanding of the field's current state and future development trends. The results highlight the dynamic and multidimensional nature of TPACK research, emphasizing the importance and complexity of integrating educational technology into early childhood education.

Although this research offers valuable insights into the field, there are limitations, such as its reliance on existing literature and secondary data, which may not encompass all relevant studies. Future research could explore the application of TPACK in different educational environments through field investigations and case studies.

In conclusion, this study provides essential perspectives on the current status and future trajectory of early childhood teacher TPACK competencies. As technology continues to evolve in education, research into early childhood teacher TPACK will remain pivotal in supporting teachers' effective integration of technology and pedagogical content in rapidly changing educational environments.

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