



Hotspots and Development Trends in Global Mathematics Education Research on a Quantitative Analysis Utilizing the Cite Space Knowledge Map

Li Lei^{a*}, Tang Yu^b

- a. Philippine Christian University, Manila, Philippine
b. Baishabu Town Center Elementary School, Linyi, China.

Abstract: Utilizing the literature from the Web of Science Core Collection database spanning the years 2013-2023 as a sample, this study employs the bibliometric tool Cite Space to analyze publication quantity, countries, research institutions, journals, and research topics. The results indicate a rapid development in the field of mathematics education research in recent years, with the United States, England, Germany, Australia, China, and their associated research institutions forming close collaborations, significantly influencing global developments in mathematics education. Summarizing four major research themes, namely teacher professional development, mathematics education and learning, early childhood education, and instructional assessment, it is observed that teacher professional development has consistently been a research hotspot over the past decade. Influenced by the application of new technologies and the COVID-19 pandemic impacts, the research suggests that studying teacher noticing and employing continuous, interactive methods for instructional assessment are directions worthy of consideration for future research in mathematics education.

Keywords: mathematics education, CiteSpace, visualized analysis, research hotspot.

1. Introduction

Mathematics education refers to the process of imparting mathematical knowledge, cultivating mathematical thinking, and fostering problem-solving abilities through instructional activities. Mathematics education is crucial for developing skills in logical reasoning, critical thinking, and quantitative literacy, all of which are fundamental skills for success in various academic and professional domains. As a critical component within the educational system, mathematics education has consistently garnered widespread attention.

As society undergoes transformations and technology advances rapidly, the field of mathematics education is experiencing profound changes. The development of information technology and big data has brought about new opportunities and challenges to the theory and practice of mathematics education. Understanding the role and responsibilities of mathematics education as an academic discipline in this evolving landscape requires a comprehensive examination of significant academic achievements in the field. Analyzing academic literature in mathematics education allows for the identification of research directions within the academic community in different cultural contexts.

Grasping the developmental status and directions of research in mathematics education under new circumstances holds significant importance. This understanding is crucial for the continual improvement of the mathematics education system and the cultivation of students with enhanced creativity, adaptability, and critical thinking skills.

In existing academic journals, literature is scarce in the form of review articles on mathematics education research. Scholars mostly tend to focus on analyzing specific thematic areas within the field of mathematics education.

Review articles in mathematics education primarily focus on summarizing international conferences related to mathematics education and comparing various studies within the field. For instance, Li, X. et al.[1] conducted

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Corresponding email: lisanxx@126.com (Li Lei)

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a comparative analysis of research themes from five international mathematics education conferences held after the year 2000. Their findings indicate that educational research topics in the 21st century are mainly concentrated in ten areas, including specific mathematical content teaching research, mathematics education research for different educational stages and specific student groups, mathematics teacher education research, and the development of the mathematics education discipline. The fundamental trend in mathematics education research is characterized by a continuous enrichment and deepening of research content, emphasizing meta-research in mathematics education and the construction of disciplinary theoretical frameworks. This trend encompasses attention to both internal and external issues within mathematics education. Another study by Wang, B. et al.[2] examined the similarities and differences in research types, methods, and themes in domestic and international mathematics education research. Their results show that quantitative research holds the highest proportion in mathematics education research, and this trend has become increasingly apparent in recent years. Currently, hot topics in mathematics education research include mathematics textbooks and learning tasks, teaching content, and the continuous enrichment of research related to educational methods and technological tools.

Bakker, A. et al. [3] discussed whether the pandemic has altered the research themes in mathematics education for the next decade. The research findings indicate that the pandemic does indeed impact the development of mathematics education, and it is necessary to consider online educational organization methods. Borba, M. C. et al.[4] also highlights the pandemic's influence on mathematics education. They argue that digital technology has become a trend in mathematics education. Simultaneously, they discuss how humans are connected to viruses, how the pandemic exposes social inequalities, and how it will change the agenda of these three trends in mathematics education. The authors emphasize the urgent need to investigate how online mathematics education for children occurs when there is inequality in household environments and access to digital technology as the classroom transitions to the online environment.

With the advancement of information technology, the new generation of instructional technologies is gradually being applied to mathematics education. Cevikbas, M. et al.[5] discuss the potential of AR/VR in mathematics education, including its benefits and drawbacks for learners. The article provides evidence of the potential of AR/VR in consolidating learners' social-emotional, cognitive, and instructional development in mathematics learning. However, challenges such as technical glitches, costs, implementation efforts, health issues, and unfamiliarity with AR/VR pose obstacles to the successful application of AR/VR in the classroom.

This study utilizes academic papers on mathematics education research from the years 2013 to 2023 as a sample. Employing visualization techniques from bibliometrics, the research analyzes the knowledge structure, evolution, and developmental paths of international mathematics education. The objective is to assist educational decision-makers, institutions, and educators in better addressing the continuously evolving educational needs, and to provide insights for the future development and direction of mathematics education.

2. Research Design

2.1 Data Sources

Using the scientific index of the Web of Science TM Core Collection, with the search topic set as "mathematics education," literature was initially retrieved spanning the years 2013 to 2023. In this search, a refinement was performed using the terms "trend or development." Ultimately, 712 relevant and valid documents closely associated with the trends and developments in mathematics education research were obtained.

2.2 Research Methods

2.2.1 Literature Review

A search and download process has been undertaken within the Web of Science database, focusing on literature related to the themes of mathematics education, development directions, and trends. Subsequently, a systematic categorization of the downloaded literature has been performed to gain insights into the current research status and developments within this research domain. Through a comprehensive review of the literature, efforts have been made to establish a literature retrieval strategy that delineates the concepts of mathematics education and identifies the research objects within the scope of the study.

2.2.2 Visualized Analysis

utilizing the Cite Space (6.2.5) literature visualization analysis tool and employing quantitative and visual analysis methods such as co-occurrence network analysis and keyword analysis, we aim to comprehend the



evolution characteristics of research topics related to the hotspots and trends in the development of mathematics education.

2.2.3 Key Words Cluster Analysis

Employing three distinct algorithms in Cite space for keyword clustering[6], namely the Term Frequency-Inverse Document Frequency (TF-IDF) algorithm, Log-Likelihood Ratio (LLR) algorithm, and Mutual Information (MI) algorithm. Conducting content analysis on the generated clusters to unveil the primary content and developmental trends of the hotspots in mathematics education research.

3. Results and Discussion

3.1 Number of Papers Published

The literature output on trends and hot issues in mathematics education research, as shown in Figure 1, exhibits an overall linear growth trend. Particularly noteworthy is the post-pandemic period, where the annual publication count is approximately twice that of the pre-pandemic era. This indicates that the pandemic has spurred innovation and exploration in mathematics education practices, prompting educators to pay increased attention to new educational methods and models to adapt to the challenges presented by a complex environment.

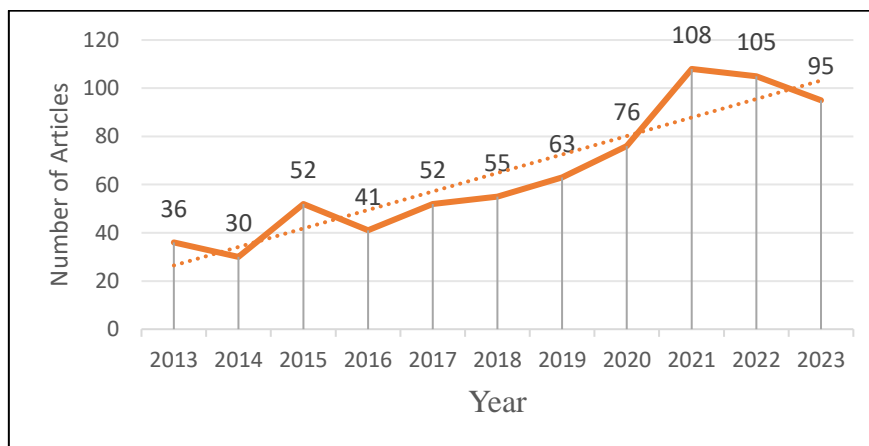


Figure 1: Number of published articles on mathematics education from 2013 to 2023

Over the past decade, a total of 66 countries have participated in research related to the development and trends in mathematics education, as illustrated in the knowledge map in Figure 2. The top three countries in terms of publication count are the United States (274), China (62), and Germany (52). As depicted in Figure 2, China initiated research in mathematics education relatively late, showing some disparities in foundational research compared to the United States, England, and Germany. However, in recent years, there has been substantial development and deeper research in this area. The United States has an early start in mathematics education research, with some publications serving as pivotal turning points in the direction of mathematics education research. This is a significant factor contributing to the leading position of the United States in the development of mathematics education. For a more in-depth understanding of the hierarchical structure of nodes in this field and to conduct further data mining, please refer to Table 1.

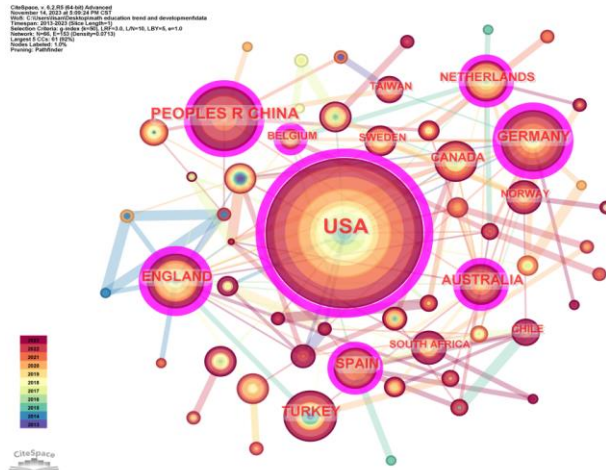


Figure 2: Visual knowledge map of high-yield countries for mathematics education research

When observing centrality, nodes with centrality greater than 0.1 are typically considered crucial factors leading to changes in the research landscape. As shown in Table 1, eight countries, including the United States, England, and Germany, exhibit high innovation capabilities, playing significant roles in the development of mathematics education. Additionally, as indicated by Figure 1, the United States has collaborative connections with 18 countries, England with 20 countries, Germany with 15 countries, China with 8 countries, and Australia with 13 countries. The more collaboration between countries, the higher the centrality. This suggests that collaborative research involving multiple countries is beneficial for the global development of the field of mathematics education.

Table 1: Top 8 high-yield countries ranked by the number and centrality of the paper

Ranking	Nation	Number of articles	Nation	Centrality
1	USA	274	USA	0.41
2	CHINA	62	ENGLAND	0.37
3	GERMANY	52	GERMANY	0.25
4	ENGLAND	51	AUSTRALIA	0.13
5	SPAIN	38	CHINA	0.12
6	AUSTRALIA	37	SPAIN	0.12
7	TURKEY	34	BELGIUM	0.12
8	NETHERLANDS	31	NETHERLANDS	0.11

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3.2 Research Institutions

The collaborative network map of high-productivity institutions comprises a total of 451 nodes and 781 edges. Figure 3 reveals that collaboration among institutions is notably close, allowing for the comprehensive utilization of literature from universities and research institutions. This fosters the emergence of new research perspectives and enables more in-depth and rapid meaningful research. The publishing entities are primarily higher education institutions or research organizations, with the top five high-productivity research institutions being the University of California System, State University System of Florida, Utrecht University, Chinese



University of Hong Kong, and Michigan State University. Among the top ten institutions in terms of publication frequency, those from the United States constitute 60%. However, collaboration between U.S. institutions and other organizations is not particularly close, indicating a tendency to leverage internal resources for independent research.



Figure: Cooperation map of high-yield institutions

3.3 Research Authors

To better reflect the core authors and relationships within the field of mathematics education, a visual analysis of the author collaboration network was conducted for the 712 papers. Additionally, clustering based on keywords was performed, as illustrated in Figure 4.

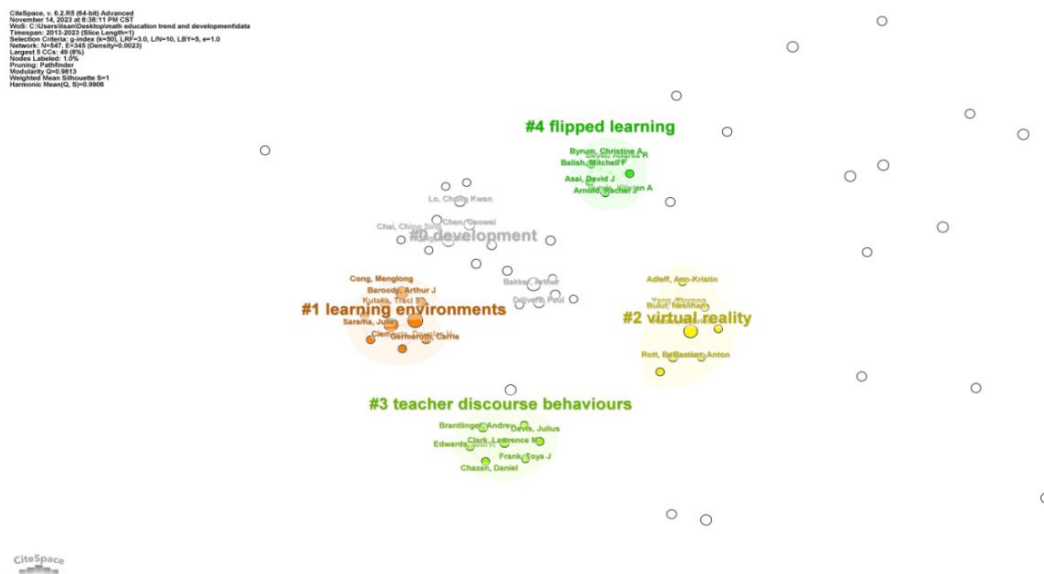


Figure 4: Cooperation map of high-yield authors

Among the core authors who have published three or more papers in the sample, there are a total of 25 individuals. The leading authors are Clements Douglas H (8), Sarama Julie (7), Kaiser Gabriele (6), and Bakker Arthur (6). Through clustering based on the number of keywords, it is observed that research efforts are

concentrated in areas such as learning environments, virtual reality, teacher discourse behavior, and flipped classrooms.

3.4 Research Hotspots and Trends

3.4.1 Key Words Co-occurrence Map and the Strongest Citation Bursts Map analysis

Keywords reflect the interrelationships between various themes portrayed in the literature, serving as highly summarized focal points of the articles. The co-occurrence network map, as depicted in Figure 5, displays 680 key nodes and 2115 connections, excluding irrelevant keywords such as "mathematics education," "mathematics," "teacher," and "student." In this map, the size of each node represents the frequency of the respective word; as the frequency increases, the circle becomes larger. Among keywords with a frequency exceeding 20, "professional development," "achievement," and "children" appear most frequently, with occurrences of 86, 70, and 40, respectively. Keywords with centrality exceeding 0.1 include "children," "performance," "thinking," "instruction," "design," and "ability." The higher the frequency of a keyword, the larger its centrality value, providing coverage of hotspots and key turning points to a certain extent.

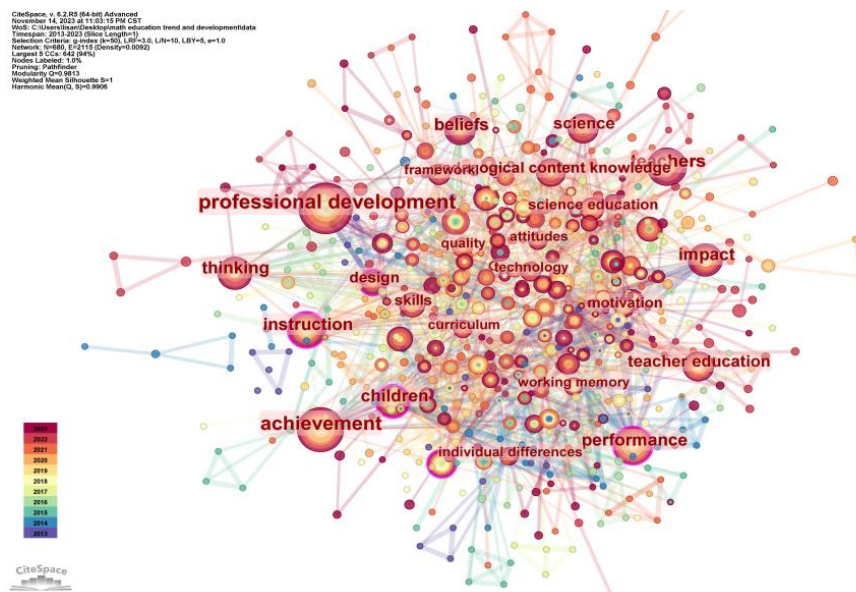


Figure 5: Keyword co-occurrence map

Utilizing the "Detect Bursts" functionality in the software allows for the identification of specialized vocabulary that experiences a rapid increase within specific years. This approach facilitates the observation of more nuanced developmental changes. Figure 6 represents the burst word map generated from the sample literature.

Top 9 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2013 - 2023
problem solving	2013	2.59	2013	2014	
number sense	2014	2.58	2014	2015	
working memory	2016	3.28	2016	2019	
school	2016	2.84	2016	2018	
teacher knowledge	2017	3.62	2017	2019	
metaanalysis	2015	4.26	2018	2020	
science education	2016	2.78	2019	2021	
teacher noticing	2021	3.48	2021	2023	
formative assessment	2021	2.7	2021	2023	

Figure 6: Top 9 keywords with the strongest citation bursts



Insights from the burst word map indicate that from 2013 to 2015, the burst keywords in mathematics education included "problem-solving" and "number sense," suggesting that the forefront of research at that time focused on the abilities related to problem-solving and numerical understanding.

From 2016 to 2019, burst keywords in mathematics education included "working memory," "school," "teacher knowledge," and "meta-analysis." Particularly noteworthy is the appearance of "meta-analysis" starting in 2015, with a burst occurring between 2018 and 2020. This indicates that the meta-analysis method took approximately three years to be widely applied to the analysis of mathematics education-related fields. Peng, P. et al.[7] utilized the meta-analysis method to explore a hot topic in the field of mathematics education during that time—the relationship between mathematics education and working memory. The study suggested that mathematics showed a comparable association with verbal working memory, numerical working memory, and visuospatial working memory. In individuals with mathematics difficulties associated with other disorders or cognitive deficits, the relationship between working memory and mathematics is stronger compared to normally developing individuals or those with only mathematics difficulties. Byun, J. et al.[8] applied the meta-analysis method to investigate the impact of digital games on mathematics education, analyzing recent trends in important digital game-based learning research. The aim was to demonstrate that digital games can enhance the motivation and performance of K-12 students in mathematics education.

From 2020 to 2023, burst keywords in mathematics education included "science education," "teacher noticing," and "formative assessment." This timeframe coincided with the outbreak of the pandemic, which propelled new agendas in mathematics education research. Particularly, the emergence of new educational methods such as online classrooms and learning through electronic devices led to "teacher noticing" and "formative assessment" becoming primary research frontiers. For educators themselves, the ability to respond to the diverse needs of different students poses a comprehensive test across various aspects of professional development and teaching practices. Van Es, E. A. et al.[9] emphasized that teacher noticing is a core construct in teaching, providing an expanded framework for teacher noticing and suggesting that teachers, during the observation process, are not merely passive observers. They actively shape interactions, gain additional information, and allow for further observation and interpretation of student thinking. On the other hand, formative assessment plays a crucial role in post-pandemic mathematics education. By promoting personalized learning, providing real-time feedback, and supporting remote teaching, formative assessment contributes to enhancing teaching effectiveness and better meeting the learning needs of students. Wafubwa, R. N. et al.[10] through experimental design, confirmed the positive impact of formative assessment on secondary school performance.

3.4.2 Keywords Cluster Map Analysis

To further analyze the research directions in mathematics education, keyword clustering was performed, as illustrated in Figure 6. Over the past decade, mathematics education has primarily revolved around nine key themes: in-service teachers, teacher training, classroom environment, flipped classrooms, learning progression, education policy, early childhood education, communities of practice, and professional development. Upon a more in-depth investigation of the clustered information, these can be condensed into four core themes: teacher professional development, mathematics teaching and learning, early childhood education, and instructional assessment.

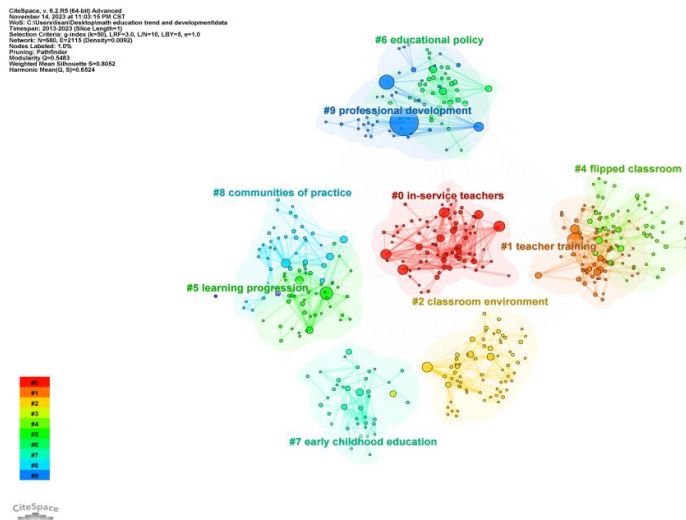


Figure 6: Keywords cluster map

Theme 1: Teacher professional development

Over the past decade, teacher professional development has consistently been a focal point of discussion in the field of mathematics education. Teacher professional development is an ongoing process of continuous learning and improvement, contributing to the vitality and innovativeness of the education system and enabling the provision of higher-quality educational services to students. In the ever-evolving social environment, teacher professional development is particularly crucial.

Within this theme clustering label, the main focus is on in-service teachers, teacher training, discourse analysis, educational innovation, confidence, reflection, curriculum reform, and more. Particularly, after the outbreak of the pandemic and the emergence of new forms of education, higher demands have been placed on the comprehensive qualities of teachers. Cao, Y. et al.[11] investigated how Chinese teachers perceive the impact of online teaching on mathematics learning. The results indicated that the effectiveness of online teaching is largely dependent on student self-discipline. The author suggests expanding the use of technology in teaching and integrating it with mathematical practices. Teachers play a crucial role in online learning, with the expectation of enhancing the effectiveness of online teaching.

Other studies within this clustering have also analyzed various factors influencing teachers' instructional behavior, such as teachers' autonomous motivation, sense of satisfaction, moral norms, and constraints. Additionally, teachers' living environment, educational experiences, and communication skills can impact their development. Future research should explore which factors have significant effects on teacher development, allowing for the formulation of relevant interventions. Emphasizing teacher professional development holds great significance for teachers themselves, schools, society, and the education system.

Theme 2: Mathematics teaching and learning

This clustering covers a broad spectrum with a large number of studies, representing another major research focus in the field of mathematics education. Most researchers employ a combination of theory and practice in their studies, providing guiding significance for teachers in the teaching and learning of mathematics and playing a significant role in enhancing the quality of mathematics education. In terms of mathematics teaching, it involves aspects such as instructional design, behaviors, principles, models, and methods. Emerging topics include situational teaching, problem-based teaching, online and offline integrated teaching, and VR teaching, among others. For example, Park, J. H. et al.[12] explored the factors influencing situational interest in mathematics learning, suggesting that sustained variations in teaching and learning methods to maintain situational interest can yield better results. Regarding mathematics learning, it encompasses learning strategies, behaviors, emotions, interests, performance, psychology, and more. Mathematics anxiety has become a particular concern for teachers and parents. Barroso, C. et al.[13] using a meta-analytical approach, confirmed a significant relationship between mathematics anxiety and mathematics, a relationship that persists from childhood into adulthood.

The application of new technologies in mathematics teaching has led to the comprehensive development of the mathematics teaching and learning system, covering almost every aspect of mathematics instruction and



learning. This has essentially formed a complete research trajectory, providing a thorough theoretical foundation and practical guidance for both mathematics education and learning.

Theme 3: Early childhood education

Early childhood mathematics education plays a crucial role in both the learning of mathematical subjects and the overall development of children. This thematic cluster focuses primarily on mathematical cognition, computer games, elementary education, thinking, confidence, interdisciplinary studies, interests, etc. Cui, Y. et al.[14], through experimental design, confirmed that enhancing children's interest in learning positively affects the mathematics performance of fourth-grade children. Relevant authorities should effectively communicate the importance of parental involvement in early childhood mathematics learning activities to the public, and the government should provide more support to encourage parental participation. Early childhood mathematics education not only contributes to the academic development of children but also cultivates essential skills related to daily life and future learning. Providing enriching experiences in mathematical learning has a profound impact on the holistic growth of children.

Theme 4: Instructional assessment

Summarizing the clustering information of key nodes, teaching assessment is mainly divided into four knowledge base groups: classroom teaching, teaching evaluation, multidimensional strategies, and basic education research. The importance of mathematical education assessment cannot be overlooked. By assessing students' understanding and mastery of mathematical concepts, teachers can dynamically adjust teaching strategies to meet individualized learning needs, thereby improving teaching effectiveness. Teaching assessment is also a key means of monitoring the achievement of subject standards, helping educational institutions better understand whether educational goals are being achieved. Additionally, assessment results can provide parents with transparent and in-depth insights into students' academic performance, promoting parent-school cooperation. For teachers, assessment is a powerful tool for professional development, guiding them in continually improving teaching methods.

Especially in the post-pandemic era, with more artificial intelligence involved in mathematics education, the improvement of teaching methods and adaptation of mathematical learning poses a severe challenge to the level of mathematics education and the quality of talent cultivation. In conclusion, teaching assessment is a crucial strategy in mathematics education. It can promote student learning, support teacher professional development, enhance educational quality, and contribute to the establishment of a more effective mathematics education system.

4. Conclusions and Recommendations

4.1 Conclusions

This paper, based on the Cite Space software, conducts qualitative and quantitative analyses of international journals within the research field. The following conclusions are drawn:

1. From the visualized results of the distribution of countries, institutions, and authors in the field of mathematics education, it can be observed that prolific contributors in terms of publications are concentrated in the United States, China, and Germany. The top three prolific research institutions are the University of California System, the State University System of Florida, and Utrecht University. Among the authors with high publication output, notable names include Clements Douglas H, Sarama Julie, Kaiser Gabriele, and Bakker Arthur. Collaboration between institutions and scholars is relatively close, with the United States holding a prominent overall ranking, indicating its leadership in academic research in the field of mathematics education compared to other countries.
2. The current focus of research in the field of mathematics education is on teacher professional development, mathematics teaching and learning, early childhood education, and instructional assessment. Teacher professional development is a prominent research area in terms of both publication volume and the number of keywords, especially about teacher noticing. Other areas are explored in-depth only in specific directions.
3. Examining the evolutionary characteristics and development trends of research over the past decade reveals that the early years primarily focused on teacher professional development, education policies, classroom environments, and flipped classrooms. In the middle period, there was heightened attention to educational policy and early childhood education. In the later years, new educational methods and approaches were

integrated into the mathematics education system. Scholars shifted their focus towards the adaptability of teacher teaching and student learning. Naturally, teacher professional development and teaching assessment have gained widespread attention in the mathematics education system.

4.2 Recommendations

With the development of the new generation of information technology and artificial intelligence, an increasing number of new technologies will be applied to mathematics education. The application of new technologies and improvements in teaching methods pose a challenge to the professional development of teachers. Continuously refining research on teacher noticing has great significance in enhancing the quality of teaching and learning.

Teaching assessment serves as a guarantee for the healthy development of the mathematics education system. The improvement of new methods in educational learning is bound to drive research in new teaching assessment methods. Continuous and interactive assessment practices are crucial for shaping and enhancing the learning experience, such as formative assessment.

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