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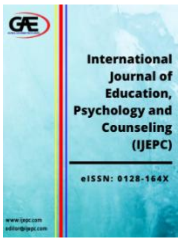

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RESEARCH HOTSPOTS AND TRENDS IN MATHEMATICS PEDAGOGICAL CONTENT KNOWLEDGE FROM A CITESPACE PERSPECTIVE：AN ANALYSIS OF SSCI LITERATURE OVER THE PAST DECADE

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Abstract:

In order to grasp the research results of mathematics pedagogical content knowledge(MPCK), this article adopts bibliometric methods and uses CiteSpace software to visually analyze the research literature on MPCK in the past decade, and sort out the research hotspots and future trends of MPCK. The results show that scholars' research on MPCK can be roughly divided into four areas: technology-enabled integration of MPCK, teacher knowledge construction and professional development, integration of disciplinary nature and cognitive processes, and scaled-up practice and innovation in assessment systems.Based on the analysis results, inspirations for promoting mathematics teachers to improve their subject teaching knowledge are proposed: firstly, build a school climate of trust; secondly, establish coherent digital technology systems; thirdly, strengthen continuity in teacher training, aiming to contribute certain reference value to subsequent research.

Keywords:

CiteSpace, Mathematics Pedagogical Content Knowledge, Hot Topics,Trends, Visual Analysis

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Introduction

Reflecting on the observed separation between subject-matter knowledge and pedagogical knowledge in classroom practice, Shulman introduced the concept of pedagogical content knowledge (PCK) as a distinct form of teacher knowledge that connects these two domains. PCK has since been recognized as a core component of teacher professional development and a key means of overcoming instructional barriers. In the field of mathematics education, a teacher's mathematics pedagogical content knowledge(MPCK) largely shapes their instructional competence, MPCK therefore constitutes a foundational element in the development of mathematics teachers' professional capabilities. Empirical studies indicate that the relationship between teachers' subject knowledge and instructional outcomes is not simply linear, and that accumulated teaching experience does not automatically translate into improved teaching quality. From the teacher's perspective, effective instruction depends on the ability to accurately judge students' cognitive characteristics and learning contexts, and to dynamically integrate MPCK into pedagogical decision-making by transforming subject-matter knowledge into representations that students can more readily understand and accept. This process of knowledge translation reduces students' cognitive load and thereby enhances instructional efficiency and learning effectiveness.

Since its introduction, the concept of PCK has attracted widespread scholarly attention, generating a substantial body of literature on its nature, scope, influencing factors, developmental pathways, and mechanisms of action. To identify current research hotspots and emerging trends in mathematics teachers' pedagogical content knowledge, this study employs CiteSpace to conduct a bibliometric visualization of SSCI-indexed literature on MPCK in the Web of Science over the past decade (2016–2025). The aim is to offer constructive support for future MPCK research and to provide practical reference for the professional development of mathematics teachers and the improvement of student mathematics learning.

Research Methods and Data Sources

Research Methods

This study adopts a bibliometric approach to systematically review and analyze the literature on mathematics teachers' pedagogical content knowledge. The primary analytical tool is CiteSpace, which generates visual knowledge maps from bibliographic metadata (e.g., keywords, authors, and institutions) and supports co-occurrence and evolutionary analyses. CiteSpace enables objective and intuitive detection of research hotspots, core author and institutional networks, and thematic evolution, reducing the subjectivity often associated with traditional, narrative literature reviews.

Specifically, we use CiteSpace to perform co-occurrence analyses of institutions and authors, keyword clustering, and burst-term detection in order to reveal current research foci and dynamic development trends within the MPCK field. After identifying key documents and cluster topics via CiteSpace, the researcher conducts close, manual reading of highly cited and otherwise central papers to extract and synthesize their research aims, theoretical frameworks, methods, main findings, and practical implications. Through systematic extraction, organization, categorization, and critical review of abstracts and conclusions, this step provides richer qualitative support for interpreting the bibliometric results.

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Data Sources

The bibliographic data were drawn from the Web of Science Core Collection, limited to journals indexed in the Social Sciences Citation Index (SSCI). Search queries targeted literature on mathematics pedagogical content knowledge (terms related to mathematics PCK and the acronym MPCK). The initial search covered the period 2016–2025; records indexed for 2025 were retrieved up to the search date of 20 July 2025, and therefore reflect publications available in the database as of that date. The initial search returned 481 records. Each record's title, abstract, and keywords were then reviewed manually, and items clearly unrelated to mathematics PCK (for example, studies focused on chemistry, biology, language instruction, programming, neuroscience, higher-education contexts, or reading) were excluded. After this screening, 384 relevant records remained. The full records and cited-reference data for these 384 articles were exported from Web of Science in plain-text format. Prior to importing into CiteSpace, the dataset underwent standard preprocessing (e.g., deduplication and basic metadata cleaning) to ensure data quality for the subsequent analyses.

Results And Analysis

Basic Bibliometric Statistics

Annual Publication Trends

The year-by-year publication count is a key indicator of the development trajectory of a research field. The annual distribution of publications on mathematics teachers' pedagogical content knowledge for 2016–2025 (up to the retrieval date) is presented in Figure 1. Overall, MPCK research shows an upward trend with fluctuations across the period. It should be noted that the 2025 data were collected up to 20 July 2025, and the 15 records captured for 2025 reflect only publications indexed by that date; therefore the 2025 figure is incomplete and should not be directly compared with full-year counts or used to infer the trend for the entire year. From 2019 onward, except for a minor decline in 2023, annual publication counts have generally remained above 40 articles per year, indicating sustained and stable international scholarly interest in MPCK over the past six years.

Figure 1: Change Trend Of Annual Document Volume

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Visual Analysis of Institutions

A co-occurrence analysis of institutions was conducted in CiteSpace for the 2016–2025 journal records, with a time slice of 1 year, node type set to “Institution”, and Top N=24 per slice (other settings left at defaults). The run produced an institutional co-occurrence map consisting of 200 nodes and 272 links, with a network density of 0.0137, indicating a multi-centered and modular collaboration ecology in the MPCK research field (Figure 2). The modularity value was Q=0.4925 (>0.3) and the mean silhouette score was S=0.7558 (>0.5), which together indicate clear, well-defined clusters with good internal homogeneity. Major contributors in terms of output included the Institute for Science and Mathematics Education (IPN, Kiel), the Leibniz Association, the University of Hamburg, University of Georgia, Middle East Technical University, and the Australian Catholic University, reflecting their high productivity and academic influence in this area.The institutional collaboration network shows a core–periphery structure: German research institutions such as IPN, the Leibniz Association, the University of Hamburg, Humboldt-Universität zu Berlin, and the University of Cologne form a densely connected core cluster, while institutions from the United States, Canada, China, Turkey, and Australia occupy peripheral positions. Subnetworks—for example, those connecting East China Normal University and Beijing Normal University with University of Georgia and Middle East Technical University—indicate multinational collaborations across China, the United States, and Turkey. Collaborations between Australian Catholic University and German institutions further demonstrate Asia–Europe linkages. Overall, most institutional collaborations reflect a degree of regional concentration, with relatively lower participation from institutions outside Europe and North America. Approximately 30% of institutions (many represented as small, unnamed nodes) lie at the network margin, suggesting that a substantial portion of research remains driven by single institutions rather than integrated into the core collaborative ecosystem.

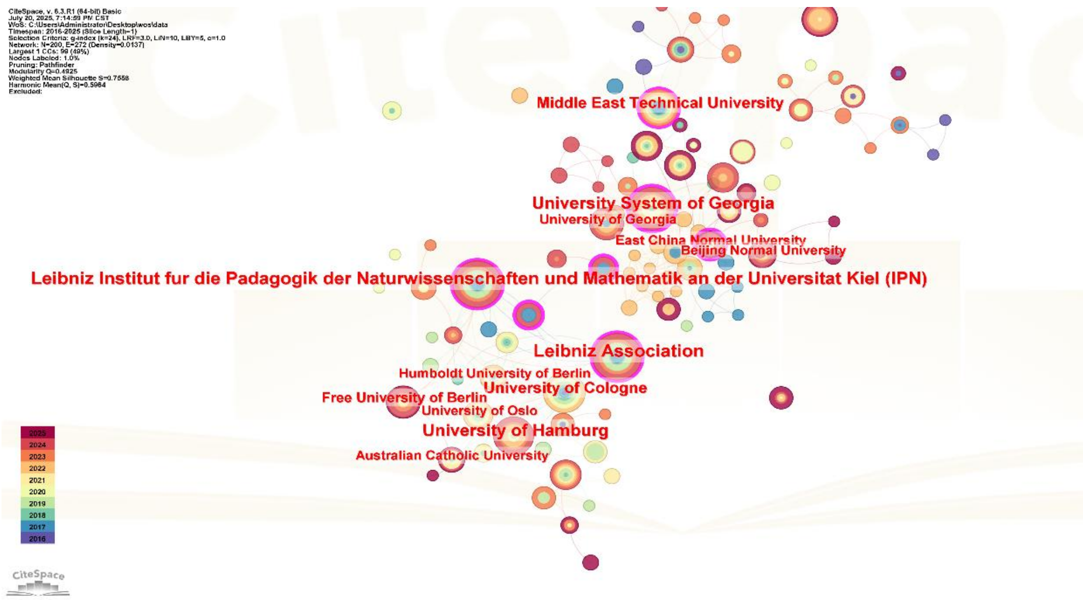

Figure 2: Organization Co-Occurrence Knowledge Map

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Visual Analysis of Authors

An author co-occurrence analysis was run in CiteSpace for the same period (time slice=1 year; node type= “Author” ; Top N=24 per slice; other parameters default). The resulting author network contained 237 nodes and 152 links, with a network density of 0.0054 (Figure 3). The modularity Q=0.4925 (>0.3) and mean silhouette S=0.7558 (>0.5) again indicate clearly defined clusters with strong intra-group cohesion but relatively sparse inter-group collaboration. The author co-occurrence map shows that Gabriele Kaiser, Sigrid Blömeke, and Johannes König were among the largest and most central nodes during 2016–2025; these authors have numerous links to other researchers, indicating high productivity and broad collaboration. This pattern aligns with institutional cooperation in Germany: Kaiser, Blömeke, and König have jointly led follow-up projects (e.g., the TEDS-FU continuation) funded by German research agencies, illustrating close collaborative ties. In summary, a core group of established authors (represented by Kaiser and colleagues) continues to dominate output and occupy central network positions, while newer researchers have gradually entered and become more active in the field in recent years.

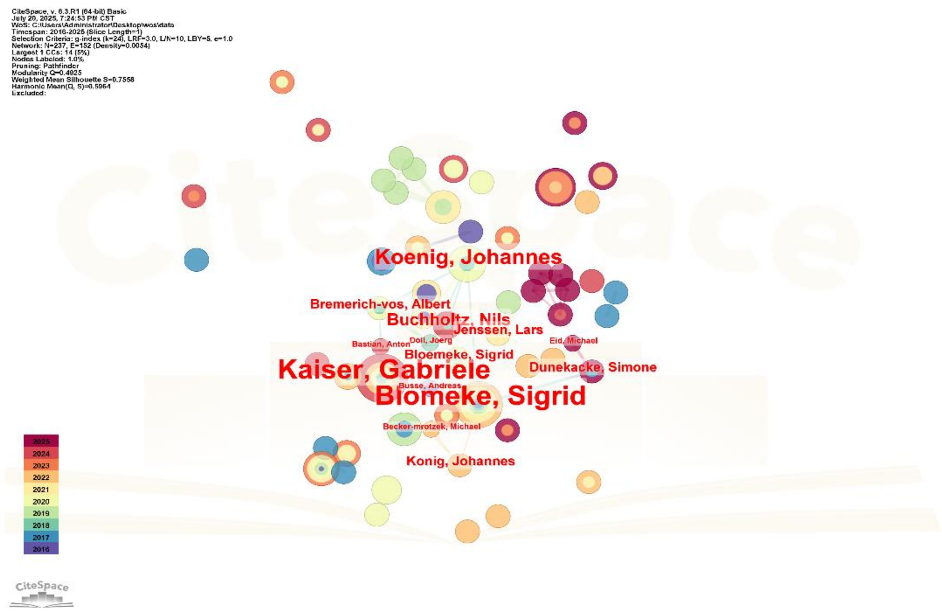

Figure 3: Author Co-Occurrence Knowledge Map

Research Hotspot Topics

Research hotspots reveal the principal emphases and trajectories within the field of mathematics pedagogical content knowledge, offering both theoretical significance and practical value for future work. Keywords, as condensed representations of a paper’s focus, are particularly useful for co-occurrence analysis; patterns among high-frequency keywords thus reflect prevailing research hotspots. Below we present the keyword clustering analysis and interpret the major thematic areas in MPCK research.

Keyword Clustering Map Analysis

A keyword clustering analysis was performed in CiteSpace with time slice=1 year, node type is “Keyword” , Top N=24 per slice, and other defaults. The analysis produced a keyword co-occurrence network containing 293 nodes and 961 links, with a network density of 0.0225

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(Figure 4). The modularity value was Q=0.4925 (>0.3) and the mean silhouette score was S=0.7558 (>0.5), indicating clear and internally cohesive cluster structure. The clustering output yielded eleven clusters, which can be summarized by labels such as: integration of technology in PCK, explicit knowledge, mathematical content knowledge, teacher education, technological pedagogical knowledge, mathematics teaching knowledge, teacher knowledge, scaled implementation, problem posing, mathematics teachers, and professional beliefs. These clusters collectively represent the main hotspots in MPCK research to date. Overall, the field concentrates on deepening understanding of teachers' subject and pedagogical knowledge, while also emphasizing the coordinated development of technology integration, dissemination, and classroom practice—a research profile that integrates knowledge theory, technological application, and practice feedback.

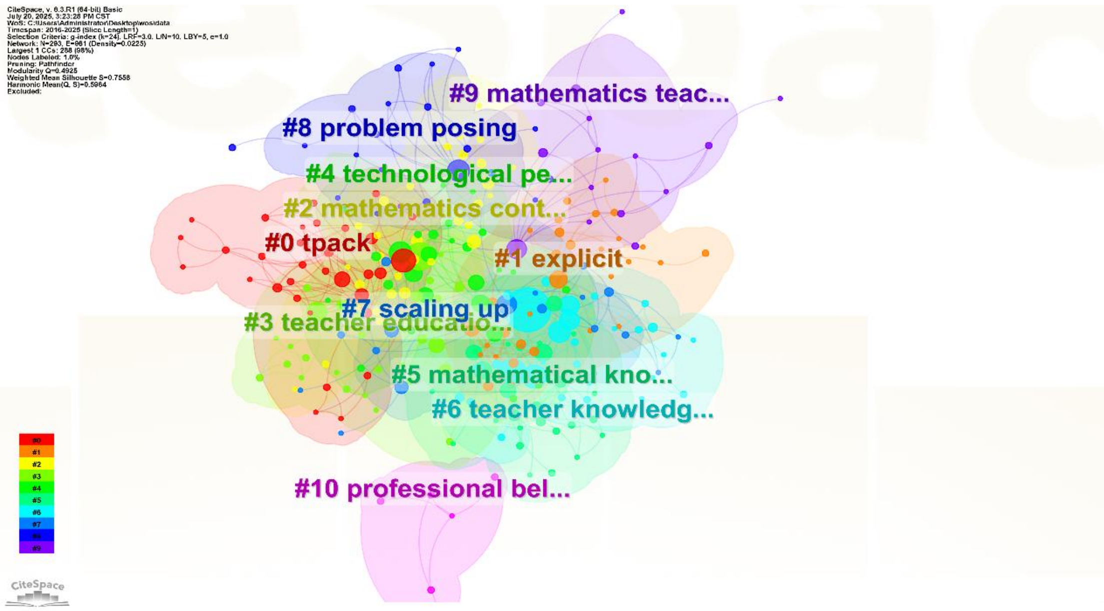

Figure 4: Knowledge Map Of Keyword Clustering Network

Cluster Label Analysis

Based on the keyword clustering network knowledge graph and using the CiteSpace Cluster Explorer module, we used the log-likelihood ratio (LLR) algorithm to extract the core labels of each cluster, ultimately generating a keyword co-occurrence network cluster table, as shown in Table 1.

Table 1: Keyword Co-Occurrence Network Clustering Table

Cluster number	Cluster size	Clustering average contour value	Tag words (LLR algorithm)
0	34	0.835	tpack (21.39, 1.0E-4);technology integration (12.98,0.001); pedagogical content knowledge (10.71, 0.005);artificial intelligence (9.81,0.005); pls-sem (9.81, 0.005)

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1	34	0.593	explicit (16.69, 1.0E-4); views(11.11, 0.001); conceptions (11.11, 0.001); students (11.11,0.001); instruction (7.42, 0.01)
2	34	0.777	mathematics content knowledge (17.34, 1.0E-4);professional vision (13.03,0.001); mathematics pedagogical content knowledge (12.26, 0.001); early childhood teachers (10.15,0.005); mobile eye tracking(5.52, 0.05)
3	33	0.742	teacher education (11.63,0.001); teacher training (8.01,0.005); professional knowledge(8, 0.005); physics education(5.88, 0.05); pre-service teachers (5.13, 0.05)
4	32	0.805	technological pedagogical content knowledge (13.56, 0.001); science teachers (12.83,0.001); educative curriculum materials (8.54, 0.005);confirmatory factor analysis(8.54, 0.005); educational technology (8.54, 0.005)
5	31	0.773	mathematical knowledge for teaching (9.68, 0.005);pedagogical content knowledge (pck) (7.9, 0.005); tpack (5.92, 0.05); teacher education (5.6, 0.05); mathematics education (4.76, 0.05)
6	30	0.724	teacher knowledge (23.59,1.0E-4); teacher pedagogical content knowledge (8.57,0.005); teacher content knowledge (8.57, 0.005);elementary school (8.57, 0.005);fractions (8.57, 0.005)
7	19	0.768	scaling up (10.89, 0.001);computational thinking (10.89, 0.001); teacher beliefs (8.45,0.005); performance assessment (7.21, 0.01);mathematics teacher education(6.43, 0.05)
8	19	0.697	problem posing (13.66, 0.001);advanced mathematics (12.01, 0.001); pedagogical content knowledge (6.1, 0.05); generating function (5.99,0.05); partition of integers (5.99, 0.05)
9	16	0.835	mathematics teachers (10.82,0.005); mixed methods (7.19, 0.01); heuristic bias (6.26, 0.05);learning-by-teaching (6.26, 0.05); teachable agent (6.26,0.05)
10	6	0.937	professional beliefs (10.25,0.005); nature of scientific inquiry (10.25, 0.005); inquiry-based teaching (10.25, 0.005);5e lesson planning (10.25,0.005); scaffolding practice(10.25, 0.005)

Analysis of keywords across clusters shows overlap among cluster topics; nevertheless, the literature in MPCK can be grouped into four broad thematic domains: (a) technology-enabled integration of MPCK, (b) teacher knowledge construction and professional development, (c)

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integration of disciplinary nature and cognitive processes, and (d) scaled-up practice and innovation in assessment systems.

(a) Technology-enabled integration of MPCK
This theme examines how digital technologies structurally reshape mathematics pedagogical content knowledge, corresponding primarily to cluster #0 (TPACK), cluster #4 (technological pedagogical knowledge), and cluster #5 (mathematics teaching knowledge). Findings indicate that in the technology-integration domain (cluster #0, LLR = 9.81), digital tools such as dynamic geometry software and interactive visualization platforms are no longer merely instructional aids but have become integral components of MPCK. The intertwining of technology, pedagogy, and content through "human–computer collaborative" teaching modes increases classroom interactivity and enables abstract mathematical concepts to be represented in directly perceivable forms, thereby deepening students' understanding of mathematical representations. Overall, the incorporation of digital technology broadens the repertoire of instructional strategies and accelerates the shift from traditional mathematics instruction toward a more modern, visualization-oriented paradigm.

(b) Teacher knowledge construction and professional development
This domain covers cluster #6 (teacher knowledge), #9 (mathematics teachers), #3 (teacher education), and #10 (professional beliefs), and highlights the multi-level developmental mechanisms of MPCK. Core findings include: teachers' professional beliefs significantly affect the efficiency with which knowledge is translated into practice; novice teachers progress from pre-service to induction stages through induction training and mentoring that help bridge the theory–practice gap; mid-career teachers develop from "passive implementation" to "active instructional design" via lesson study and professional exchange; expert teachers undergo a shift from skill accumulation to conceptual reconstruction. Research has moved from static descriptions of knowledge toward dynamic modeling of mechanisms, providing theoretical scaffolding for teacher education reform and underscoring the need for context-sensitive, situated professional development.

(c) Integration of disciplinary nature and cognitive processes
Centering on cluster #2 (mathematical content knowledge), #8 (problem posing), and #1 (explicit knowledge), this theme explores the fit between the distinctive characteristics of mathematics and cognitive processes. At the cognitive level, studies analyze how teachers monitor student cognition in real time and transform highly abstract mathematical concepts into teachable representations. The tension between mathematical rigor and simplification for instruction positions problem-posing tasks as critical contexts for assessing MPCK, highlighting how disciplinary traits constrain and challenge instructional design. The concept of "explicit knowledge" — externalizing cognitive strategies to reduce students' cognitive load — has been proposed. Overall, this theme advances PCK theory toward math-specific contextualization and lays a theoretical basis for interventions grounded in mathematical cognition.

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(d) Scaled-up practice and innovation in assessment systems
This theme revolves around cluster #7 (scaled application), cluster #4 (curricular materials), and cluster #3 (pre-service teachers), and addresses bottlenecks in translating MPCK from theory to large-scale practice. First, the development of standardized curricular materials and performance assessment instruments has produced replicable training programs for pre-service teachers; this approach aligns with Copur-Gencturk and Tolar (2022), who showed that structured lesson plans improve cross-school training quality. Second, combining modular instructional units with real-time teacher support has achieved consistent student achievement gains across districts. However, large-scale implementation faces tensions with contextual adaptability, so it is necessary to preserve core MPCK elements while allowing flexible local adaptations. Collectively, these recent findings signal a movement toward evidence-driven policy and practice in MPCK, providing methodological foundations for systematically strengthening the teacher workforce.

Research Trends
Burst terms are keywords whose citation frequency increases sharply within a specific time window, and they provide a direct way to identify hot topics and emerging trends. To trace the developmental trajectory of MPCK research, we used CiteSpace's "Burst Terms" detection and generated a burst-term timeline (Figure 5).

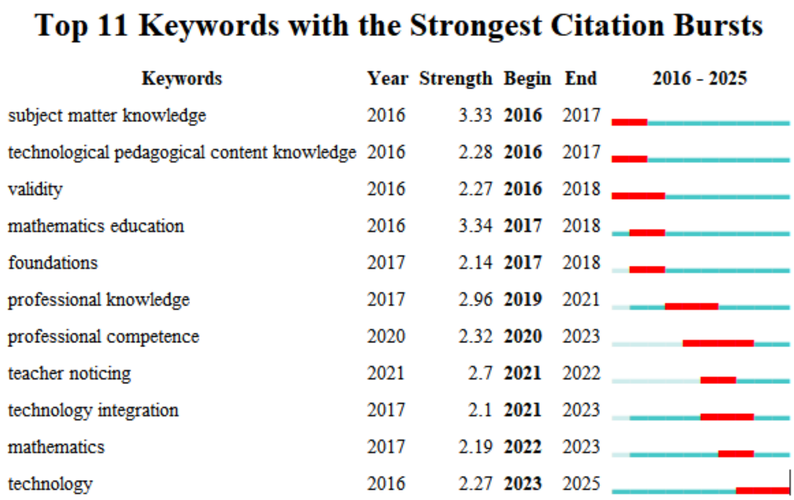

Figure 5: Keyword Emergence Diagram

Based on burst intensity and duration (Figure 5), MPCK research in the past decade can be divided into four characteristic evolutionary phases (the 2025 data are provisional), with representative burst terms revealing deeper paradigm shifts:

(a)Knowledge construction phase (2016-2018)
Research in this phase centered on theoretical foundations of teachers' knowledge structures, with "subject matter knowledge" (SMK; burst strength = 3.33) as a focal term, establishing deep understanding of mathematical concepts as the basis of teaching competence. The

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TPACK framework (technological pedagogical content knowledge; strength = 2.28) was introduced to explore interactions among technology, pedagogy, and mathematical content. Studies on "validity" (strength = 2.27) used classroom observation scales and other instruments to quantify the impact of teacher knowledge on instructional outcomes. This phase laid a solid conceptual and measurement foundation for subsequent empirical work.

(b)Practice-oriented professional turn (2019-2021)
From 2019, attention shifted from knowledge per se to context-sensitive enactments of competence. The burst of "professional knowledge" (strength=2.96) reflects focus on diagnostic judgment and task design; "teacher noticing" (strength =2.7) emphasized teachers' sensitivity to key classroom events (e.g., student misconceptions) and their momentary decision making. Research on "professional competence" (strength=2.32) addressed the full cycle from design through implementation to reflection, proposing developmental ladders from knowledge acquisition to classroom insight and offering clear pathways for practice-driven teacher growth.

(c)Deepening of technology integration (2021-2023)
During this period, "technology integration" (strength=2.1) remained a central concern, with scholars investigating how AI systems, dynamic geometry software, and other tools intervene in mathematical cognition and help visualize abstractions. At the same time, the core of the discipline ("mathematics" , strength=2.19) re-emerged, stressing that technology must serve the development of mathematical thinking (e.g., algorithmic reasoning, spatial intuition). Empirical studies examined domain-specific effects of technologies across algebra, geometry, and other subfields.

(d)Technology-driven reconfiguration (2023-2025)
From 2023 onward, "technology" (strength=2.27) experienced sustained bursts as the frontier shifted toward AI-driven instructional systems, immersive VR/AR environments, and big-data analytics. These technologies are redefining personalized learning pathways and mathematical situational experiences, enabling real-time diagnostic feedback on error patterns. The central tension for this phase is how to reconcile efficiency gains with the preservation of deep mathematical thinking, avoiding overreliance on computational tools that might undermine understanding of mathematical fundamentals.

In summary, MPCK research has evolved from an initial constructivist stage grounded in subject matter and TPACK theory, through a practice-oriented phase emphasizing professional competence and classroom insight, into a period of deep technology–mathematics integration, and now into a phase characterized by technology-driven paradigm reconfiguration. These four linked phases mark the field's transition from static descriptions of knowledge to dynamic models of mechanism, and from individual teacher development to scaled instructional reform, responding to the demands of a digitized era for both mathematics teaching and teacher professional growth.

Conclusions and Implications

Mathematics pedagogical content knowledge has long been a central concern within teacher professional development. Through basic bibliometric analyses, this study examined publication trends, highly productive institutions, research hotspots, and evolving trends in

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MPCK research. First, scholars have shown relatively stable interest in MPCK, particularly at well-established comprehensive universities. Second, as research on the nature, components, and influencing factors of PCK has matured, attention has increasingly shifted toward technology integration, quantitative measurement and evaluation, and intelligent instruction—developments that lay a foundation for deeper and broader MPCK research and provide actionable references for classroom teachers seeking to improve instructional quality.

This study is limited to SSCI-indexed journal articles in the Web of Science; future work should broaden the scope to include additional high-quality indexed sources to obtain a more comprehensive dataset. Drawing on the evolution of research hotspots and key findings, and grounded in the theoretical core of MPCK, we synthesize three practical implications aimed at improving teachers' MPCK levels, optimizing instructional strategies and representational transformation skills, accelerating the restructuring of mathematics teacher professional development toward evidence-based decision making, and enhancing students' mathematical proficiency by establishing sustained, active learning mechanisms.

Build A School Climate Of Trust

A trusting institutional climate fosters teacher belonging and can stimulate intrinsic motivation for instructional improvement. Trust is conveyed through communicative practices and affirmative feedback, enabling teachers to perceive themselves as valued professionals. Blömeke et al. found that teachers who perceive supportive trust environments display higher levels of MCK and MPCK and exhibit stronger instructional self-efficacy, which in turn relates to better classroom decision making.

Establish Coherent Digital Technology Systems

Develop integrated frameworks that combine information technologies with content encoding and platform infrastructures to leverage the synergies of pedagogical–technological integration. By presenting mathematics in vivid, dynamic, and interactive formats, digital systems can engage students in immersive experiences that make learning both enjoyable and effective. Merono, Calderón, and Arias-Estero argue that given current social and educational demands, digital pedagogy has permeated all aspects of education and that teachers' digital competencies must keep pace with these developments.

Strengthen Continuity in Teacher Training

Emphasize continuity across pre-service, induction, and in-service stages, providing comprehensive, multi-angle, and progressive training that allows teachers to adjust, integrate, and optimize their MPCK according to their actual professional level. Such coherent pathways reduce frustration, increase professional identification, and clarify the constituent elements and driving logic of teacher training, thereby promoting high-quality professional development.

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