



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

Li Lei<sup>a\*</sup>, Tang Yu<sup>b</sup>

- a. Philippine Christian University, Manila, Philippines
- 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 rapid development in the field of mathematics education research in recent years, with the United States, England, Germany, Australia, and China, along with their associated research institutions, forming close collaborations that have significantly influenced 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 impacts of the COVID-19 pandemic, the research suggests that studying teacher noticing and employing continuous, interactive methods for instructional assessment are directions worth considering 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 logical reasoning, critical thinking, and quantitative literacy, all of which are fundamental to success in 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 necessitates a comprehensive examination of the field's significant academic achievements. Analyzing academic literature in mathematics education enables the identification of research directions within the academic community across different cultural contexts.

Understanding the current state and future directions of research in mathematics education under new circumstances is significant. This understanding is crucial for the continual improvement of the mathematics education system and for cultivating 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 mainly focus on analyzing specific thematic areas within mathematics education. Review articles in mathematics education primarily summarize international conferences on the topic and compare various studies within the field. For instance, a comparative analysis of research themes from five international mathematics education conferences held after the year 2000 has been conducted (Li & Cao, 2017). The findings indicate that educational research topics in the 21st century are mainly concentrated in ten areas, including

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

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specific mathematical content-teaching research, mathematics education research across 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, with an emphasis on meta-research in mathematics education and the construction of disciplinary theoretical frameworks.

This trend encompasses attention to both internal and external issues within the field of mathematics education. Another study examined the similarities and differences in research types, methods, and themes in domestic and international mathematics education research ([Wang & Cheng, 2021](#)). The 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 & Zenger, 2021](#)). Some studies discussed whether the pandemic has altered the research themes in mathematics education for the next decade, and the findings indicate that the pandemic does indeed impact the development of mathematics education, highlighting the need to consider online educational organization methods.

Other studies also emphasize the pandemic's influence on mathematics education, arguing that digital technology has become a trend in the field. 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 ([Borba, 2021](#)). 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 classrooms transition to the online environment. With advances in information technology, a new generation of instructional technologies is gradually being applied to mathematics education ([Park & Han, 2021](#)). These studies discuss the potential of AR/VR in mathematics education, including its benefits and drawbacks for learners. Evidence shows that AR/VR can consolidate 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 its successful application in the classroom. This research utilized academic papers on mathematics education published between 2013 and 2023 as a sample. By employing visualization techniques from bibliometrics, the study 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 continuously evolving educational needs and to provide insights into the future development and direction of mathematics education.

## **2. Research Design**

### **2.1 Data Sources**

Using the Web of Science TM Core Collection's scientific index, with the search topic set to "mathematics education," literature was initially retrieved spanning the years 2013 to 2023. In this search, 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 in the Web of Science database, focusing on literature related to mathematics education, development directions, and trends. Subsequently, a systematic categorization of the downloaded literature was performed to gain insights into the current research status and developments in this domain. Through a comprehensive review of the literature, a literature retrieval strategy has been established to delineate the concepts of mathematics education and identify 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 understand the evolution of research topics related to the hotspots and trends in the development of mathematics education.



### 2.2.3 Key Words Cluster Analysis

Three distinct algorithms were employed in CiteSpace for keyword clustering: the Term Frequency-Inverse Document Frequency (TF-IDF), Log-Likelihood Ratio (LLR), and Mutual Information (MI) algorithms (Çakiroğlu & Coşkun, 2023). Content analysis was then conducted on the generated clusters to reveal the primary content and developmental trends of hotspots in mathematics education research.

## 3. Results and Discussion

### 3.1 Number of Papers Published

The literature on trends and hot issues in mathematics education research, as shown in Figure 1, exhibits a linear growth trend. Notably, the post-pandemic period has seen an annual publication count approximately twice that of the pre-pandemic era. This suggests that the pandemic has spurred innovation and exploration in mathematics education practices, prompting educators to pay closer attention to new methods and models to adapt to the challenges posed by a complex environment.

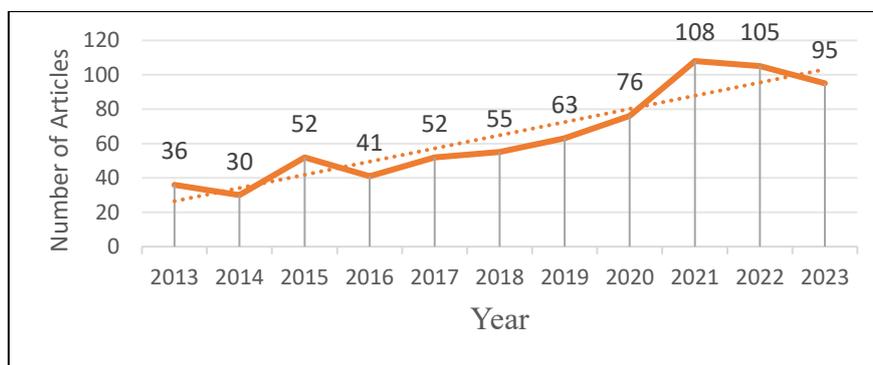


Figure 1: Number of published articles on mathematics education from 2013 to 2023

Over the past decade, 66 countries have participated in research on the development and trends in mathematics education, as illustrated in the knowledge map in Figure 2. The top three countries by 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 a long history of early leadership in mathematics education research, with some publications serving as pivotal turning points in this field. This is a significant factor contributing to the United States' leading position 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.

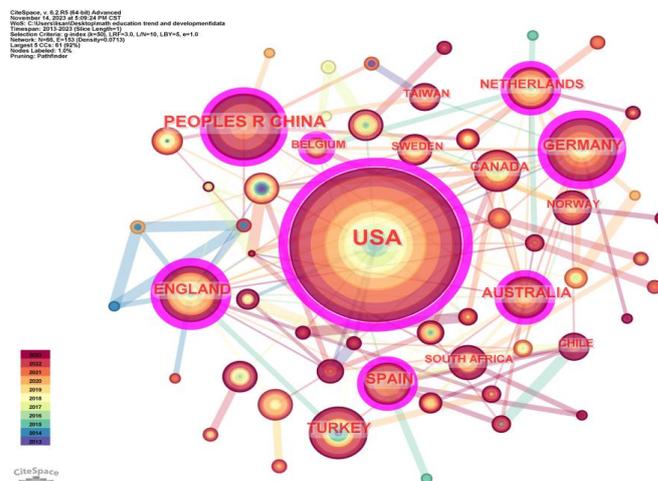


Figure 2: Visual knowledge map of high-yield countries for mathematics education research

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

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

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 451 nodes and 781 edges. Figure 3 reveals that collaboration among institutions is notably close, enabling the comprehensive use of literature from universities and research institutions. This fosters the emergence of new research perspectives and enables more in-depth, rapid, yet 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, the State University System of Florida, Utrecht University, the Chinese University of Hong Kong, and Michigan State University. Among the top ten institutions by publication frequency, those in the United States account for 60%. However, collaboration between U.S. institutions and other organizations is not particularly close, suggesting a tendency to rely on internal resources for independent research.



**Figure 3:** 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, keyword-based clustering was performed, as illustrated in Figure 4.

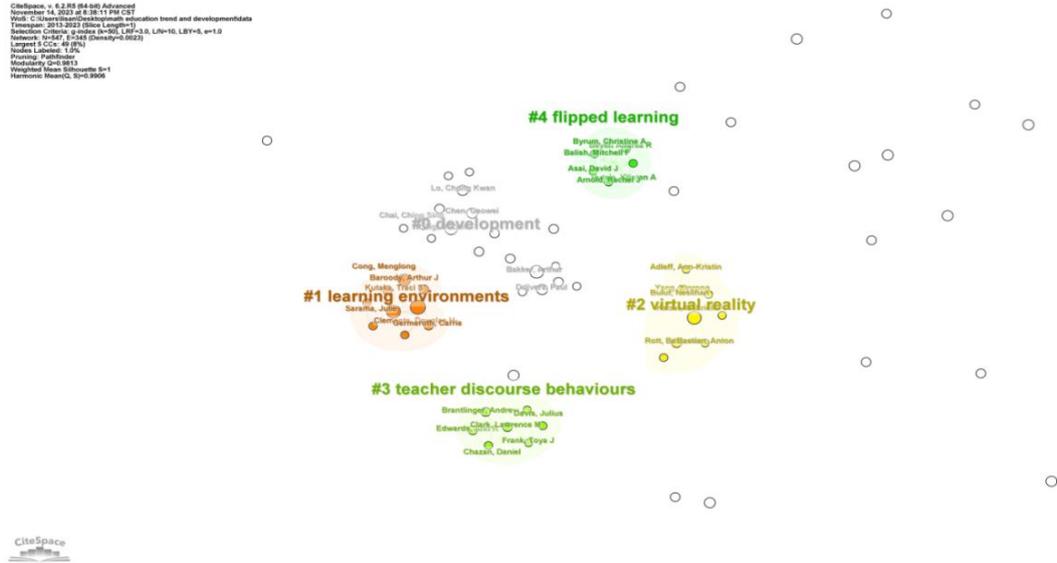


Figure 4: Cooperation map of high-yield authors

Among the core authors who have published three or more papers in the sample, there are 25 individuals. The leading authors are Clements Douglas H (8), Sarama Julie (7), Kaiser Gabriele (6), and Bakker Arthur (6). Clustering by keyword count shows 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 among the themes portrayed in the literature, serving as highly condensed focal points of the articles. The co-occurrence network map, as depicted in Figure 6, 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 86, 70, and 40 occurrences, respectively. Keywords with centrality exceeding 0.1 include "children," "performance," "thinking," "instruction," "design," and "ability." The higher a keyword's frequency, the greater its centrality value, providing coverage of hotspots and key turning points to some extent.

#### 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 5: Top 9 keywords with the strongest citation bursts

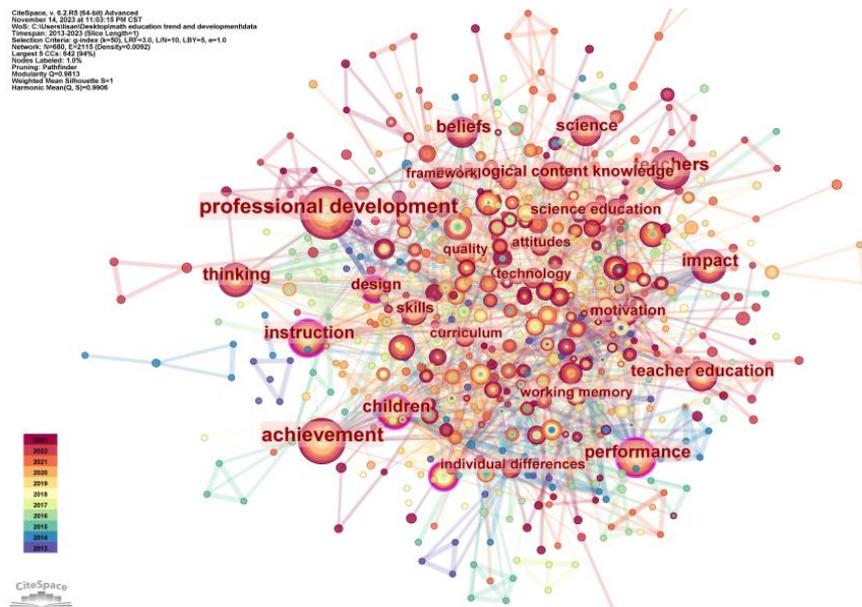


Figure 6: Keyword co-occurrence map

Using the "Detect Bursts" functionality in the software enables the identification of specialized vocabulary that experiences rapid increases in specific years. This approach facilitates the observation of more nuanced developmental changes. Figure 5 represents the burst word map generated from the sample literature.

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 problem-solving and numerical understanding. From 2016 to 2019, the most frequently used 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 ([Barroso & Daucourt, 2021](#)). During that time, researchers used meta-analysis to explore a hot topic in mathematics education: the relationship between mathematics education and working memory. The study suggested that mathematics showed a comparable association with verbal, numerical, 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 typically developing individuals or those with only mathematics difficulties ([Byun & Joung, 2018](#)). Another meta-analysis investigated the impact of digital games on mathematics education, analyzing recent trends in key research on digital game-based learning. 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, the most frequently used burst keywords in mathematics education were "science education," "teacher noticing," and "formative assessment." This timeframe coincided with the pandemic, which propelled new agendas in mathematics education research. In particular, the emergence of new educational methods, such as online classrooms and learning via electronic devices, led to "teacher noticing" and "formative assessment" becoming primary research frontiers. For educators, the ability to respond to diverse students' needs poses a comprehensive test of professional development and teaching practices ([Van Es & Sherin, 2021](#)). Teacher noticing is a core construct in teaching, providing an expanded framework and suggesting that teachers, during the observation process, are not merely passive observers. They actively shape interactions, gather additional information, and enable 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 enhances teaching effectiveness and better meets students' learning needs ([Wafubwa & Csikos, 2022](#)). Through experimental design, researchers 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 7. Over the past decade, mathematics education has primarily revolved around nine key themes: in-service teachers, teacher training, classroom environment, flipped classrooms, learning progression, 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.

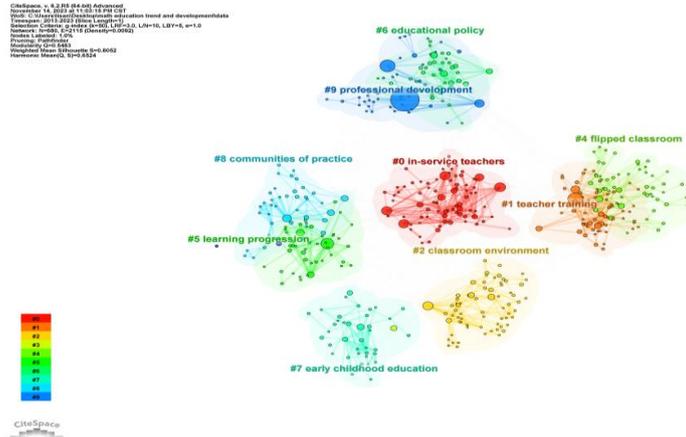


Figure 7: Keywords cluster map

#### Theme 1: Teacher professional development

Over the past decade, teacher professional development has consistently been a focal point of discussion in mathematics education. Teacher professional development is an ongoing process of continuous learning and improvement that contributes to the vitality and innovation of the education system and enables 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 focus is on in-service teachers, teacher training, discourse analysis, educational innovation, confidence, reflection, curriculum reform, and more. Following the pandemic and the emergence of new forms of education, higher demands have been placed on teachers' comprehensive qualities. Research has investigated how Chinese teachers perceive the impact of online teaching on mathematics learning (Cao & Kang, 2021). The results indicated that the effectiveness of online teaching largely depends on students' self-discipline. It has been suggested that the use of technology in teaching be expanded and integrated with mathematical practices. Teachers play a crucial role in online learning, with the expectation of enhancing the effectiveness of online teaching. Other studies in this theme have also examined various factors influencing teachers' instructional behavior, including 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 examine which factors have significant effects on teacher development, enabling the formulation of relevant interventions. Emphasizing teacher professional development is of great significance to teachers themselves, schools, society, and the education system.

#### Theme 2: Mathematics teaching and learning

This cluster spans a broad spectrum of studies, representing another primary research focus in mathematics education. Most researchers employ a combination of theory and practice in their studies, providing guiding insights for teachers in the teaching and learning of mathematics and playing a significant role in enhancing the quality of mathematics education. In mathematics teaching, it involves instructional design, teaching behaviors, principles, models, and methods. Emerging topics include situational teaching, problem-based teaching, online and offline integrated teaching, and VR-based teaching (Park & Han, 2021). Sustained variations in teaching and learning methods to maintain situational interest can yield better results. Learning Mathematics encompasses strategies, behaviors, emotions, interests, performance, and psychology. Mathematics anxiety has become a particular concern for teachers and parents. A meta-analytical approach confirmed a significant relationship between mathematics anxiety and mathematics performance, a relationship that persists from

childhood into adulthood ([Barroso & Daucourt, 2021](#)). The application of new technologies in mathematics teaching has contributed 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 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 in children's overall development. This thematic cluster focuses primarily on mathematical cognition, computer games, elementary education, thinking, confidence, interdisciplinary studies, interests, and related topics, using an experimental design to confirm that enhancing children's interest in learning positively affects fourth-grade children's mathematics performance ([Cui & Leung, 2021](#)). 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 children's academic development but also cultivates essential skills for daily life and future learning. Providing enriching experiences in mathematical learning has a profound impact on children's holistic growth.

### **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 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, in-depth insights into students' academic performance, thereby 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, as more artificial intelligence is involved in mathematics education, improving teaching methods and adapting mathematical learning pose severe challenges to the quality of mathematics education and the cultivation of talent. 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 uses CiteSpace software to conduct qualitative and quantitative analyses of international journals in the field of research. 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 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, as evidenced by both publication volume and the number of keywords, especially those related to 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 poses a challenge to teachers' professional development. Continuously refining research on teacher noticing is of great significance for enhancing the quality of teaching and learning. Teaching assessment serves as a guarantee for the healthy development of the mathematics education system.

The development of new educational methods is bound to drive research into new teaching and assessment methods. Continuous, interactive assessment practices are crucial for shaping and enhancing the learning experience, including formative assessment.

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This research did not receive any funding.

#### Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

#### Declarations

##### Ethics approval and consent to participate

This study was conducted in accordance with ethical guidelines, and all necessary approvals were obtained.

##### Consent for publication

Not applicable.

##### Competing interests

The authors declare no competing interests.

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