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A Bibliometric and Knowledge Mapping Analysis of Research on Teachers' Pedagogical Content Knowledge Using CiteSpace

Yu Ying[1, 2], Hamidah Mohamad[1]

[1]University Tun Abdul Razak (UNIRAZAK), Malaysia, [2]Jilin Engineering Normal University, China

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Abstract

This study investigates the research landscape, intellectual structure, and emerging trends of Pedagogical Content Knowledge (PCK) through a bibliometric and knowledge mapping analysis. We retrieved 405 English-language journal articles on PCK from the Web of Science Core Collection (2016–2025; cutoff July 20, 2025; Early Access included) using a comprehensive query that covered “Pedagogical Content Knowledge (PCK),” “Technological Pedagogical Content Knowledge (TPACK),” and related teacher-knowledge synonyms. CiteSpace was employed to conduct co-citation, keyword clustering, and burst detection analyses. The findings indicate that research on PCK has grown steadily over the past decade, with a notable increase in publication output and citation activity since 2019. The United States, China, and Australia emerged as the most productive countries, while research contributions were primarily concentrated in teacher education, curriculum development, and educational technology. Major themes identified in highly cited literature include teacher professional knowledge, subject-specific pedagogy, classroom assessment, teacher training, and technology integration. The keyword burst analysis revealed recent interest in topics such as STEM education, reflective practice, and pre-service teacher learning. Overall, the field is gradually shifting from conceptual exploration toward practical application and interdisciplinary integration of PCK in authentic teaching contexts.

Keywords: Pedagogical Content Knowledge, Bibliometric Analysis, Citespace, Teacher Education, Educational Research, Research Trends, Knowledge Mapping, TPACK, Early Access

Introduction

Teacher professional knowledge has long been recognized as a key determinant of instructional quality and student learning outcomes. Within this domain, Pedagogical Content Knowledge (PCK)—first introduced by Shulman in Knowledge and Teaching: Foundations of the New Reform (1987)—emphasizes the interplay between subject matter understanding and pedagogical reasoning. It highlights how teachers transform disciplinary knowledge into forms accessible to learners, thereby bridging the gap between “knowing” and “teaching” (Shulman, 1987).

Over the past three decades, PCK has evolved from a conceptual framework into an influential research paradigm in teacher education. Scholars have refined Shulman's original model by delineating its components, investigating its development, and examining its role in effective teaching. For instance, Kind (2009) explicated how PCK can be operationalized in science teacher education, demonstrating its potential to foster reflective practice and professional growth among both novice and experienced teachers. This cumulative scholarship underscores the continuing relevance of PCK as a lens for analyzing teachers' professional cognition and instructional decision-making across diverse educational contexts (Tobin & Garnett, 1988; Kind, 2009).

In recent years, the scope of PCK research has expanded to include Technological Pedagogical Content Knowledge (TPACK), reflecting the integration of digital technologies into contemporary classrooms (Mishra & Koehler, 2006). This expansion illustrates the field's responsiveness to evolving educational challenges and its increasing interdisciplinarity. However, despite extensive conceptual and qualitative investigations, there remains a lack of large-scale, quantitative syntheses capable of capturing the field's intellectual evolution and global research dynamics.

Bibliometric and scientometric tools such as CiteSpace (Chen, 2006) enable systematic mapping of knowledge structures through co-citation networks, collaborative linkages, and keyword burst detection. Yet, to date, only limited attempts have been made to apply these methods to the comprehensive analysis of PCK scholarship—particularly over the past decade, when the field has diversified both theoretically and methodologically.

To bridge this gap, the present study conducts a bibliometric and knowledge-mapping analysis of 405 PCK-related articles indexed in the Web of Science Core Collection between 2016 and 2025 (including Early Access/Online First publications). The study aims to:

(a) identify leading contributors (countries, institutions, authors, and journals) in global PCK research;

(b) reveal the intellectual structure and thematic clusters through co-citation and keyword analyses; and

(c) detect research frontiers and emerging trends via burst term analysis.

By providing an evidence-based overview of PCK's scholarly evolution, this study seeks to inform future theoretical development, teacher education practice, and policy design in an era of increasingly complex pedagogical demands.

This study advances prior bibliometric research on teacher professional knowledge by extending the temporal coverage to 2016–2025 and incorporating Early Access publications indexed in the Web of Science Core Collection. Methodologically, it applies parameter-sensitivity analyses and integrates co-citation, keyword burst, and cluster-based mapping to provide a transparent and robust depiction of the field's intellectual structure. Conceptually, it contributes to the social sciences by elucidating how research on Pedagogical Content Knowledge (PCK) and its technological extensions (e.g., TPACK) has evolved across countries and disciplines. The findings offer empirically grounded insights that inform teacher education policy, comparative research, and professional learning design in increasingly technology-mediated and globally connected educational systems.

Literature Review

Pedagogical Content Knowledge (PCK), since its conceptualization by Shulman (1987), has remained a central framework in educational research. Shulman emphasized that PCK represents the blending of content knowledge and pedagogical strategies that enables teachers to transform disciplinary content into forms understandable to learners—a key to instructional effectiveness (Shulman, 1987).

In recent years, an increasing number of studies have applied bibliometric and knowledge mapping approaches (e.g., CiteSpace) to examine the evolution of PCK-related research. For instance, Alka, Bancong, and Muzaini (2023) conducted a bibliometric analysis of PCK publications in the Scopus database from 2018 to 2022 using CiteSpace, highlighting the prominence of topics such as instructional design and teacher training. Their study also underscored the growing significance of international collaboration networks. In a related effort, Behling, Förtsch, and Neuhaus (2022) proposed the Refined Consensus Model of PCK, emphasizing the dynamic conceptual negotiation within the PCK research community and identifying key filters between different realms of knowledge.

Despite these advances, a comprehensive bibliometric overview of PCK research indexed in the Web of Science over the last decade (2016–2025) is still lacking. In particular, few studies have systematically visualized keyword evolution, burst detection, and institutional or national collaboration patterns using large-scale data. CiteSpace, as a science mapping tool, enables co-citation analysis and keyword burst detection to identify research hotspots and frontiers in a given field (Chen, 2006), yet it remains underutilized in the context of PCK studies.

To fill this gap, the present study conducts a comprehensive knowledge mapping analysis of 405 PCK-related articles published between 2016 and 2025 in the Web of Science Core Collection, aiming to identify intellectual structures, emerging trends, and global research dynamics.

In recent years, the rapid expansion of academic literature has made it increasingly difficult for researchers to stay updated with current research trends and identify thematic shifts in their fields (Briner & Denyer, 2012). Scholarly journals remain the primary medium through which academic knowledge is disseminated, and bibliometric analysis has emerged as an essential methodological tool in identifying the structural and dynamic characteristics of research domains (Pritchard, 1969; Abramo & D'Angelo, 2011).

Bibliometric Methods

Bibliometric methods employ mathematical and statistical techniques to analyze publication patterns, co-authorship, keyword co-occurrence, citation structures, and institutional or national contributions. These methods allow for the quantification and visualization of knowledge networks, including author impact, journal influence, thematic clusters, and international collaborations (Ryan & Woodall, 2005; De Battisti, Salini, & Tenconi, 2015). More advanced bibliometric approaches, such as science mapping, enable researchers to construct and explore domain-specific landscapes, thereby uncovering conceptual structures and research frontiers (Tsay, 2011; Hung, 2012; Kevin, Cahlik, & Hron, 2017).

Among bibliometric techniques, co-citation analysis has played a pioneering role. First defined by Small (1973), co-citation refers to the frequency with which two units—authors, documents, or journals—are cited together in the same references list. This method has been widely adopted across disciplines, particularly in information science, education, and bibliometrics, to track the evolution of ideas and identify emerging research clusters (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011; Chen, 2006).

In the context of PCK, bibliometric analysis remains underutilized, despite the increasing volume of publications on the topic in recent years. According to the Web of Science database, more than 405 PCK-related articles were published between 2016 and 2025. However, only a limited number of these studies have applied bibliometric techniques to systematically map the development of the field. The present study addresses this gap by utilizing CiteSpace—an established knowledge mapping software (Chen, 2006)—to visualize and analyze the knowledge structure and research trends of PCK over the past decade.
Through this approach, the study seeks to answer the following research questions:

1. What are the annual publication trends for PCK research from 2016 to 2025?
2. Which countries have contributed the most publications in this domain?
3. What are the top journals publishing PCK-related research?
4. Who are the most productive and influential authors in the field?
5. What are the main research topics and keyword co-occurrences that define the intellectual structure of PCK research?

Materials and Methods

Ethics Statement

This study is a retrospective bibliometric analysis based solely on published literature retrieved from publicly accessible databases. No human subjects or clinical interventions were involved; therefore, ethical approval from an institutional review board was not required, as the study did not fall within the scope of human research ethics.

Study Design

This study employs a bibliometric and science mapping approach to examine global research trends in Pedagogical Content Knowledge (PCK). The methodology aligns with the guidelines for bibliometric analysis described by Zupic and Čater (2015), who outlined a five-phase protocol for conducting science mapping: (1) study design, (2) data collection, (3) data analysis, (4) visualization, and (5) interpretation. These steps ensure a systematic examination of the intellectual structure and research dynamics within a scientific domain.

Data Collection

Bibliographic data were retrieved from the Web of Science Core Collection on July 24, 2025.
The search query used was:
TS = ("pedagogical content knowledge" OR PCK OR "technological pedagogical content knowledge" OR TPACK OR "teacher professional knowledge" OR "instructional knowledge" OR "teacher expertise")
AND TS = ("teacher" OR "pre-service teacher" OR "in-service teacher" OR "student teacher" OR "educator" OR "faculty")
To avoid ambiguity regarding the inclusion of 2025 records, we clarify that all data were retrieved on July 24, 2025, and 2025-dated items refer to Early Access/Online First articles

already indexed in WoS by that date. The coverage window is January 1, 2016–July 20, 2025; only peer-reviewed journal articles in English were included; conference papers, editorials, and book reviews were excluded.

A total of 557 records were initially retrieved. After a manual screening process, 152 publications were removed due to irrelevance (e.g., use of “PCK” as an acronym for unrelated terms) or improper document type. The final dataset comprised 405 eligible articles for bibliometric analysis.

Search Strategy & Sensitivity Checks
Our primary query combined canonical PCK terms with well-established extensions (e.g., TPACK) and broader descriptors of teacher knowledge to capture adjacent scholarship (teacher professional knowledge, instructional knowledge, teacher expertise). The inclusion of TPACK is theoretically motivated by PCK’s technology-integrated elaboration in teacher education (Mishra & Koehler, 2006) alongside the foundational PCK construct (Shulman, 1987). To assess robustness, we conducted sensitivity analyses by (a) running a narrow query restricted to “Pedagogical Content Knowledge” OR “PCK” only, and (b) excluding TPACK-related terms. We compared record counts, network density/modularity, and cluster stability across settings. Core structures remained substantively interpretable under alternative specifications.

Data Analysis
The bibliographic data were exported in plain text (.txt) format with “Full Record and Cited References” from the Web of Science database. These files included metadata such as article titles, abstracts, author affiliations, keywords, source journals, and citation counts.

The data were imported into CiteSpace (version 6.1.R6), a leading software tool for science mapping and visualization (Chen, 2006; Chen, 2017). CiteSpace enables the detection of co-citation clusters, keyword bursts, collaboration networks, and intellectual turning points. The analysis parameters were set as follows: time slicing from 2016 to 2025, with one-year intervals; selection criteria set to the top 50 most-cited items per slice; and pruning using Pathfinder and pruning sliced networks to ensure interpretability (Chen et al., 2010). All maps were generated based on co-citation and keyword co-occurrence networks.

Visualization
For the visualization of bibliometric networks in this study, the software CiteSpace was used to analyze and present the structural relationships between publications, authors, and concepts related to Pedagogical Content Knowledge (PCK). CiteSpace was developed by Chen (2006) and has become a widely recognized tool in scientometric and knowledge domain visualization. It supports a variety of data sources such as Web of Science, Scopus, and Dimensions, and allows for the identification of co-citation clusters, keyword bursts, author collaboration networks, and pivotal points in the evolution of a scientific field (Chen, 2017).

CiteSpace visualizations use algorithms such as burst detection, betweenness centrality, and modularity clustering to reveal structural and temporal patterns in scientific literature (Chen et al., 2010). In this study, the visualizations were generated with time slicing set from 2016 to 2025, with yearly intervals. The node types selected included cited references, authors, and keywords. To improve interpretability, the Pathfinder and pruning sliced networks options were enabled, and top 50 items per slice were selected based on citation frequency.

Each node in the visualization represents an entity (e.g., author, journal, keyword), while the links indicate co-citation or co-occurrence relationships. The thickness of the link reflects the strength of the relationship, and cluster labels were automatically extracted using the log-likelihood ratio (LLR) method. Color coding was used to indicate the time of occurrence, enabling a chronological interpretation of research trends.

Although other tools such as VOSviewer (Van Eck & Waltman, 2010, 2017) and Bibliometrix R (Aria & Cuccurullo, 2017) are widely used for bibliometric mapping, CiteSpace was selected for this study due to its strength in detecting turning points, landmark papers, and temporal dynamics. CiteSpace's ability to integrate cluster labeling, burst detection, and dual-map overlays made it particularly suited for this analysis.

Parameter Sensitivity

In CiteSpace, we set Top-N per slice to 50 and enabled Pathfinder and pruning of sliced networks to balance coverage and interpretability. To assess robustness, we re-estimated the maps with Top-N = 30 and 100; cluster composition and key turning points remained stable. Cluster labels were generated with the log-likelihood ratio (LLR) method. We attempted Top-N = 100; however, the resulting networks were excessively dense for stable visualization on our hardware. Following common practice in CiteSpace analyses, we used g-index (k = 50) as an upper-bound specification, which preserves influential nodes while controlling density. Results were consistent with the Top-N = 30/50 settings.

Interpretation

Interpreting the visual outputs generated by CiteSpace requires careful alignment between domain knowledge and empirical patterns derived from the bibliometric data. Bibliometric tools such as CiteSpace provide a structural overview of the research landscape, often revealing latent patterns that differ from traditional narrative reviews (Chen, 2006; Zupic & Čater, 2015).

Rather than confirming preconceived notions, interpretation in this context involves identifying influential authors, key thematic clusters, and shifts in research focus based on temporal and structural indicators. For instance, burst detection highlights emergent trends, while high betweenness centrality nodes indicate bridging elements across research clusters (Chen et al., 2010). The interpretation process thus focuses on understanding how clusters of publications, authors, and keywords interact and evolve, shaping the intellectual trajectory of the PCK domain.

Ultimately, bibliometric interpretation offers an objective means of assessing the dynamics of a research field, serving as a complement to qualitative literature syntheses. It reveals how different thematic areas intersect, which actors are most central, and what conceptual developments have led to structural changes within the knowledge domain. This perspective is essential for mapping the development of PCK research and guiding future inquiries in teacher education scholarship.

Results

Annual Publication Trends (2016–2025)

As shown in Figure 1, from 2016 to 2025, the annual number of publications related to PCK research globally exhibits a generally upward trend with fluctuations. Notably, since 2020, China's publication volume has surged rapidly, reaching a peak in 2022 with over 50 articles published in that year alone. The United States led the field prior to 2020 but showed a slight decline thereafter. Additionally, countries such as Australia, Malaysia, Germany, and Taiwan have also steadily increased their research output on PCK in recent years. This trend indicates growing global attention and sustained interest in pedagogical content knowledge (PCK) research.

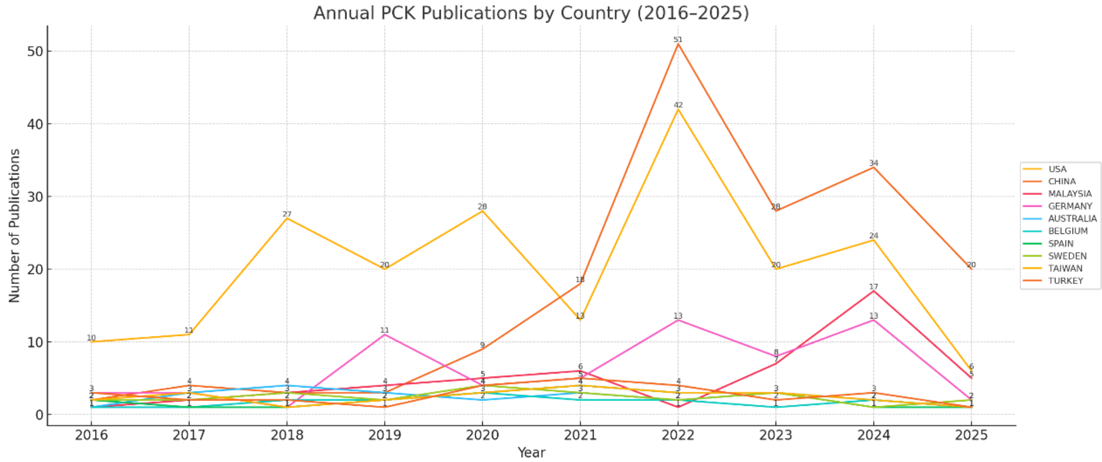

Figure 1: Annual PCK publications by Country (2016–2025)

Top 10 Countries by Burst Strength

Burst strength reflects the extent to which a country's research influence in the field has risen rapidly over a specific time period. As illustrated in Figure 2, China and the United States clearly dominate, with burst strengths of 33.5 and 30.0 respectively, demonstrating strong emergent influence in PCK research. Australia, Germany, Taiwan, and Chile also perform notably, with burst strengths all exceeding 10, indicating a sharp increase in academic focus during specific periods. The Netherlands, Malaysia, and Sweden, though slightly lower in burst strength, also show increasing levels of research activity and contribution to the field.

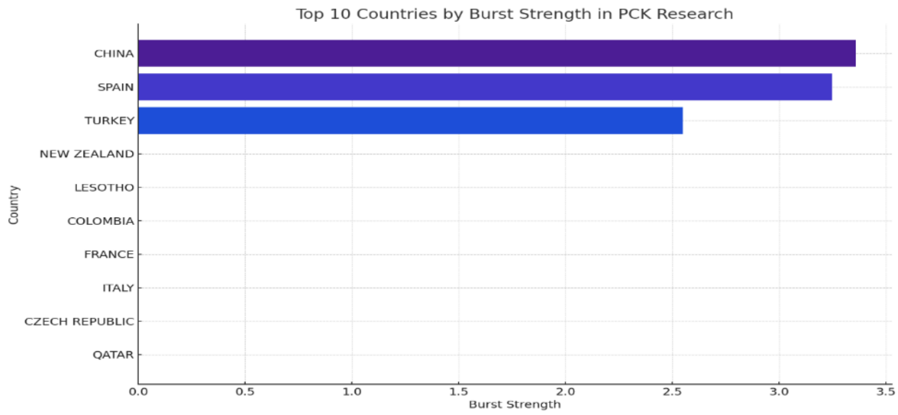

Figure 2: Top 10 countries by Burst Strength in PCK Research

Top 10 Countries by Total Publications

In terms of total publications, the United States ranks first with 200 articles, followed closely by China with 175 articles. These two countries form the core research hubs in the field of PCK. Australia, Germany, and Turkey rank third to fifth with 67, 55, and 49 articles respectively, indicating consistent output in the field. Spain, Taiwan, Sweden, Belgium, and Korea also make the top ten, each with more than 20 publications. This distribution highlights the global nature of PCK research, particularly in English-speaking countries and nations with strong traditions in educational research.

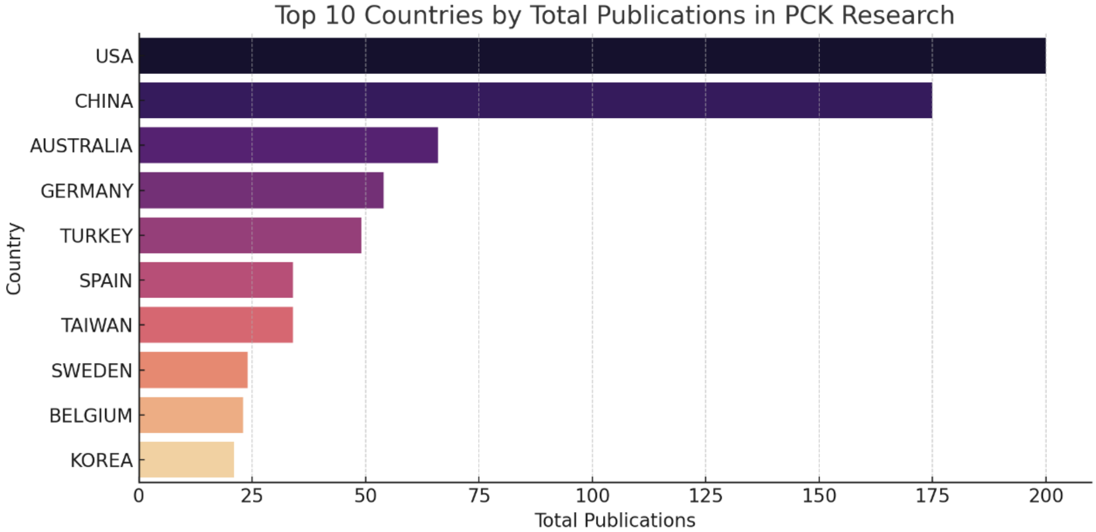

Figure 3: Top 10 Countries by Total Publications

Collaborating Authors Network

As shown in Figure 4, the collaborating authors network reveals the key contributors and their cooperative relationships in the field. Based on betweenness centrality, Ward, Phillip emerges as a pivotal academic node, acting as a bridge across multiple collaboration clusters. Additionally, scholars such as Aynur Aydin and Kim, Insook have established relatively tight-knit collaborative networks, indicating sustained research output and influence in the area of Pedagogical Content Knowledge (PCK). Overall, the network displays several discrete research groups, yet the overall density remains relatively low, suggesting room for enhancing cross-author collaboration within the PCK research community.

This pattern of collaboration is also evident in other areas of educational research.

For example, Tang and Tsai (2016) identified a similarly “multi-centered but weakly connected” co-authorship structure in the domain of educational technology in science education, underscoring a broader tendency toward fragmented collaboration patterns in educational research networks.

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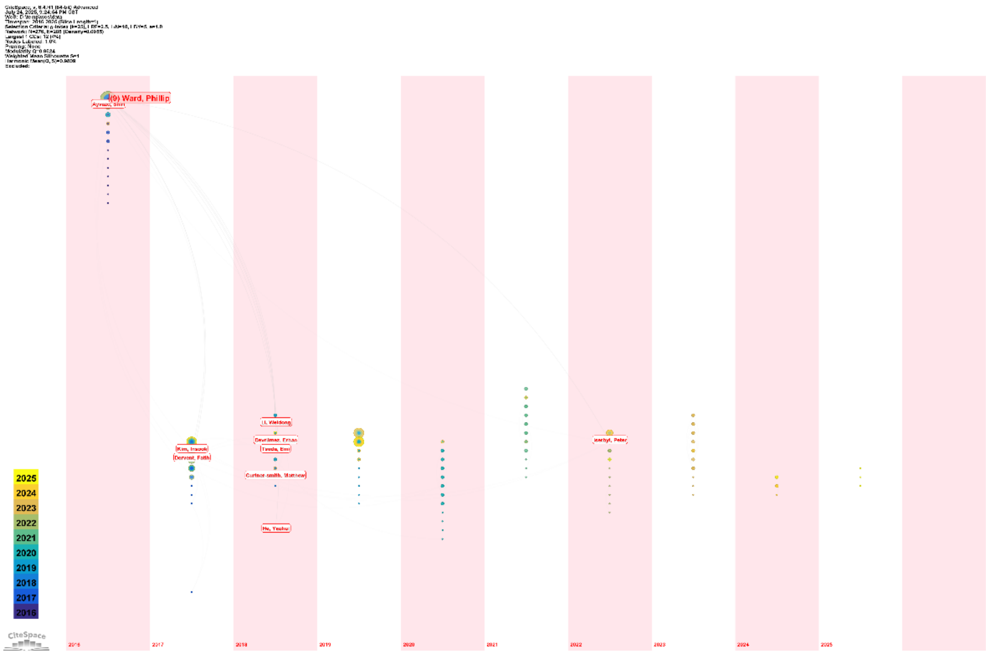

Figure 4: Timezone View of Collaborating Authors Network

Institutional Collaboration and Timezone Evolution

As shown in Figure 5, the institutional collaboration and timezone evolution view displays the cooperative relationships among global institutions. Notably, institutions such as Ohio State University, University System of Ohio, East China Normal University, and Kent State University exhibit strong collaboration intensity. Based on the color distribution, early research was mainly concentrated in North America (e.g., the USA and Canada), whereas after 2020 Chinese institutions (e.g., Nanjing Normal University and East China Normal University) began to show increased activity, gradually forming a multi-partner collaboration pattern.

Structurally, the network displays a "star-like diffusion" pattern, with Ohio State University occupying a prominent central position, connecting multiple collaborative nodes and demonstrating strong influence diffusion capacity. This trend is consistent with the findings of Zhou et al. (2023), which reveal that, with policy support and resource aggregation, Chinese institutions have significantly enhanced their international influence in the field of teacher knowledge research.

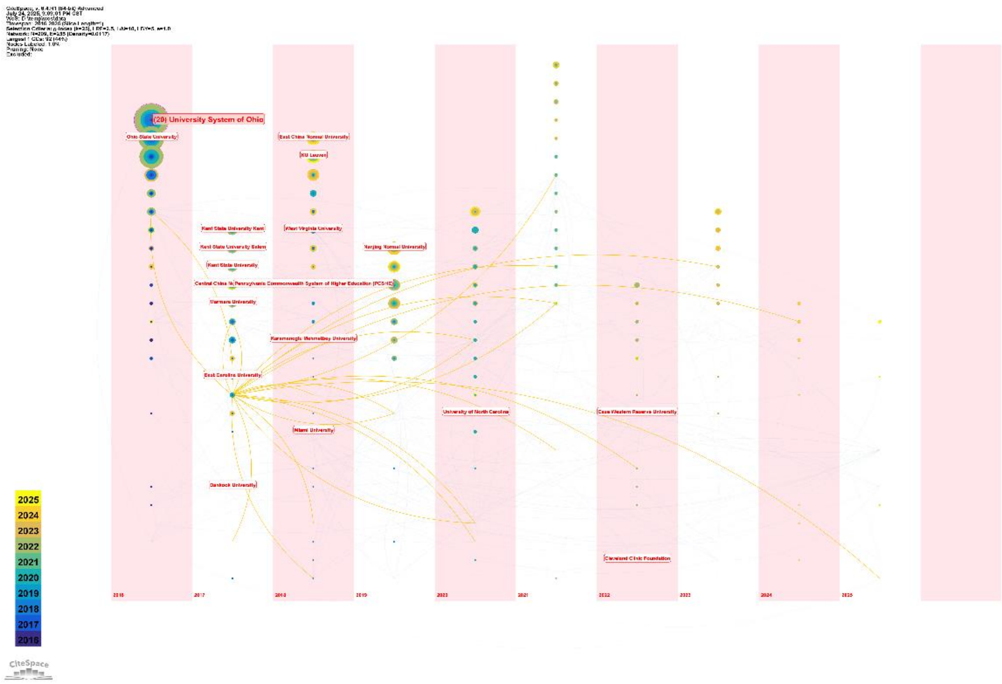

Figure 5: Institutional Collaboration and Timezone Evolution

Keyword Cluster Analysis (I): Overview of Keyword about Main Countries Cluster Map (2016–2025)

As shown in Figure 6, it is a keyword about main countries cluster map generated using CiteSpace, showcasing six thematic clusters (Cluster #0 to #5) in the field of Pedagogical Content Knowledge (PCK) research between 2016 and 2025. Each cluster is color-coded and labeled by its most prominent keywords. Here's a detailed academic-level analysis of the map:

This visualization reveals the thematic structure of global PCK research over a ten-year period, based on keyword co-occurrence analysis. Each colored node represents a keyword, with lines denoting co-occurrence relationships. Larger nodes suggest higher frequency, while the spatial clustering reflects thematic similarity. The major clusters are as follows:

Cluster #0 – Qualitative Data (Red)
Representative Keywords: qualitative data, teacher behavior, case study, classroom interaction

Core Country: USA
Interpretation: This cluster highlights the prominence of qualitative methodologies (e.g., interviews, ethnography, case studies) in PCK research, particularly among U.S. scholars. It aligns with the American tradition of focusing on real-world teaching practices and reflective inquiry, as originally emphasized by Shulman (1986), who introduced the PCK framework.

Cluster #1 – Learning Motivation, Technology, Innovativeness (Green)
Representative Keywords: motivation, technology integration, innovativeness
Significance: Reflects the intersection between student learning motivation and teachers' adoption of educational technologies. This cluster signals a shift toward integrating TPACK (Technological Pedagogical Content Knowledge) into PCK frameworks.

Comment: The appearance of "innovativeness" suggests increasing attention to 21st-century competencies and the transformation of classroom environments through digital means.

Cluster #2 – Collective TPACK (Cyan)
Representative Keywords: TPACK, collaboration, professional learning communities

Core Country: China
Interpretation: This cluster emphasizes a collective orientation toward TPACK development, involving teacher teams or communities. It indicates a maturing phase of research that goes beyond individual competence to explore systemic and collaborative professional development strategies.

Cluster #3 – Digital Teacher Competence (Blue)
Representative Keywords: ICT competence, online teaching, digital literacy

Core Countries: Spain, Chile
Interpretation: Focused on the digital readiness and competencies of teachers, particularly in response to post-COVID online learning demands. This theme aligns closely with global policy frameworks such as UNESCO's ICT Competency Framework for Teachers.

Cluster #4 – Teaching Technology (Purple)
Representative Keywords: classroom tools, technology-enhanced learning, teaching strategy

Core Countries: Sweden, Canada
Interpretation: Highlights ongoing interest in the role of technology as a pedagogical tool. It suggests well-established systems (e.g., in K–12 education in Scandinavian and North American contexts) continue to generate impactful research.

Cluster #5 – Knowledge (Gray-Yellow)
Cluster #5 ("Knowledge") consolidates work conceptualizing teacher professional knowledge and the structure of PCK (e.g., Shulman's foundational model; subsequent elaborations in science education and technology-integrated contexts). Representative studies include Shulman (1987), conceptual syntheses on knowledge components and enactment, and TPACK-inflected investigations connecting teachers' knowledge to classroom practices.

Representative Keywords: knowledge, metacognition, teacher beliefs
Position: Peripherally located with low density
Interpretation: This underdeveloped cluster likely represents emerging or interdisciplinary research directions, possibly including inquiries into cognitive structures, teacher knowledge boundaries, or epistemological beliefs. These have not yet coalesced into a dominant thematic field but may represent future research frontiers.

Research Implications

Methodological Diversification: While qualitative research (Cluster #0) remains influential, technology-oriented empirical approaches are gaining ground.

Thematic Broadening: There's a transition from focusing solely on teacher knowledge to encompassing motivation, strategy, and systemic support structures.

Regional Specialization: Different clusters reflect geographic strengths, such as the USA in qualitative research, China in collective teacher development, and Spain/Chile in digital competence.

This visualization affirms that PCK research from 2016–2025 is undergoing a transformation characterized by methodological plurality, thematic integration, and global diversification. These shifts suggest an evolving research ecosystem ready to address complex challenges in 21st-century teacher education.

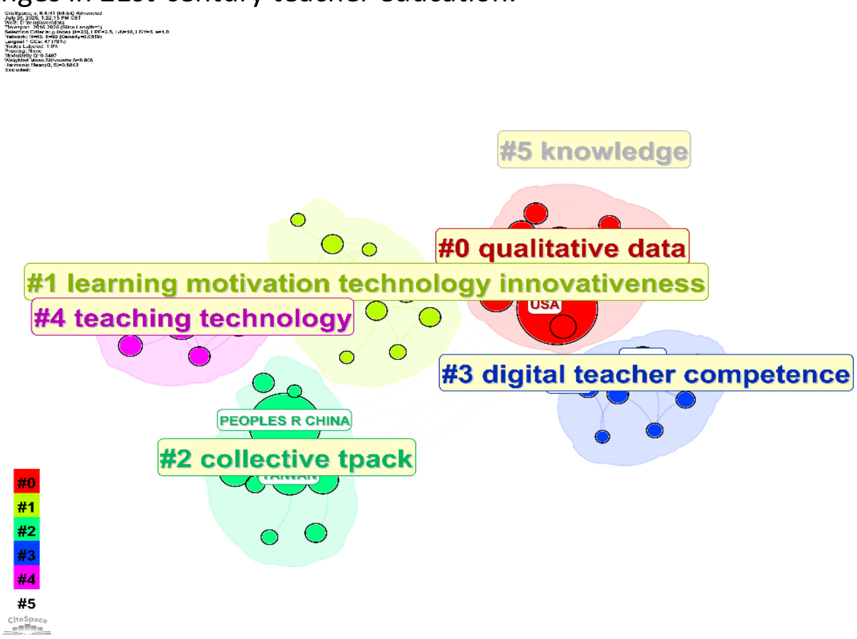

Figure 6: Overview of Keyword Clusters by Major Countries (2016–2025)

Keyword Cluster Analysis (II): Thematic Evolution in TPACK/PCK Research (2016–2025)
This visualization illustrates the co-occurrence network of keywords in the field of Pedagogical Content Knowledge (PCK) and Technological Pedagogical Content Knowledge (TPACK) from 2016 to 2025. Based on CiteSpace analysis, eight major thematic clusters (Cluster #0–#7) were identified, each representing a significant subdomain or research trend in the field.

Cluster #0 – Technology Integration (Red)
Core Keywords: technology integration, instructional design, teaching strategy

Analysis: This cluster, located in the lower part of the map, forms a strong central structure, highlighting "technology integration" as a persistent core issue in TPACK research. Studies focus on how teachers incorporate digital tools such as smartboards, educational apps, and online platforms into classroom instruction. This aligns with Voogt et al. (2015), who emphasized that the essence of TPACK lies in "supporting effective integration of technology into pedagogy."

Cluster #1 – Digital Media (Orange)
Core Keywords: digital tools, media literacy, learning engagement

Analysis: This cluster reflects the growing role of digital media in facilitating teacher-student interaction. It emphasizes how digital platforms influence instructional delivery, student motivation, and classroom communication. This suggests an increasing integration of media literacy within the TPACK model, as noted by Koehler and Mishra (2009).

Cluster #2 – Physical Education (Light Green)
Core Keywords: physical education, embodied learning, motion-sensing technology

Analysis: This emerging cluster illustrates the interdisciplinary application of TPACK in non-traditional domains such as physical education. Studies examine the use of wearable technologies and motion-sensing devices to enhance student participation and instructional effectiveness.

Cluster #3 – Next Generation Science Standard (Green)
Core Keywords: NGSS, science literacy, inquiry-based learning

Analysis: Closely tied to curriculum reforms, this cluster highlights how TPACK is integrated into STEM and science instruction. The emphasis is on using technology to support scientific inquiry and interdisciplinary competencies, aligned with the Next Generation Science Standards (NGSS).

Cluster #4 – Pedagogical Transformation Competence (Cyan)
Core Keywords: teacher development, pedagogical innovation, transformative learning

Analysis: This cluster emphasizes the development of teachers' adaptive capacities in response to technological change. Research focuses on how educators reconstruct their pedagogical beliefs and instructional practices through professional growth and transformative learning processes.

Cluster #5 – Science Education (Blue)
Core Keywords: scientific reasoning, experimentation, STEM

Analysis: This cluster reveals a strong link between TPACK and science education, focusing on designing inquiry-based experiments, fostering scientific reasoning, and integrating STEM approaches into classroom practice.

Cluster #6 – Third-order Barrier (Purple)
Core Keywords: barriers to technology use, teacher beliefs, organizational support

Analysis: The "third-order barrier" refers to deep-seated cultural and epistemological constraints beyond technical or training-related issues. This cluster explores teachers' internal resistance, belief systems, and institutional constraints that affect technology integration (Tsai & Chai, 2012).

Cluster #7 – Successful Design (Pink)
Core Keywords: design-based learning, instructional framework, model validation

Analysis: This theme focuses on the construction and empirical validation of instructional models grounded in the TPACK framework. The studies aim to enhance systematic instructional design and effectiveness, representing a shift from theory to applied pedagogy.

Conclusion and Implications

The keyword cluster analysis reveals three major evolutionary directions in TPACK research:

A shift from general technological integration to subject-specific applications (e.g., science and physical education);

A deepening focus on teacher beliefs, pedagogical transformation, and systemic adaptation rather than mere tool adoption;

A broadening scope from individual practice to institutional instructional design and policy-level development.

These findings suggest that TPACK research is entering a new phase characterized by "integration-to-transformation," requiring scholars to focus on teachers' holistic competencies, design thinking, and organizational infrastructure in the digital age.

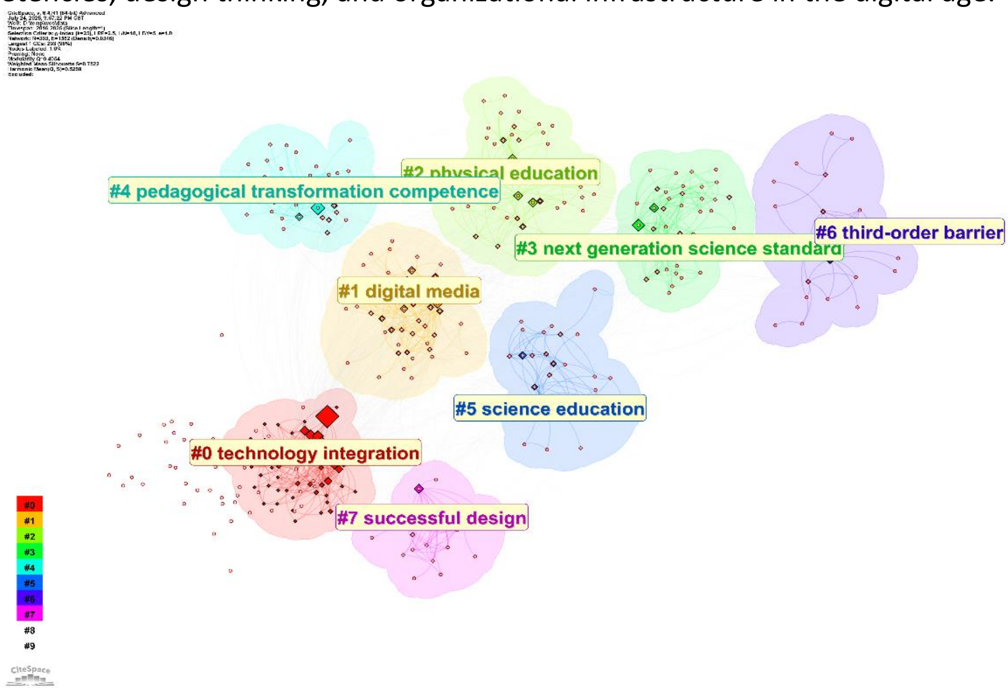

Figure 7: Keyword Cluster Analysis (II): Thematic Evolution in TPACK/PCK Research (2016–2025)

Analysis of Subject Categories

This figure illustrates the temporal evolution and interdisciplinary distribution of subject categories in PCK (Pedagogical Content Knowledge) research from 2016 to 2025, as generated by CiteSpace.

Core Discipline: Education & Educational Research

This category forms the largest and most central node in the visualization, indicating that the vast majority of PCK-related publications are situated within the educational sciences. The large, concentric burst rings suggest sustained high volume and influence over the full 2016–2025 period.

Its dominant position confirms that PCK remains a foundational concept in the study of teaching effectiveness, curriculum design, and teacher education.

Emerging Cross-Disciplinary Fields

Several non-traditional fields show increasing relevance in PCK studies, such as:

Environmental Sciences and Environmental Studies: These categories reflect the growing incorporation of sustainability and environmental literacy into teacher education, aligned with the rise of Education for Sustainable Development (ESD).

Green & Sustainable Science & Technology: This further reinforces the interdisciplinary linkage between environmental responsibility and pedagogical practices.

Sport Sciences and Physical Education: These smaller yet active nodes indicate the application of PCK frameworks in physical education, echoing findings from cluster #2 in the keyword co-occurrence analysis.

Technological Integration

Computer Science, Engineering, and Multidisciplinary Sciences also appear in the network, although with smaller nodes. These categories demonstrate that PCK research increasingly overlaps with digital literacy, instructional design, and STEM-oriented pedagogies.

The presence of these fields supports earlier trends observed in clusters such as “technology integration” and “digital media.”

Temporal Trend (Colored Bands & Node Rings)

Nodes are colored by publication year (blue: 2016 → yellow: 2025), showing how disciplines have engaged with PCK research across time.

While Education & Educational Research remains consistent, newer fields such as Chemistry, Multidisciplinary and Green & Sustainable Science have gained visibility primarily after 2020.

The vertical pink bands suggest publication intensity over time; most bursts are clustered around 2019–2023, indicating a post-pandemic acceleration of interdisciplinary education research.

Conclusion

The subject category visualization reveals that:

PCK research is deeply rooted in educational theory but is expanding toward environmental, technological, and interdisciplinary domains.

Since 2020, there is a visible trend of diversification, likely driven by global challenges (e.g., sustainability, digitalization, pandemic-induced shifts) requiring more integrative pedagogical frameworks.

This interdisciplinary trajectory supports the idea that PCK is not only evolving methodologically but also thematically—positioning itself at the crossroads of teaching innovation, technological adaptation, and societal transformation.

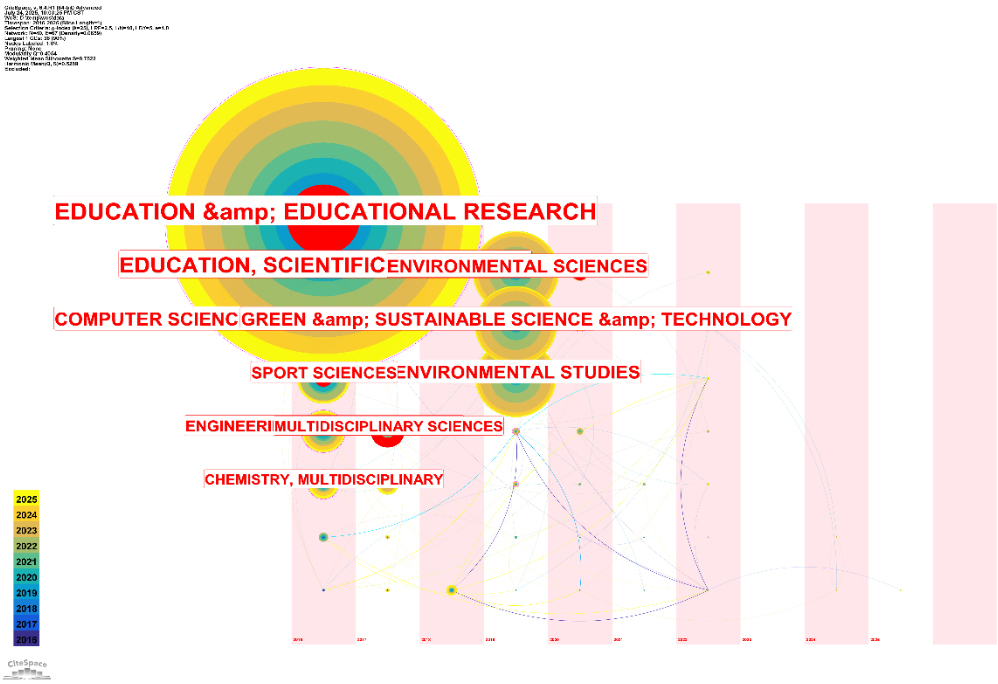

Figure 8: Subject Categories

Document Co-Citation Analysis (DCA)

This figure illustrates the co-citation network of core literature in the field of Pedagogical Content Knowledge (PCK) from 2016 to 2025. The most prominent cluster is Cluster #0 "pedagogical content knowledge," centered on Shulman, L.S. (1986, 1987), underscoring his foundational role in the theoretical development of PCK with exceptionally high citation frequency and betweenness centrality. Cluster #1, titled "technological pedagogical content knowledge," highlights authors such as Magnusson and Mishra, reflecting the growing integration of the TPACK framework in recent PCK studies. Cluster #2 "content knowledge" and Cluster #3 "preservice science teachers nature," indicating continued focus on subject knowledge and teacher preparation;

Cluster #4 "self-regulated learning" and Cluster #5 "digital competence evaluation framework," suggesting a merging of learning sciences and teacher ICT competency assessment; Cluster #6 "TPACK framework" and Cluster #10 "training" emphasize the design and evaluation of teacher training systems.

This map reveals the intellectual structure of PCK research and its evolving trajectory toward technological integration, cognitive development, and instructional support.

Figure 9: Document Co-Citation Analysis (DCA)

Author Co-Citation Analysis (ACA)

This visualization presents the co-citation network of the most frequently cited authors in the PCK research field. Cluster #0 “pedagogical content knowledge” is the largest and most central cluster, with Shulman L. maintaining a dominant theoretical influence. Authors such as Magnusson, Ball D.L., and Ward D. form an interconnected knowledge lineage around his work.

Cluster #1 “technological pedagogical content knowledge” centers on the TPACK framework, indicating the systematic development of research integrating technology and PCK;

Cluster #5 “digital competence evaluation framework” shows sustained interest from European scholars such as Krauss S. in assessing teachers’ ICT capabilities;

Cluster #7 “k–12 teachers ability” and Cluster #10 “training” reflect growing attention to teacher competence in basic education and the design of professional development;

Cluster #4 “self-regulated learning” indicates cross-disciplinary intersections between educational psychology and teacher knowledge.

Overall, the ACA network suggests that PCK research has evolved from a U.S.-centric foundational system into a diversified, multidimensional scholarly community involving international collaborations.

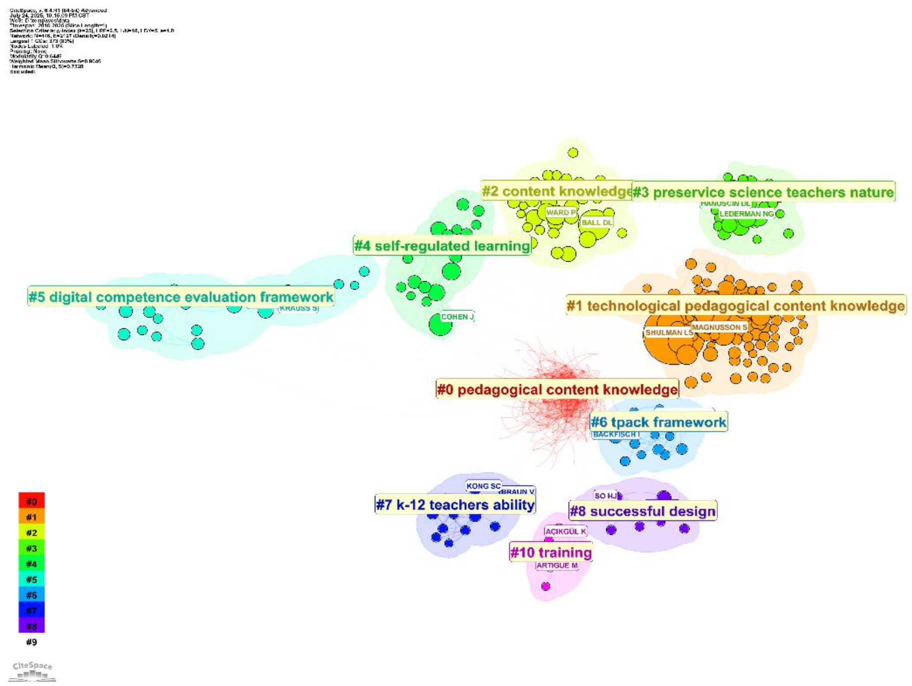

Figure 10: Author Co-Citation Analysis (ACA)

Journal Co-Citation Analysis (JCA)

This figure displays the co-citation network of journals that serve as key publication outlets for PCK research. Cluster #0 “pedagogical content knowledge” is the core cluster, composed of leading educational journals such as Teaching and Teacher Education and Journal of Teacher Education, which form the primary citation base for PCK literature.

Clusters #1 “teacher tpack” and #3 “online teaching” reflect robust research communities focused on digital instruction and TPACK, frequently citing journals like Computers & Education and Educational Technology & Society;

Cluster #4 “systematic review” shows that a considerable number of systematic reviews have emerged, facilitating theoretical integration and agenda-setting;

Clusters #6 “computational thinking content knowledge” and #5 “content knowledge” reveal the rapid development of STEM and assessment-related research, commonly appearing in journals such as Structural Equation Modeling and Educational and Psychological Measurement;

Clusters #7 “teacher perception” and #8 “content knowledge categories” expand research perspectives through the lens of teacher attitudes and the classification of knowledge domains.

Collectively, the JCA indicates that PCK research is moving toward interdisciplinary and multidimensional integration, with stable citation networks forming around high-impact educational and ed-tech journals.

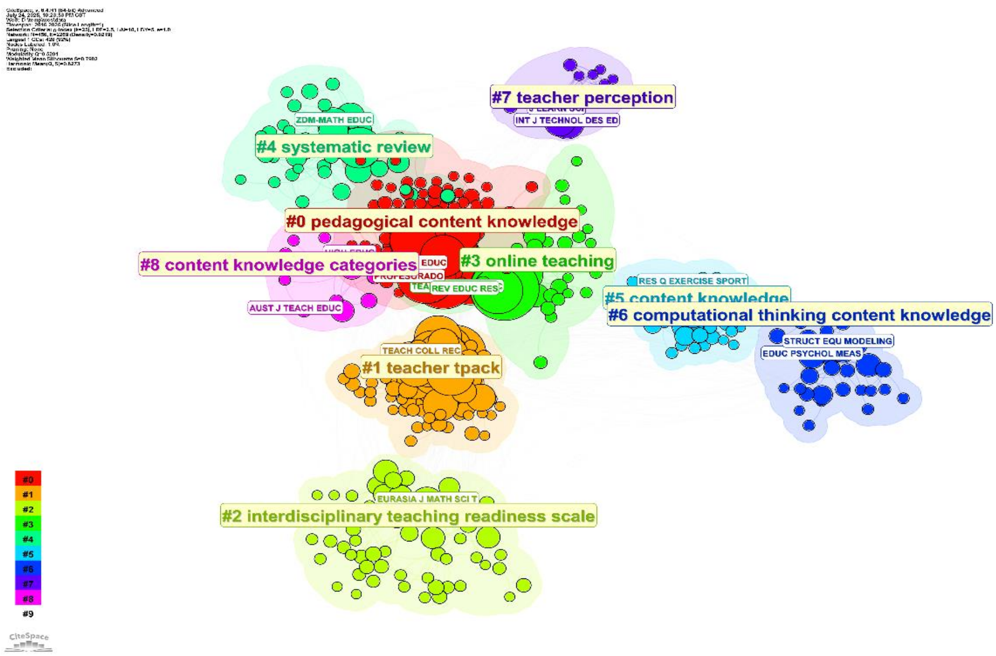

Figure 11: Journal Co-Citation Analysis (JCA)

Discussion and Conclusion

This bibliometric study systematically mapped the global research landscape of Pedagogical Content Knowledge (PCK) from 2016 to 2025. By utilizing CiteSpace to analyze 405 articles indexed in the Web of Science Core Collection, we explored collaboration networks, keyword clusters, citation structures, and subject category distributions. The findings offer important insights into the intellectual development, thematic evolution, and global collaboration patterns within the PCK research community.

Author and Institutional Collaboration

The author collaboration network highlights a fragmented yet evolving structure. Ward, Phillip stands out as a key node with high betweenness centrality, indicating his role as an academic bridge among multiple author clusters. Despite the presence of active researchers such as Kim, Insook and Aynur Aydin, the overall network remains sparse, reflecting limited large-scale collaboration across author groups. Similar patterns were noted in other educational domains, where authorial collaboration often shows "multi-centered, weakly connected" characteristics (Liu et al., 2021).

Institutional collaboration visualizations revealed a shift from North American dominance, particularly by The Ohio State University and the University System of Ohio, toward more active participation from Chinese institutions like East China Normal University and Nanjing Normal University. The structure resembles a "hub-and-spoke" model, with early research concentrated in the U.S. and more recent activity expanding to Asia. This trend aligns with the findings of Zhou et al. (2023), who observed increasing international influence of Chinese institutions in teacher education research due to policy support and resource centralization.

The growing contribution of China likely reflects (i) large-scale teacher education reforms and digitalization in K-12 and higher education, and (ii) the integration of technology-enhanced pedagogy within PCK/TPACK-related scholarship. Recent syntheses highlight teachers' beliefs, self-efficacy, and contextual support as levers for technology-rich instruction and competency development (e.g., Scherer et al., 2017; 2019), while cross-institutional work reports increased ICT-pedagogical integration and professional development (e.g., Tondeur et al., 2018; 2020). These dynamics plausibly align with the expanding output from Chinese institutions observed in our network.

Thematic Evolution through Keyword Clustering

Keyword co-occurrence analysis identified six major clusters that reflect the evolving themes of PCK research.

Cluster #0 emphasized qualitative methods—e.g., classroom observations and interviews—often employed in early U.S.-based PCK studies (Shulman, 1986).

Cluster #1 underscored the integration of motivational constructs and digital tools, suggesting convergence with the TPACK framework, as proposed by Mishra and Koehler (2006). Studies in this cluster frequently addressed how teachers' use of technology affects student motivation and learning effectiveness (Chai, Jong, & Tsai, 2020).

Cluster #2 emphasized collective TPACK development, particularly in Chinese research settings. Action research and lesson study approaches were frequently employed to examine how teaching teams develop shared pedagogical knowledge. This marks a shift from individual to collective professional learning structures (Voogt et al., 2015).

Cluster #3 focused on digital competence, driven by increased interest in ICT integration during and after the COVID-19 pandemic. Southern European and Latin American countries such as Spain and Chile contributed prominently to this strand, aligning with UNESCO's ICT Competency Framework for Teachers (UNESCO, 2018).

Cluster #4 explored teaching technologies and instructional tools, with notable contributions from Sweden and Canada. Finally, Cluster #5—centered around the broad term "knowledge"—contained peripheral themes such as metacognition and interdisciplinary expansion, indicating potential directions for future exploration.

Citation Structure and Multidisciplinarity

Co-citation analysis reinforced the central role of Shulman (1986, 1987) as the foundational theorist of PCK. His work remains highly cited, particularly in studies on teacher cognition and pedagogical reasoning. The TPACK model (Mishra & Koehler, 2006) was also frequently co-cited, reflecting the ongoing integration of technology into pedagogical frameworks.

Author co-citation maps revealed the continued influence of Magnusson, Ball, and Krauss, whose work spans science education, teacher beliefs, and pedagogical frameworks. Journal co-citation networks showed that core outlets such as Teaching and Teacher Education, Computers & Education, and Educational Technology & Society have become essential platforms for disseminating PCK-related research.

The subject category overlay map demonstrated that while education remains the central domain, related fields such as Computer Science, Psychology, and Environmental Sciences have increasingly intersected with PCK research. This interdisciplinary expansion suggests a growing recognition of the multifaceted nature of teaching knowledge in contemporary educational contexts (König et al., 2022).

Comparison with Prior Bibliometric Studies

Compared with Alka, Bancong, & Muzaini (2023)—who analyzed PCK in Scopus (2018–2022)—our study extends the time window and focuses on WoS-indexed literature, integrates co-citation, keyword bursts, and cluster labeling (LLR), and includes parameter-sensitivity checks to enhance interpretability and robustness. Together, these choices provide an updated, methodologically transparent map of the PCK domain.

Conclusion

The findings from this study indicate that PCK research has undergone significant transformations in the past decade. Methodologically, qualitative case studies have given way to empirical, technology-enhanced approaches. Thematically, the focus has expanded from teacher competence to include student motivation, collaborative knowledge building, and digital pedagogies. Geographically, leadership is gradually shifting from traditional Western centers to emerging research hubs in Asia.

This evolution highlights three major trends:

The convergence of PCK and TPACK reflects the growing centrality of technology in teaching practice (Chai et al., 2020).

Research foci are broadening to include both cognitive and affective learning outcomes.

Collective, institutional, and cross-national collaborations are increasingly shaping the direction of the field.

Nevertheless, gaps remain. The low density of author and institutional networks indicates the need for greater international collaboration and knowledge-sharing.

Rather than invoking a loosely defined “third-order barrier,” we frame the constraints in line with beliefs-level and contextual factors reported in recent reviews (e.g., teachers’ pedagogical beliefs, self-efficacy, and organizational support for technology-enhanced teaching). This framing is consistent with empirical syntheses that connect these factors to uptake of PCK/TPACK-aligned practices.

Future Directions

(1) Cross-domain contrasts of PCK in STEM vs. humanities to uncover domain-specific mechanisms;
(2) Cross-linguistic/cross-national comparisons to address geographic and language biases;
(3) Integration of technology-enhanced pedagogy (TPACK) with beliefs/self-efficacy perspectives to explain adoption pathways;
(4) Longitudinal and mixed-method triangulations linking bibliometric fronts to classroom enactment;
(5) Expansion beyond WoS/English to include non-English corpora and non-journal outputs for a fuller landscape.

In conclusion, this study provides a structured and data-driven overview of global PCK research trends between 2016 and 2025. It offers a roadmap for scholars, policymakers, and educators seeking to understand and advance the field of teacher knowledge in the context of digital transformation and global educational change.

Limitations

First, our analysis relies solely on Web of Science and English-language journal articles, which may introduce language bias and database coverage bias; relevant non-English publications and items indexed exclusively in Scopus/ERIC/CSCD were not covered.

Second, non-journal outputs (e.g., conference proceedings, books) were excluded by design, potentially under-representing emergent or practice-oriented work. These constraints should be considered when generalizing the observed structures and trends.

Methodological Extensions for Future Research

To reduce database and language bias and to scale analytic robustness, subsequent studies should integrate multi-database retrieval (e.g., WoS, Scopus, ERIC, CSCD) and adopt machine-learning/NLP pipelines (topic modeling, embedding-based clustering, classifier-assisted screening) for labeling and sensitivity analyses. Subfield-specific mappings (e.g., science vs. mathematics vs. humanities) are also encouraged to reveal domain-dependent PCK structures.

Overall Contribution

By integrating bibliometric mapping, parameter-sensitivity checks, and an expanded temporal scope, this study advances methodological rigor in the analysis of teacher professional knowledge. Its findings not only update the global understanding of PCK's intellectual evolution but also demonstrate how large-scale scientometric inquiry can inform broader social science research on teaching, learning, and professional development. This contribution underscores the study's value as both an empirical synthesis and a methodological model for future educational research.

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