



Global Mapping of Research on Mathematics Learning Difficulties: A Bibliometric Analysis of Cognitive Factors and Educational Technology

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Abstrak

Kesulitan belajar matematika (difficulty learning mathematics) merupakan isu penting dalam pendidikan global yang berpengaruh terhadap perkembangan kognitif dan prestasi siswa. Penelitian ini bertujuan memetakan tren riset global mengenai kesulitan belajar matematika dan faktor kognitif dengan pendekatan bibliometrik. Sebanyak 215 dokumen awal diidentifikasi dari basis data Scopus periode 2016–2025, yang kemudian disaring secara ketat hingga tersisa 168 dokumen relevan untuk dianalisis. Analisis dilakukan menggunakan VOSviewer 1.6.20 dengan fokus pada analisis tren publikasi dan sitasi, co-occurrence kata kunci, serta jejaring kolaborasi penulis dan institusi. Hasil menunjukkan dominasi kontribusi dari negara maju (Amerika Serikat, Inggris, Tiongkok) diikuti peningkatan partisipasi dari negara berkembang seperti Indonesia. Kluster riset utama meliputi working memory, mathematics anxiety, problem solving, serta integrasi machine learning dan gamification. Secara praktis, pemetaan ini memberikan dasar bagi pengembang kurikulum dan pendidik untuk merancang intervensi pembelajaran adaptif berbasis teknologi, sekaligus mendorong kolaborasi internasional untuk mengatasi kesenjangan literasi matematika global.

Abstract

Difficulty learning mathematics is a crucial issue in global education, influencing cognitive development and student achievement. This study aims to map global research trends on difficulty learning mathematics and cognitive factors using a bibliometric approach. A total of 215 initial documents were identified from the Scopus database for the 2016–2025 period, which were then rigorously screened, resulting in 168 relevant documents for analysis. Analysis was performed using VOSviewer 1.6.20, focusing on publication and citation trend analysis, keyword co-occurrence, and collaboration networks of authors and institutions. The results indicate a dominance of contributions from developed countries (the United States, England, China), followed by increasing participation from developing countries like Indonesia. Major research clusters include working memory, mathematics anxiety, problem solving, and the integration of machine learning and gamification. Practically, this mapping provides a foundation for curriculum developers and educators to design technology-based adaptive learning interventions, while also fostering international collaboration to address the global mathematics literacy gap.

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Keywords:

difficulty learning mathematics, cognitive development, Machine Learning, Gamification, Working Memory

Introduction

Mathematics is one of the fundamental subjects that plays an important role in training students' logical, analytical, and systematic thinking skills. However, it cannot be denied that many students experience difficulties in learning (Aldon, 2021; P. C. Crismono, 2017a, 2017b; Hraste, 2018). This difficulty in learning mathematics not only affects academic performance but can also lower students' self-confidence and motivation in studying. Globally, it is estimated that around 3–6% of children experience significant difficulties in mathematics despite having normal intelligence and access to adequate education. If not recognized and addressed early, these difficulties can continuously affect academic achievement and even increase the risk of psychological problems in the future (Dowker, 2017; Zainudin et al., 2022). This situation makes the issue of difficulty learning mathematics an important concern in the field of education and urges the need for a deeper understanding of its background and contributing factors.

Previous research shows that difficulty learning mathematics is multicausal, influenced by a combination of internal (cognitive and affective) factors as well as external factors. Internal cognitive factors include various barriers in students' thinking processes, such as difficulty processing numerical information, difficulty understanding abstract mathematical concepts, and limitations in children's working memory capacity (P. C. Crismono, 2017b; Hacker, 2019). In addition, affective factors such as mathematics anxiety and low learning motivation have also been reported to contribute to the emergence of these difficulties. This finding is in line with recent studies indicating that cognitive aspects of working memory play a significant role in difficulty learning mathematics. In other words, the level of children's cognitive development, including their ability to remember, pay attention, and think abstractly, greatly affects their ability to absorb mathematics lessons (P. Crismono, 2023; Musso, 2019).

A deep understanding of these cognitive factors is important for educators to design targeted learning strategies to help students overcome their learning barriers (Bagnasco, 2016; Dennis, 2016). In addition to cognitive factors, advancements in educational technology also provide a new dimension in efforts to improve mathematics learning outcomes. The integration of technology in mathematics education is increasingly seen as an important innovative solution to address learning difficulties. Various approaches have been proposed by researchers to support students who struggle in mathematics, including the use of educational technology (such as interactive learning software, e-learning platforms) in the teaching process (Mahoney,

2017; Mendoza, 2021; Scherer, 2016). The use of technology can offer a more concrete, engaging, and adaptive learning experience tailored to each student's needs, thereby potentially reducing difficulties in understanding concepts. Trend. Research trends over the past decade have shown significant attention to this topic, with “technology” recorded as one of the main focuses in mathematics education publications, alongside classical topics such as algebra, calculus, geometry, and proof (P. C. Crismono, Maghfiroh, et al., 2025; Stein, 2020). This confirms that the use of modern technology is considered crucial in mathematics learning reform to enhance student understanding and engagement.

Learning difficulties in mathematics remain a global educational issue that has serious impacts on cognitive development, motivation, and student achievement, with a prevalence that continues to rise despite various pedagogical interventions. Amid this urgency, previous research tends to focus on experimental studies and classroom interventions, while comprehensive mapping of global research directions is still very limited (Fyfe, 2017; Zhao et al., 2017). In particular, bibliometric studies that specifically integrate the three domains of difficulty learning mathematics, cognitive factors (such as working memory, problem solving, and math anxiety), as well as educational technology innovations such as gamification and machine learning are still rarely found, so the direction of scientific development, academic collaboration networks, and research theme trends have not been systematically documented (Baten, 2020; Donthu et al., 2021; Putri et al., 2025). Based on this research gap, this study aims to analyze the global research landscape on mathematics learning difficulties by reviewing citation patterns, keyword clusters, publication trends, and the contributions of countries and institutions through a bibliometric approach assisted by VOSviewer, thereby producing a scientific map that can serve as a conceptual and practical foundation for the development of learning strategies and further research in this field.

This research introduces novelty in terms of using a bibliometric approach to map the research landscape in the field of difficulty learning mathematics and cognitive development. By utilizing VOSviewer software, this study will analyze scientific publication data to uncover emerging patterns in research related to these topics (Abidin et al., 2025; Fadilla et al., 2023; Karim, 2022). Through the analysis of keyword co-occurrence, the study will identify which key concepts are most dominant and how they are interrelated within the literature. Additionally, citation network analysis is conducted to examine the relationships between publications based on citation patterns, allowing the identification of citation trends and which

works are most influential in shaping knowledge in this field. Equally important, this bibliometric approach enables mapping of research contributions globally, for instance, by examining which authors, institutions, or countries are the most productive. publishing studies on difficulty learning mathematics as well as the potential for future international collaboration.

The results of this mapping are expected to provide new insights into research trends and the development of knowledge related to difficulty learning mathematics and cognitive factors, identifying which areas have been widely studied and which areas have received less attention, as well as highlighting opportunities for further research. In other words, this bibliometric approach assisted by VOSviewer will contribute as a scientific roadmap to holistically understand the dynamics of research on difficulty learning mathematics and cognitive development on a global scale (Trinh, 2024; Warsitasari, 2024).

The research problem in this study encompasses four main questions aimed at understanding the global research landscape related to difficulty learning mathematics and cognitive development in the educational context. First, how the trend in the number of scientific citations on this topic has changed from 2016 to 2024. Second, what the main topic clusters are that emerge based on bibliometric analysis in the field of mathematics education and cognitive development. Third, the geographical distribution of scientific articles discussing this topic across different countries. And fourth, which institutions or universities have the largest contribution to the number of publications on difficulty learning mathematics and cognitive development.

This problem statement includes an analysis of trends, author contributions, collaborations, and the impact of difficulty learning mathematics in various fields based on a bibliometric approach in the article.

Method

This study adopts a bibliometric design, a systematic quantitative approach to mapping the intellectual and social structure of a research field. This design was chosen because of its ability to objectively analyze large volumes of literature, reveal hidden patterns, and identify directions in the development of knowledge that may not be visible through traditional literature reviews. In this context, the bibliometric approach is highly relevant for synthesizing thousands of publications on learning difficulties in mathematics into a comprehensive

knowledge map (P. C. Crismono, 2023; Lim et al., 2024; Petrescu-Mag et al., 2025; D. Wang & Qin, 2025). As a data source, this study exclusively uses the Scopus database. The choice of Scopus is based on its position as one of the world's leading bibliographic indexing and abstracting databases, offering the widest international literature coverage and high reliability in tracking Citation. Scopus is recognized for its comprehensive indexing of high-reputation journals and important conference proceedings, ensuring that the data analyzed represents the mainstream of global scientific discourse.

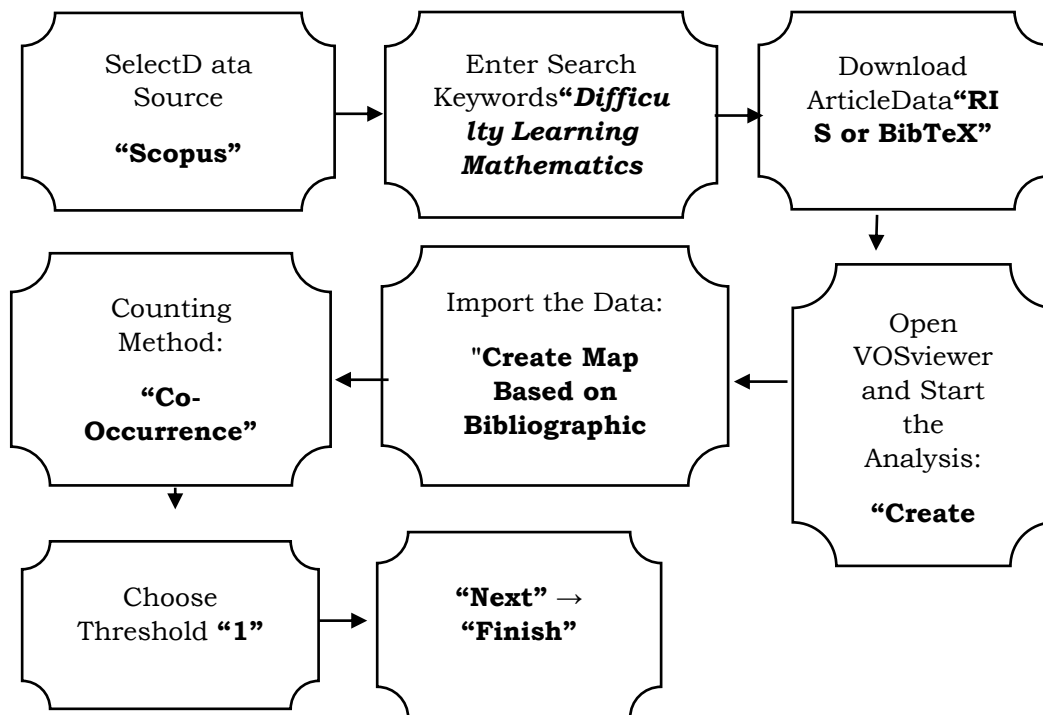


Figure1.

Settings and download of Publish or Perish for importing and preparing VOSviewer data

The data collection process was conducted using the search string TITLE-ABS-KEY ("mathematics difficulty" OR "learning difficulty mathematics"). This choice of keywords was deliberately designed to capture the essence of the research topic with broad coverage while remaining focused. The publication range set was 2016–2025, a ten-year period chosen to reflect the dynamics of the most recent research and to identify emerging trends in this decade (Abdelwahab et al., 2024; P. C. Crismono, Hudi, et al., 2025; Hidayatullah et al., 2024). Inclusion criteria were applied strictly, encompassing journal articles and proceedings that had undergone peer review and were written in English or Indonesian to ensure empirical quality and relevance. Conversely, exclusion criteria explicitly ruled out book reviews, editorials, and errata to maintain the analysis focus on original research findings and to avoid bias from secondary sources (Arifurrohman & Crismono, 2025; Dalal et al., 2023; Wardani et al., 2024). The initial screening process yielded 215 documents, which then underwent further eligibility screening using the Publish or Perish (PoP) software to eliminate duplicates and irrelevant publications based on abstract and title review. This stage is crucial for maintaining validity and producing a clean final dataset, consisting of 168 documents.

Bibliometric Analysis The data analysis was conducted using VOSviewer version 1.6.20, a software specifically designed for constructing and visualizing bibliometric maps. VOSviewer was chosen due to its capability to process large datasets, identify statistically significant clusters, and produce network visualizations that are intuitive and easy to interpret. Three main types of analysis were conducted to reveal the profile of this research from various dimensions (Habibi et al., 2022; Kaya & Kutluca, 2024; Suprpto et al., 2023).

To comprehensively reveal the research structure from the conceptual to the social level, three main types of bibliometric analyses were conducted. At the conceptual level, Keyword Network Analysis (Co-occurrence Analysis) was used to identify central themes and relationships between concepts (such as working memory, mathematics anxiety) by analyzing the frequency of co-occurring keywords, which were then grouped into thematic clusters (Alshabibi et al., 2022; Wulandari et al., 2023). At the intellectual level, Citation Network Analysis (Co-citation Analysis) mapped the epistemological foundations of the field by identifying the most influential publications that are frequently cited together, thus revealing the evolution of fundamental findings over time. Meanwhile, at the macro level, Country and

Institutional Contribution Analysis mapped the social structure of research, identifying centers of global research excellence and highlighting disparities in contribution between countries, as well as exploring the potential of existing collaborative networks (Özdemir et al., 2025; Warsitasari, 2024).

Results and Discussion

1. Trend of Decreasing Number of Scientific Citations from 2016 to 2026

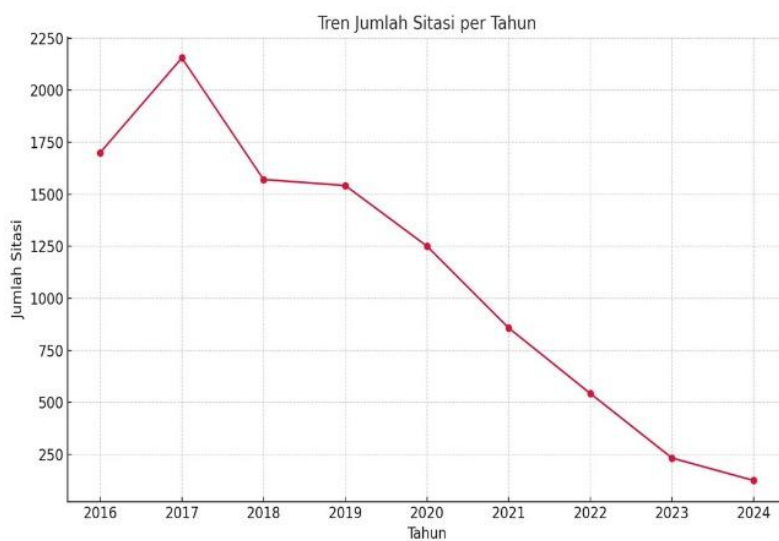


Figure 2

Trend of citations by year

The chart shows the trend in the number of scientific citations from 2016 to 2024. The horizontal axis (X) represents the years, while the vertical axis (Y) indicates the number of citations that occurred each year (Meiguins et al., 2019; Noordende, 2016). The data is visualized as a red line with markers at each year, providing a clear depiction of the fluctuations in the number of citations over that period.

From the graph, it can be seen that the number of citations peaked in 2017 with a figure approaching 2,200 citations. This indicates that in that year there was high academic or research activity, or perhaps there were several publications that became key references in various subsequent studies. However, after 2017, the number of citations shows a fairly sharp declining trend (Rellensmann, 2017).

color grouping (for example, red, green, blue) represents cluster groupings based on thematic proximity, identified through the VOSviewer algorithm (Jackson, 2017; Saeedi & Hemmert, 2020).

The analysis identified five main clusters representing the pillars of global research on mathematical learning difficulties. The largest cluster (colored red) focuses on fundamental cognitive factors, which form the core of this research network. This theme is followed by clusters on pedagogical interventions (green), technology integration (blue), affective factors (yellow), and early skills development (purple). These findings suggest that research in this field has evolved from merely identifying problems to exploring multidimensional solutions encompassing cognitive, affective, and technological aspects (Forsyth, 2017; Ruffini et al., 2024).

A deeper interpretation of each cluster grouping provides insights into the direction of global research:

- **The Red Cluster (Fundamental Cognitive Factor)** is dominated by the keywords working memory, cognitive development, problem solving, and mathematics difficulties. The dominance of this cluster underlines that the global scientific consensus places cognitive barriers as the root of difficulties in learning mathematics. The implication is that future research must continue to explore the underlying neurocognitive mechanisms to develop more precise interventions (Fyfe, 2017).
- **The Green Cluster (Pedagogical Interventions)** consists of the keywords mathematics learning, instructional strategies, intervention, and remediation. This cluster represents practical efforts in the classroom. The close relationship between intervention and instructional strategies indicates a shift from problem identification to the development of empirically proven learning solutions.
- **The Blue Cluster (Technology Integration)** features modern keywords such as machine learning, gamification, adaptive learning, and cognitive load. This is the most dynamic cluster and reflects the direction of current research. The emergence of machine learning and adaptive learning indicates a trend toward personalized learning. Its connection with cognitive load suggests a focus on designing technology that is not only innovative but also cognitively efficient for students (Gashaj et al., 2023; Miller, 2018)
- **The Yellow Cluster (Affective Factor)** centers on the keywords mathematics anxiety, motivation, self-efficacy, and attitude. The presence of this cluster complements the

cognitive perspective by emphasizing that the affective aspect is not merely a side effect, but a crucial variable that directly influences cognitive processes and learning outcomes.

- **The Purple Cluster (Early Skill Development)** highlights the keywords spatial ability, early elementary, number sense, and executive function. This cluster indicates the importance of early detection and intervention from a young age. The focus on spatial ability and number sense as a foundation reflects global awareness that preventing mathematical difficulties is far more effective than remediation later on.

Overall, this density visualization not only maps the existing topics but also reveals the evolution of research from conventional approaches to innovative, technology-based, and holistic solutions, encompassing various dimensions of student learning (Morsanyi, 2018; Ren et al., 2025).

3. Map of the Distribution of Scientific Articles Worldwide

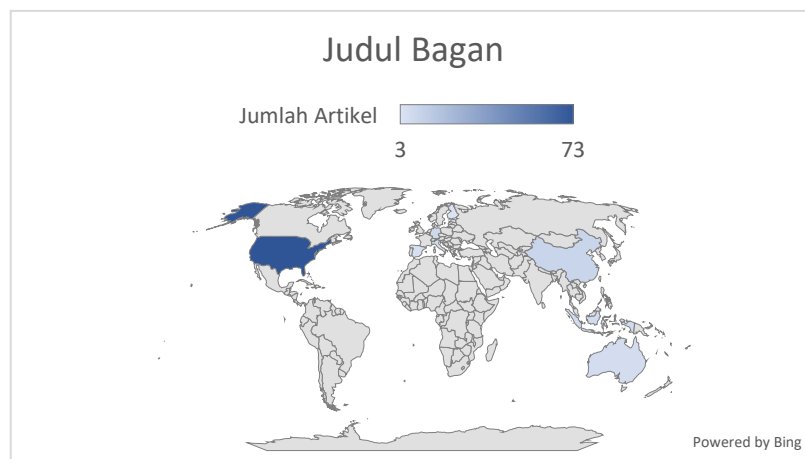


Figure 4.

Geographical Distribution of Research on Difficulty Learning Mathematics Based on the Number of Published Articles

This visualization presents the distribution of the number of scientific articles by country in the form of a world thematic map (choropleth map). The map uses shades of blue to indicate the intensity of the number of articles originating from each country. The darker the blue on a country, the higher the number of articles coming from that country. Conversely, lighter blue areas or uncolored regions indicate a lower contribution or even no contribution of articles at all.

From the map, it can be seen that the United States is the country with the highest number of articles, indicated by the darkest blue color. Other countries that also appear to make a significant contribution in the number of articles are Canada, the United Kingdom, Germany, China, Japan, and Australia. These countries generally have advanced education and research systems as well as strong publication infrastructure (de Castro & Porto, 2023; Thompson, 2021).

Meanwhile, most areas in Africa, Central Asia, and South America appear uncolored or very lightly colored. This indicates that the contribution of countries in these regions to the number of scientific articles is still low. This disparity can be caused by various factors, including limited access to research resources, low research funding, and challenges in international publication (Chao, 2021; Wagner et al., 2015).

This visualization generally illustrates the global imbalance in scientific contribution. Developed countries tend to dominate the production of scientific articles, while developing countries still face challenges in increasing their engagement and contribution in the realm of international academic publications (Hamzaoui et al., 2025; Rostami et al., 2025). These findings are important as a point of reflection in developing international cooperation and equitable access to research and higher education.

4. Top 10 Affiliates Based on Number of Publication Contributions

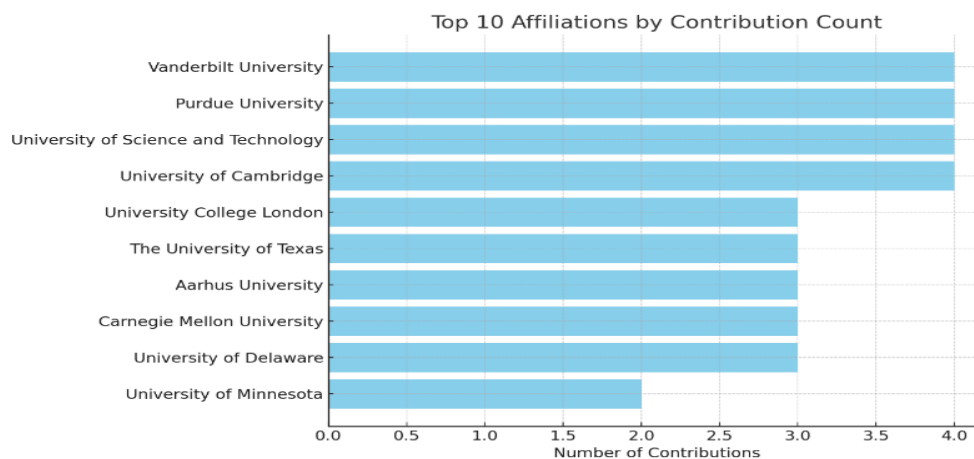


Figure 5.

Top 10 Institutions with the Highest Contributions in Research on Difficulty Learning Mathematics

This visualization maps the distribution of scientific publication contribution based on institutional affiliations, focusing on the top 10 universities. In this analysis, "contribution" is defined as the number of articles published where the affiliation is listed, calculated using the

full counting method (where each institution affiliated with an article receives one full point). The results show a clear hierarchy in global research contributions.

Based on quantitative data, the ten institutions with the highest contributions are as follows:

1. Vanderbilt University (4 articles)
2. Purdue University (3 articles)
3. University of Science and Technology (3 articles)
4. University of Cambridge (2 articles)
5. University College London (2 articles)
6. The University of Texas (2 articles)
7. Aarhus University (2 articles)
8. Carnegie Mellon University (2 articles)
9. University of Delaware (2 articles)
10. University of Minnesota (2 articles)

Analysis shows Vanderbilt University as the main epicenter of research in this field, with the highest contributions indicating the presence of a highly influential research group or study center (Hussein, 2023; Kosiol, 2019). Following it, Purdue University and the University of Science and Technology form the main challenger group, consistently making significant contributions to the literature (Tam, 2020). Meanwhile, prestigious institutions such as the University of Cambridge and University College London, although contributing less, still play an important role in enriching academic discussion, indicating that this research attracts global interest from various centers of excellence (Kim, 2022; Roerecke et al., 2019).

Overall, this distribution not only shows who is the most productive, but also highlights the concentration of expertise in certain institutions. The diversity of affiliations, although uneven, indicates the presence of a broad collaborative network and strengthens the credibility and global impact of research on mathematical learning difficulties (İNCİ & KÖSE, 2024; Jaya et al., 2025; Wahyuni et al., 2025).

Overall, the pattern of increasing publications on the topic of learning difficulties in mathematics has been especially noticeable since 2020, and this phenomenon is not only a natural academic trend but is also closely related to the global context. The surge in research during this period can be explained by the COVID-19 pandemic, which caused a major transformation in the learning process from face-to-face to online systems, thereby creating new challenges in numerical literacy, learning motivation, math anxiety, as well as access to

technology; a finding consistent with Tashtoush, (2023), who identified declines in motivation and increases in the digital divide as direct impacts of remote learning.

At the same time, the global issue of the mathematical education crisis is gaining increasing attention, marked by international reports on low numeracy achievement and the need to enhance 21st-century competencies. This situation has encouraged researchers to shift their focus from merely traditional cognitive difficulties to approaches based on educational technology, gamification, adaptive learning, AI-based tutoring, and learning analytics. This aligns with Sayed, (2023), who highlights how AI-based platforms and content personalization are innovative solutions to maintain student engagement in mathematics learning in the digital era.

As revealed by Mamolo, (2022), changes in research themes are also reflected in keyword clusters that increasingly show the integration of mathematics difficulty, cognitive factors, and educational technology. The study indicates that the focus of the scientific community has shifted from merely identifying mathematical difficulties cognitively to a more holistic approach, which also examines psychological aspects (anxiety) and offers technology-based solutions. Thus, publication dynamics not only depict quantitative growth but also a paradigm shift from conventional approaches to a more personalized, adaptive, and digital learning model in response to global educational challenges.

Overall, this study not only confirms the evolution of research on learning difficulties in mathematics from a purely cognitive perspective towards deep technological integration, but also reveals its driving force, which is the global response to the challenges of modern education. This trend indicates a paradigm shift towards a more holistic, adaptive, and responsive mathematics learning ecosystem, ultimately aiming to improve the quality and equity of student learning outcomes worldwide.

Conclusion

This study systematically maps the global research landscape on mathematics learning difficulties, focusing on cognitive factors and the integration of educational technology through a bibliometric approach. Based on an analysis of 168 documents from the Scopus database during the 2016–2025 period, two main conclusions can be drawn. First, this study confirms a significant paradigm shift in mathematics learning difficulties research post-2020, driven by responses to global challenges, namely the COVID-19 pandemic, with the focus shifting from conventional cognitive approaches to innovative technology-based solutions. Second, the analysis reveals a striking imbalance in scientific contributions, where developed countries

dominate knowledge production, while developing countries are still in the process of increasing participation, indicating a blind spot in the global literature. The implications of these findings are twofold; on one hand, theoretically, this study provides a comprehensive scientific map of research evolution, and on the other hand, practically, it offers an empirical basis for curriculum developers and educators to design adaptive, technology-based learning interventions. Although it provides valuable insights, this study has limitations, relying on Scopus data and focusing on quantitative analysis rather than methodological quality. Therefore, future research is recommended to conduct qualitative content analysis of the most influential publications and explore the implementation of educational technology in the context of developing countries to create a more equitable, adaptive, and globally sustainable mathematics learning ecosystem.

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