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From Cognition to Emotion: Recent Global Research Directions in Mathematical Proficiency

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Abstract. Research on mathematical proficiency has gained increasing global attention due to its significance in education and psychology. This study presents a bibliometric analysis of 1,884 articles published between 2020 and 2024 to identify research trends, key contributors, thematic clusters, and global collaboration networks in the field. Utilising VOSviewer and Bibliometrix, two widely used tools for science mapping and visualisation, the analysis reveals 10 thematic clusters, with mathematics, mathematics achievement, academic achievement, and math anxiety emerging as central topics. Among these, mathematics achievement appears as one of the most frequently used keywords, underscoring a strong focus on the relationship between mathematical proficiency and academic outcomes. The United States leads global contributions, supported by prolific institutions and interdisciplinary work published in high-impact journals such as the Journal of Educational Psychology. The analysis also shows a rising number of collaborations across countries and institutions. The findings highlight a growing emphasis on cognitive and socio-emotional factors, including executive functions, working memory and growth mindset. These insights provide a comprehensive roadmap for researchers and policymakers to guide future inquiry, foster interdisciplinary collaboration and develop holistic strategies to improve mathematical proficiency at scale. Limitations include the exclusive use of Scopus-indexed and English-language articles, as well as reliance on keyword-based retrieval. Future studies might incorporate multiple databases, explore culturally contextualised trends, or examine underexplored themes such as pedagogical content knowledge and digital learning environments.

Keywords: bibliometric analysis; mathematical proficiency; mathematics achievement; mathematics education; Scopus database

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1. Introduction

Mathematical proficiency has become a critical focus in mathematics education research due to its strong connection to students' academic success and cognitive development. Empirical studies have demonstrated that early understanding of mathematical concepts, such as equality, can predict students' readiness for learning algebra at later educational stages (Hornburg et al., 2022). Moreover, mathematical proficiency is significantly associated with overall academic achievement, with executive functions playing a pivotal role in students' mathematical performance (Albert et al., 2020; Ellis et al., 2021). It also enables learners to tackle real-world problems effectively, underscoring its importance across educational and societal domains (Alfayez, 2022; Altarawneh & Marei, 2021).

Mathematical proficiency comprises five interrelated strands: procedural fluency, conceptual understanding, strategic competence, adaptive reasoning and productive disposition (Alfayez, 2022; Barham, 2020; Reid O'Connor, 2024). This multidimensional framework emphasises not only knowledge recall or procedural execution, but also the ability to flexibly apply mathematical concepts to problem-solving in various contexts (Ballon et al., 2024; Junpeng et al., 2020). Furthermore, mathematical proficiency has become integral to Science, Technology, Engineering, and Mathematics (STEM) education, which promotes critical thinking and interdisciplinary learning (Eshaq, 2024; Hasibuan et al., 2024; Kong & Mohd Matore, 2022).

Beyond cognitive dimensions, recent research has shown that mathematical proficiency is influenced by emotional and social factors such as mathematics anxiety, learning motivation, and environmental support (Abín et al., 2020; Ng et al., 2016; O'Connor et al., 2023). Studies have also highlighted the role of family engagement and home-based learning activities in shaping children's early mathematical development (Ellis et al., 2023; Ribner et al., 2023). As such, mathematical proficiency is understood as a holistic construct involving the interplay of cognitive, affective, and social factors.

Key challenges in enhancing students' mathematical proficiency include individual differences in executive function, mathematics anxiety, and the influence of the social environment. Studies have shown that variations in executive function can affect students' academic performance, including mathematical skills (Albert et al., 2020; Ellis et al., 2021). Additionally, mathematics anxiety can hinder the learning process and reduce students' motivation to achieve (Gur et al., 2023; Maldonado Moscoso et al., 2020). The social environment, including parental support and classroom interactions, also plays a crucial role in shaping students' mathematical development (Han et al., 2024; Tang & Tran, 2023).

The past two decades have seen a growing global interest in exploring mathematical proficiency through interdisciplinary and evidence-based approaches. Various solutions have been proposed to improve students' performance, including the integration of educational technology (Chan &

Zhou, 2020), the application of problem-based learning (Hassan et al., 2023), and STEM-based interventions that enhance students' reasoning and creative skills (Eshaq, 2024; Kong & Mohd Matore, 2022). Nevertheless, challenges still persist in improving student performance, closing pedagogical gaps, and advancing research quality, such as inconsistencies in research methodologies, the dominance of cognitive perspectives, and limited emphasis on social and emotional variables. These challenges highlight the need to synthesise and map current knowledge to guide future investigations and inform pedagogical practices.

Bibliometric analysis has become an effective method for systematically examining trends, thematic developments, and influential contributors within a research field. It is particularly useful in identifying publication patterns, knowledge gaps, and collaborative structures across disciplines. Prior bibliometric studies have demonstrated how emerging technologies like augmented reality and artificial intelligence are reshaping mathematics education (Angraini et al., 2024; G.-J. Hwang & Tu, 2021), while others have explored the impact of growth mindset and cultural factors on student learning outcomes (Xu et al., 2022). This analytical approach has also identified key contributors, leading institutions, and the most influential journals, thus offering valuable guidance for future research directions in mathematics education (Chin & Chew, 2022; Muhammad et al., 2024; Phan et al., 2022a). Although prior bibliometric studies have addressed areas such as augmented reality, artificial intelligence, growth mindset, and cultural influences, few have specifically examined mathematical proficiency as a central theme.

Despite these contributions, there has been limited bibliometric analysis specifically focused on mathematical proficiency. A comprehensive understanding of the global landscape—particularly regarding thematic clusters, influential publications, and international research collaborations—remains lacking. To address this gap, this study applies bibliometric analysis to map the evolution and structure of mathematical proficiency research, highlighting major contributors and emerging trends in the field. By addressing this gap, the present study offers a comprehensive mapping of mathematical proficiency research, informing both scholarly understanding and practical directions for future investigation.

This study focuses specifically on global trends, utilising bibliometric analysis to identify the evolution, structure, and key actors within the field. Accordingly, the following research questions guide this study:

1. Which countries, institutions, and authors are the most productive in publishing research on mathematical proficiency between 2020 and 2024?
2. Which journals play a significant role in disseminating research on mathematical proficiency, and how impactful are these journals based on publication and citation metrics?
3. What are the most frequently used keywords and thematic clusters in research on mathematical proficiency, and how have these themes evolved over time?

4. Which articles and authors have received the most citations, and what thematic contributions have these influential works provided to the mathematical proficiency literature?
5. What is the level of international collaboration in research on mathematical proficiency, and which countries have the most extensive research networks and collaborations?

2. Methodology

This study employed a five-phase bibliometric analysis to investigate global research on mathematical proficiency, using a descriptive approach based on quantitative publication and citation data. First, the researchers designed the study framework to guide the selection of relevant literature (Donthu et al., 2021; Marzi et al., 2025). Next, a systematic literature search was performed using appropriate databases to gather the necessary bibliographic data (Donthu et al., 2021; Öztürk et al., 2024). The subsequent phase involved conducting the bibliometric analysis (Öztürk et al., 2024; Wen et al., 2021).

The results were then synthesised and presented in a broader context, including theoretical and practical implications of the findings (Bo et al., 2025; Jing et al., 2024; Marzi et al., 2025). Finally, in the interpretation phase, the researchers analysed and explained the results in detail (Aria & Cuccurullo, 2017). The validity of the findings is supported by the use of Scopus as a reputable and curated data source, along with a transparent and replicable search protocol. Reliability is ensured through the application of established bibliometric tools—VOSviewer and Bibliometrix—which have been widely adopted in previous bibliometric studies for their consistency and robustness.

2.1. Study Design

In the first phase of the bibliometric study on mathematical proficiency, the researchers designed the study framework, which involved two critical steps. First, the researchers defined the objectives and scope of the study (Öztürk et al., 2024). Specifically, this research aimed to explore three key areas: (1) identifying the most productive journal sources, institutions, and influential authors in mathematical proficiency research at the global level; (2) examining the most productive countries and the significant impact of international collaboration among authors; and (3) investigating popular research topics and trends by analysing keywords in mathematical proficiency studies.

Next, the researchers selected a relevant database to gather literature that would provide access to publications related to mathematical proficiency (Cevikbas et al., 2024). The study focused on scholarly articles published in Scopus-indexed journals, following a similar approach used by other researchers conducting bibliometric analyses in mathematics education (Hodiyanto et al., 2025; Kadarisma et al., 2024; Phan et al., 2022b; Putra et al., 2024). The selection of Scopus-indexed journals was due to Scopus' reputation as one of the most respected and widely used indexing databases among researchers worldwide. Scopus maintains stringent standards for journal indexing, including rigorous peer-review and selection processes, ensuring the credibility and high quality of

published articles (Baas et al., 2020; Nasrum et al., 2025; Schotten et al., 2017). Furthermore, Scopus includes a vast number of documents not covered by other databases, many of which contain significant references and citations (Visser et al., 2021).

2.2. Compilation of Bibliometric Data

The metadata search was conducted through the official Scopus website using the *Search Documents* feature. The data were retrieved on January 11, 2025, to ensure consistency and accuracy of the bibliometric analysis. The metadata search protocol is presented in Table 1. The search was limited to articles published between 2020 and 2024 to ensure that the bibliometric analysis reflects current trends and innovations in mathematics education over the past five years. This period selection provides up-to-date insights into developments in the field, which is crucial in rapidly evolving research contexts (Donthu et al., 2021).

Table 1: Search protocol

Aspect	Description
Timespan	2020-2024
Search string	TITLE-ABS-KEY ("math proficiency" OR "mathematical proficiency" OR "mathematics proficiency" OR "math competence" OR "mathematical competence" OR "math skills" OR "mathematics skills" OR "math ability" OR "mathematical ability" OR "math achievement" OR "mathematics achievement")
Filters	Subject area limited to *Social Sciences*, *Psychology*, and *Mathematics* → Document type limited to *Article* → Publication stage limited to *Final* → Source type limited to *Journal* → Language limited to *English* → Open access limited to *All Open Access*

2.3 Analysis and Visualisation

The analysis utilised features available on the Scopus website, including *Documents per Year by Source, Documents by Country or Territory, Documents by Subject Area, Documents by Affiliation, and Documents by Author.* Additionally, the Citation Overview feature on Scopus was used to gain deeper insights into the impact and influence of articles and authors by analysing citation counts and trends. To perform a comprehensive bibliometric analysis and generate visualisations, VOSviewer (van Eck & Waltman, 2010) and Bibliometrix R-Tool (Aria & Cuccurullo, 2017) were utilised.

These tools were used to generate network, overlay, and density visualisations, which served to identify keyword co-occurrence relationships, thematic clusters, and research trends, as well as to reveal thematic differences across countries in mathematical proficiency research. This approach follows established methodologies in bibliometric research, as previously applied by Guleria and Kaur (2021), Ejaz et al. (2022) and Sharma et al. (2024), who also utilised these tools in their analyses.

Several bibliometric techniques were employed in this study to extract meaningful insights from the data. Descriptive frequency analysis was used to examine the annual publication output, contributing countries, institutions, subject areas, and author productivity. Citation analysis was conducted to evaluate scholarly impact through metrics such as total citations and h-index, identifying influential authors and articles. Keyword co-occurrence analysis using VOSviewer and Bibliometrix enabled the identification of thematic clusters and the evolution of research trends related to mathematical proficiency.

Co-authorship and international collaboration analysis provided a view of global research networks and key regional hubs. Furthermore, three-field plots and visualisations such as word clouds and treemaps were utilised to uncover relationships among authors, keywords, and journals, enriching the understanding of thematic distribution and source prominence. Together, these techniques offer a comprehensive overview of the intellectual, social, and conceptual structure of the field.

3. Results

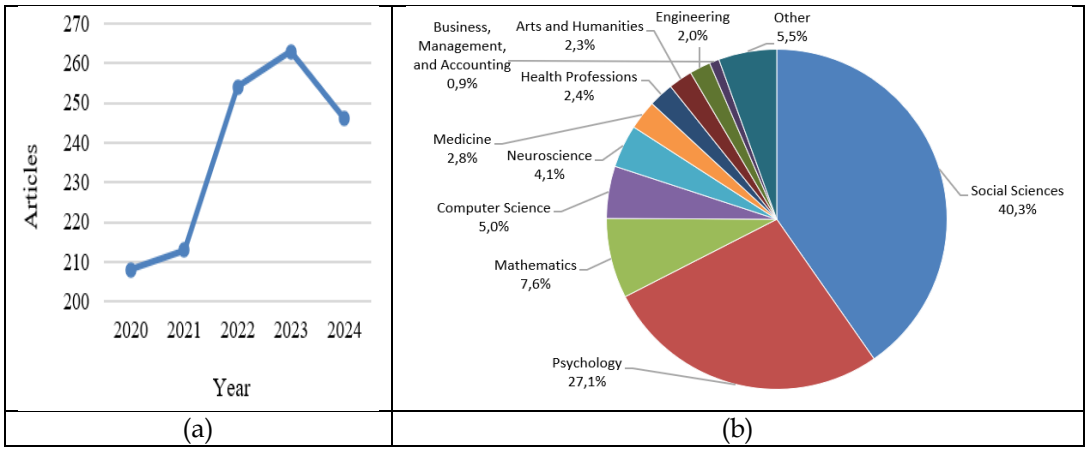
3.1 General Information

Based on the search protocol established to collect the articles for analysis, key information regarding the article collection is presented in Table 2. A total of 1,884 articles were published between 2020 and 2024, indicating an annual growth rate of 4.28%. This suggests a consistent increase in interest and attention to the topic among researchers during this period. The average number of citations per article is 7.565, signifying a relatively strong academic impact within the related research field. Additionally, 3,202 keywords were used by authors, reflecting the diversity of topics explored in mathematical proficiency research.

Table 2: Main information regarding the collection

Description	Result
Articles	1884
Period	2020-2024
Annual growth rate percentage	4.28
Average citations per article	7.565
Author's keywords	3202
Authors	3543
Authors of single authored articles	90
Co-authors per articles	3.75
International co-authorships percentage	25.84

During the same period, 3,543 authors contributed to the publications, with 90 authors producing single-authored articles. The average number of collaborators per article is 3.75, highlighting the collaborative nature of research in this field. While teamwork is prevalent, the presence of single-authored works underscores the importance of individual contributions that may provide unique and innovative perspectives in advancing knowledge. The international co-authorship rate is 25.84%, indicating significant involvement from researchers across multiple countries in mathematical proficiency research.



(a) (b)

Figure 1: (a) Documents by year; (b) Documents by subject area

Figure 1a illustrates a consistent increase in the number of publications from 2020, peaking at 263 articles in 2023. However, there was a slight decline in 2024, with 246 articles published. This decrease may reflect shifts in research focus or other dynamics influencing publication output in this field. Overall, the trend demonstrates stable and growing interest in mathematical proficiency over the past five years. Figure 1b shows the distribution of articles by subject area. The social sciences accounted for the largest share, contributing 40.3%, followed by psychology (27.1%) and mathematics (7.6%).

The dominance of social sciences, particularly in education, highlights the relevance of mathematical proficiency research in contemporary educational contexts. The relatively smaller contributions from psychology and mathematics suggest that these fields, though important, may focus less on practical applications for developing mathematical proficiency. Meanwhile, the presence of fields such as computer science (5.0%) and neuroscience (4.1%) indicates a multidisciplinary approach involving various perspectives to better understand mathematical proficiency. This distribution reflects the broad implications of this research across both mathematical and socio-psychological domains.

3.2 Most Productive Journals

Table 3 presents information on the top 10 global journals contributing to mathematical proficiency research from 2020 to 2024. Among these, Frontiers in Psychology ranks highest, with 87 articles published, significantly more than any other journal. This highlights the journal's broad interdisciplinary scope, particularly on topics connecting education and psychology. This high productivity is supported by a Citescore of 5.3 and a Scimago Journal Rank (SJR) of 0.80, indicating its strong influence within the academic community.

Table 3: Top 10 most productive journals

Journals	Publisher	Highest Percentile	Citescore 2023	SJR 2023	Number of Articles
Frontiers in Psychology	Frontiers Media S.A.	78%	5.3	0.80	87
Education Sciences	Multidisciplinary Digital Publishing Institute (MDPI)	81%	4.8	0.67	36
Frontiers in Education	Frontiers Media S.A.	62%	2.9	0.63	34
International Journal of Instruction	Gate Association for Teaching and Education	N/A	-	0	25
Journal of Experimental Child Psychology	Elsevier	70%	4.5	1.08	21
Large-Scale Assessments in Education	Springer Nature	77%	4.3	1.26	21
Eurasia Journal of Mathematics, Science, and Technology Education	Modestum LTD	80%	4.3	0.45	20
Journal of Educational Psychology	American Psychological Association	97%	11.4	2.77	20
Frontiers in Psychology	Frontiers Media S.A.	78%	5.3	0.80	87
Education Sciences	Multidisciplinary Digital Publishing Institute (MDPI)	81%	4.8	0.67	36

Note. International Journal of Instruction was discontinued in Scopus as of 2023, but the 25 articles included in this bibliometric analysis are those published while the journal was still covered by Scopus (2020-2023).

Other journals, such as Education Sciences and Frontiers in Education, also show consistent engagement with mathematical proficiency research. Despite having fewer publications, these journals maintain relatively high citescores (4.8 and 2.9), reflecting the impact of their research output. Meanwhile, more specialised journals, such as the Journal of Educational Psychology and Journal of Numerical Cognition, published fewer articles (20 and 19 articles, respectively) but are positioned in the highest percentiles with high SJR values, reflecting their academic quality and influence in specific fields. The cessation of Scopus indexing for the International Journal of Instruction after 2023, despite contributing 25 articles, underscores the challenges journals face in maintaining

long-term visibility on global indexing platforms. This highlights the importance of adhering to Scopus standards to ensure sustained accessibility.

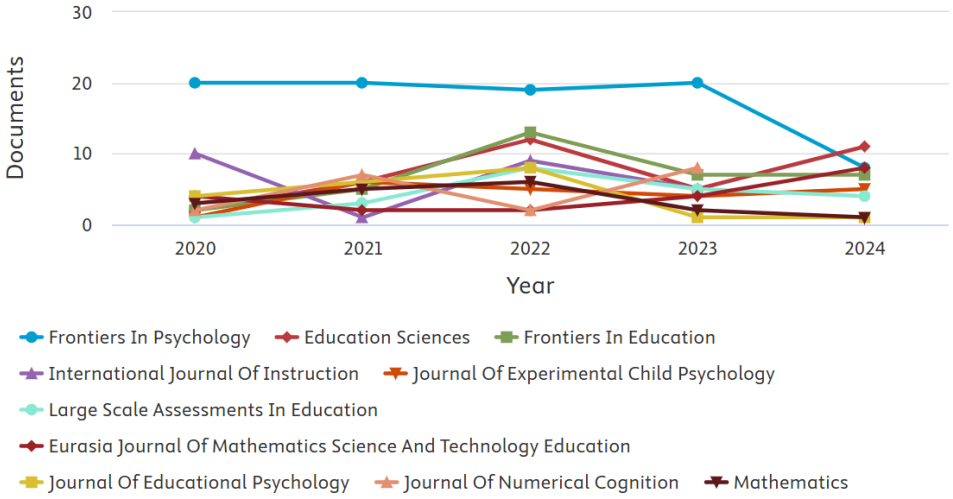


Figure 2: Annual publication trends in the top 10 most productive journals

In terms of publication trends, Figure 2 shows that Frontiers in Psychology dominated throughout the analysis period. Meanwhile, journals such as Education Sciences and Frontiers in Education demonstrated gradual increases in their contributions. In contrast, specialised journals like the Journal of Numerical Cognition and Large-Scale Assessments in Education exhibited stable yet lower publication outputs, indicating a narrower focus on specific topics.

3.3 Most Productive Authors

The data presented in Table 4 provide information on the top 10 most productive authors in mathematical proficiency research between 2020 and 2024. Melissa E. Libertus is the most prolific contributor, with 13 publications affiliated with the University of Pittsburgh, which also hosts Leanne Elliot, the second most productive author with 11 publications. Other highly productive scholars include Emily K. Farran, David J. Purpura, and David C. Geary, each of whom has made substantial contributions through affiliations with institutions recognised for their research in psychology and cognitive development.

The diversity of institutions—ranging from the University of Missouri and Purdue University in the United States to KU Leuven in Belgium and the University of Surrey in the United Kingdom—highlights the global and interdisciplinary nature of the field. Although the data do not specify author order, the presence of these names across multiple studies suggests consistent engagement and leadership in advancing mathematical proficiency research.

The author affiliations in Table 4, predominantly in the field of psychology, highlight that the topic of mathematical proficiency has been primarily researched from a psychological perspective, focusing on cognitive development (Bakker et al., 2022; Magalhães et al., 2020; Starling-Alves et al., 2024; Veraksa et al., 2020), learning motivation (Atit et al., 2020; El-Adl & Alkharusi, 2020; Liu, 2021; Tran & Nguyen, 2021; Zhang et al., 2023), and math anxiety (Demedts et

al., 2022, 2023; Gur et al., 2023; Szczygieł, 2020b, 2020a; Szczygieł et al., 2024; Szczygieł & Sarı, 2024). This shift from traditional pedagogical frameworks to a multidisciplinary approach underscores the integration of psychology as a primary framework. David C. Geary exemplifies this trend, leveraging his expertise in psychology and cognitive science to explore how individual differences, such as attention (Geary et al., 2021), memory (Geary et al., 2020), spatial ability (Geary et al., 2021), and sex differences (Geary et al., 2023), affect mathematical learning and achievement.

Table 4: Top 10 most productive authors

Author	Total Documents	Affiliation
Melissa E. Libertus	13	Department of Psychology and Learning Research and Development Center, University of Pittsburgh, United States
Leanne Elliot	11	Department of Psychology, University of Pittsburgh, United States
Emily K. Farran	10	School of Psychology, University of Surrey, United Kingdom
David J. Purpura	10	Department of Human Development and Family Studies, Purdue University, United States
David C. Geary	9	Department of Psychological Sciences, Interdisciplinary Neuroscience, University of Missouri, United States
Victoria Simms	8	School of Psychology, Ulster University, Ireland
Bert De Smedt	7	Parenting and Special Education Research Unit, KU Leuven, Belgium
Charles J. Fitzsimmons	7	Department of Psychological Sciences, Kent State University, United States
Katie A. Gilligan-Lee	7	School of Psychology, University College Dublin, Ireland
Kinga Morsanyi	7	Centre for Mathematical Cognition, University of Loughborough, United Kingdom

Figure 3 complements Table 4 by illustrating the annual publication patterns of these prolific authors. Melissa E. Libertus maintained consistent productivity, peaking in 2021 with a significant number of articles and citations. Authors like Emily K. Farran, David J. Purpura, and Leanne Elliot also displayed steady contributions but with lower output than Libertus. These consistent publication patterns reflect both the productivity and sustained relevance of these researchers in the mathematical proficiency field, contributing to the development of theory and practice.

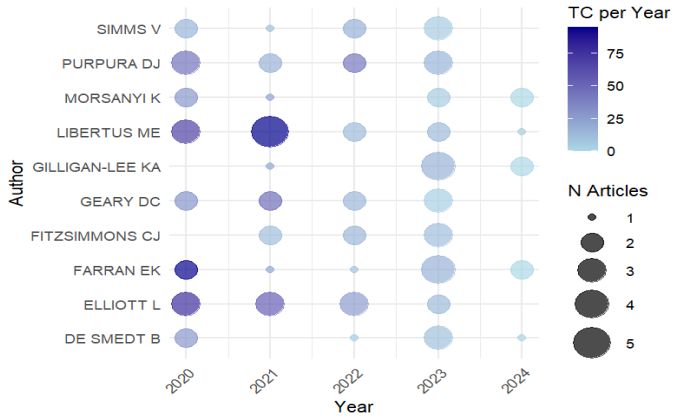


Figure 3: Authors' production over time

3.4 Most Cited Articles

Figure 4 illustrates the progression in the number of publications and total citations from 2020 to 2024. The number of documents published remained relatively stable, ranging from 208 to 263 articles per year, with a slight decline to 246 articles in 2024. However, a notable trend is the exponential increase in citations, rising from 158 citations in 2020 to 3,797 in 2024. This trend indicates that articles published in recent years have been increasingly cited, highlighting the growing influence and relevance of research on mathematical proficiency. Of the 929 documents with citations, the total number of citations reached 8,957, resulting in an h-index of 37. This h-index reflects a balance between highly cited publications and their overall impact, underscoring the significant contribution of several key articles to the academic literature on mathematical proficiency.

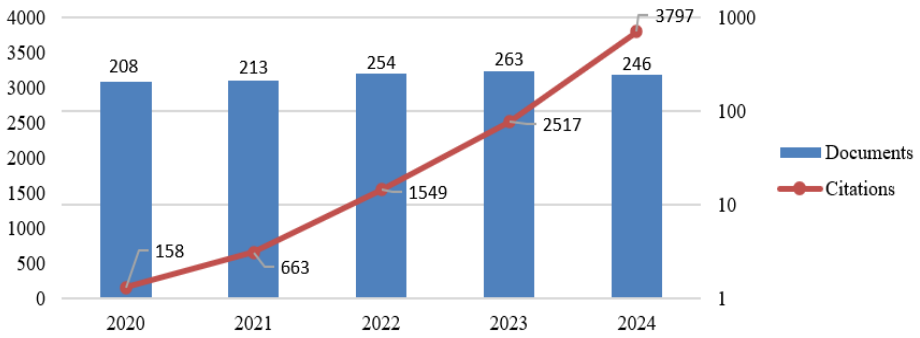


Table 5 presents the top 10 most-cited articles, each contributing between 0.73% and 2.82% of the total citations. These articles predominantly focus on interdisciplinary themes in mathematical proficiency research, particularly those linking psychological factors, home environments, and cognitive development with mathematics achievement. Notably, four of the top 10 articles were published in Psychological Bulletin, indicating a strong connection between mathematical proficiency research and the field of psychology. Other highly cited articles were published in psychology and education-focused journals such as Educational Researcher, Learning and Instruction, and the Journal of Educational Psychology. This highlights the growing shift towards a multidisciplinary approach in mathematical proficiency research.

Table 5: Top 10 most cited articles

Document Title	Sources	Total Citations	Citation Contribution
A Meta-Analysis of the Relation Between Math Anxiety and Math Achievement (Barroso et al., 2021)	Psychological Bulletin	253	2.82%
Relations Between Executive Functions and Academic Outcomes in Elementary School Children: A Meta-Analysis (Spiegel et al., 2021)	Psychological Bulletin	151	1.69%
The Home Math Environment and Math Achievement: A Meta-Analysis (Daucourt et al., 2021)	Psychological Bulletin	109	1.22%
Teachers' Bias Against the Mathematical Ability of Female, Black, and Hispanic Students (Copur-Gencturk et al., 2020)	Educational Researcher	103	1.15%
Opening Up the Black Box: Teacher Competence, Instructional Quality, and Students' Learning Progress (Blömeke et al., 2022)	Learning and Instruction	78	0.87%
The Effects of Two Digital Educational Games on Cognitive and Non-Cognitive Math and Reading Outcomes (Vanbecelaere et al., 2020)	Computers and Education	76	0.85%
The Role of Affective Teacher-Student Relationships in Adolescents' School Engagement and Achievement Trajectories (Engels et al., 2021)	Learning and Instruction	75	0.84%
Cognitive Appraisals, Achievement Emotions, and Students' Math Achievement: A Longitudinal Analysis (Forsblom et al., 2022)	Journal of Educational Psychology	73	0.82%
Reciprocal Effects of Reading and Mathematics? Beyond the Cross-Lagged Panel Model (Bailey et al., 2020)	Developmental Psychology	68	0.76%
Relationships Between Self-Regulated Learning Strategies, Learning Motivation and Mathematics Achievement (El-Adl & Alkharusi, 2020)	Cypriot Journal of Educational Sciences	65	0.73%

3.5 Most Productive Institutions

Figure 5 indicates that the University of Pittsburgh is the leading institution in mathematical proficiency research, with 28 published documents. This highlights the institution's dominant role in producing research that significantly contributes to the advancement of knowledge on this topic. Additionally, Loughborough University, Universitetet i Oslo, and KU Leuven have each published 23 documents, underscoring their positions as active research hubs in this field. Other key contributors include the University of California, Irvine, the University of Michigan, Ann Arbor, and Beijing Normal University. The

dominance of institutions from the United States and Europe reflects the continued influence of countries with strong research infrastructure, extensive access to funding, and robust academic collaboration on mathematical proficiency research.

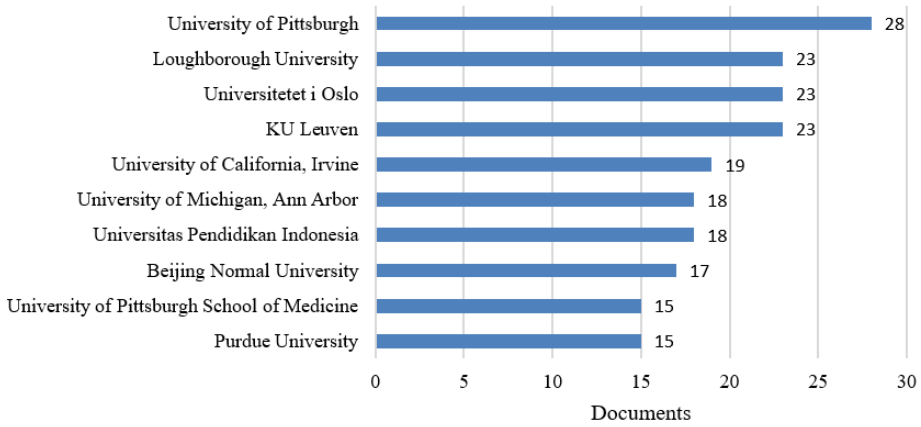


Figure 5: Top 10 most productive institutions

3.6. Most Contributing Countries

Based on Table 6, the United States leads in research contributions on mathematical proficiency, publishing 261 articles, with a significant proportion as single-country publications (SCP = 227). This reflects the country's dominance in access to research resources and institutional collaboration. In addition to the United States, countries such as Germany, the United Kingdom, and China also demonstrate high productivity with publications in reputable international journals. Notably, Norway and the Netherlands have high multiple country publications ratios (MCP_Ratio = 0.481 and 0.565, respectively), highlighting the importance of cross-national collaborations in enhancing the impact of their research. The Country Collaboration Map (Figure 6) corroborates this data, showing strong connections between countries in Europe, North America, and East Asia. The thick lines on the map indicate intense collaboration among countries with high research capacity, particularly in North America and Europe.

Table 6: Top 10 corresponding authors' countries

Country	Articles	SCP	MCP	Freq	MCP_Ratio
United States	261	227	34	0.220	0.130
Germany	68	43	25	0.057	0.368
United Kingdom	68	43	25	0.057	0.368
Spain	50	39	11	0.042	0.220
China	47	32	15	0.040	0.319
Indonesia	41	31	10	0.035	0.244
Italy	32	23	9	0.027	0.281
Turkey	32	30	2	0.027	0.063
Norway	27	14	13	0.023	0.481
Netherlands	23	10	13	0.019	0.565

Note. SCP: Single Country Publications; MCP: Multiple Country Publications; Freq: Articles/Publication; MCP_Ratio: Multiple Country Publications Ratio

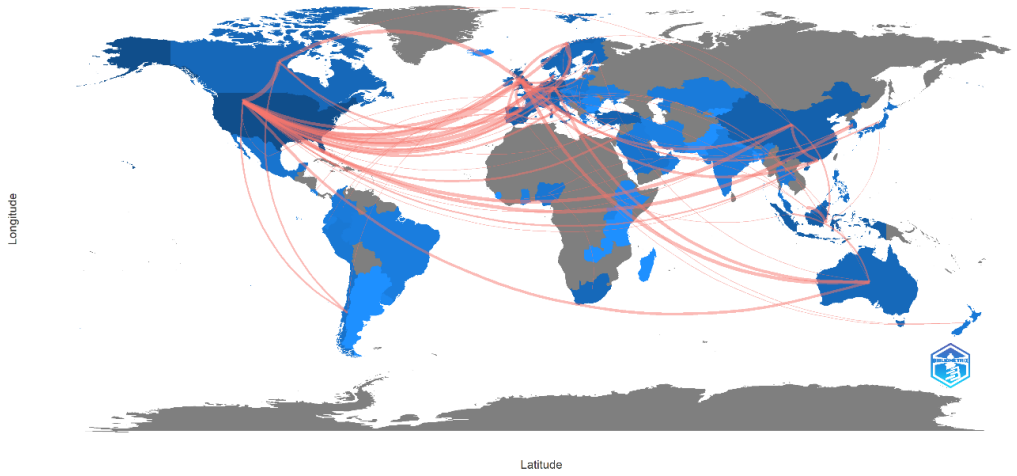


Figure 6: Country collaboration map

Table 7 reveals that the United States ranks highest in total citations with 2,903 citations and an average of 11.10 citations per article. Australia demonstrates exceptional performance, with an average of 16.60 citations per article, indicating the high quality of its research despite a smaller number of publications. The United Kingdom and Norway also exhibit strong citation performance, each with averages exceeding 10 citations per article.

Table 7: Top 10 most cited countries

Country	Total Citations	Average Article Citations
United States	2903	11.10
United Kingdom	695	10.20
Germany	459	6.80
China	288	6.10
Norway	288	10.70
Australia	283	16.60
Netherlands	278	12.10
Spain	255	5.10
Italy	240	7.50
Indonesia	215	5.20

Figure 7 depicts the relationships between article origins, publication sources, and keywords in mathematical proficiency research, highlighting country contributions and thematic focuses. The United States leads in publications, with strong links to journals like Frontiers in Psychology and Journal of Experimental Child Psychology. Spain, Germany, and the United Kingdom also contribute steadily but with lower intensity, while Indonesia's involvement is limited, primarily in Education Sciences and International Journal of Instruction. Frequently used keywords such as mathematics achievement, math anxiety, and academic achievement reflect a strong emphasis on cognitive and emotional factors influencing mathematical proficiency and its broader academic implications. The visualisation also reveals thematic segmentation, with Frontiers in Psychology focusing on math anxiety, while Education Sciences emphasises academic achievement. This underscores the multidisciplinary

nature of the field, largely shaped by U.S.-based researchers with extensive resources. Indonesia's minimal contribution highlights the need for stronger international collaborations to enhance its presence in high-impact publications.

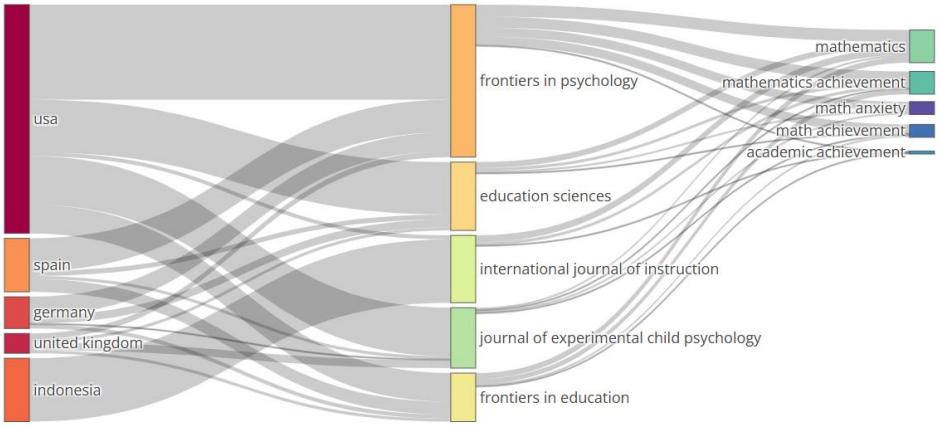


Figure 7: Three-field plot

The United States emerges as the most influential country in mathematical proficiency research, as evidenced by its dominance in leading journals such as Frontiers in Psychology and Journal of Experimental Child Psychology, which integrate psychological and educational approaches to the study of mathematical ability. Prolific authors like Melissa E. Libertus and David J. Purpura, affiliated with major institutions such as the University of Pittsburgh and Purdue University, further strengthen the U.S.'s position as a global research hub. Additionally, U.S.-based articles on mathematical proficiency receive a substantial number of citations, reflecting broad academic influence.

3.7 Keyword and Term Analysis

The visualisation in Figure 8 shows that the most dominant keywords in mathematical proficiency research are "mathematics achievement" and "mathematics", followed by others such as "academic achievement", "math anxiety", and "math achievement". This dominance highlights the central focus of research on the relationship between mathematical proficiency and academic performance, as well as the impact of affective factors such as math anxiety.

Figure 9 further supports this, with the TreeMap displaying keyword distribution frequencies. "Mathematics" (154 occurrences, 26%) and "mathematics achievement" (139 occurrences, 24%) are the two most frequently used keywords, while other terms such as "academic achievement" (51 occurrences, 9%) and "math anxiety" (39 occurrences, 7%) indicate that cognitive and emotional factors are also key areas of interest. The alignment between these visualisations provides a comprehensive overview of thematic trends in the literature, identifying dominant areas as well as opportunities for further research.

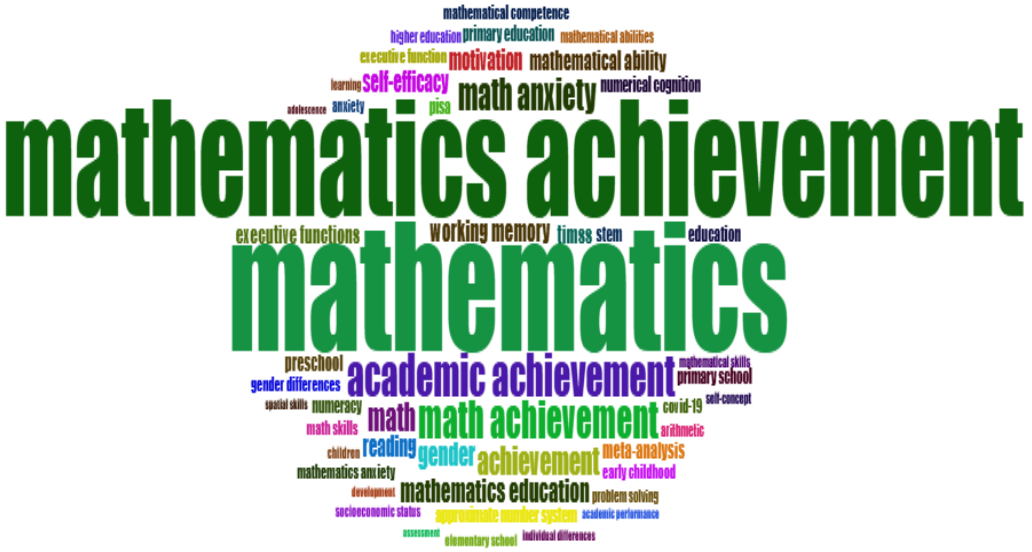


Figure 8: Word cloud of top 50 authors' keywords

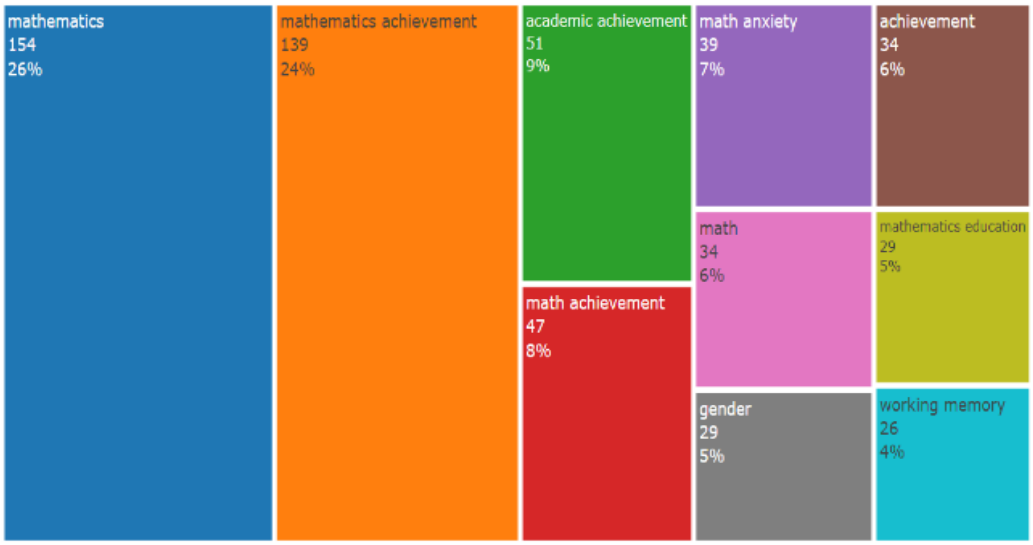


Figure 9: TreeMap of top 10 authors' keywords

The network visualisation in Figure 10 confirms that mathematical proficiency research is organised into 10 thematic clusters, with mathematics as the central node. Key subtopics such as academic achievement, math achievement, and mathematics education highlight the strong link between mathematical ability, academic performance, and affective factors like math anxiety. The interdisciplinary nature of the field is evident in clusters related to executive functions, working memory, and early childhood, indicating that research extends beyond cognition to social and educational dimensions, such as instructional quality and gender stereotypes. Emerging themes like growth mindset offer new directions for further study. Strengthening cross-disciplinary collaboration and international networks is crucial to expanding research impact and relevance.

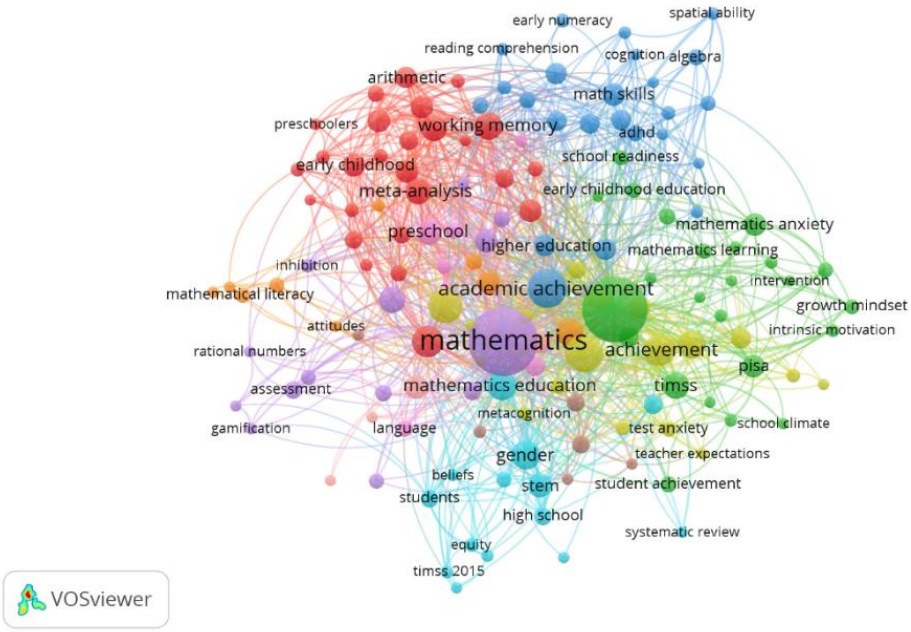


Figure 10: Author's keywords network visualisation

To clarify the thematic structure, these 10 clusters can be conceptually grouped into broader categories. Topics such as executive functions, working memory, and math achievement represent cognitive themes, while math anxiety, growth mindset, and gender stereotypes reflect emotional and motivational concerns. Meanwhile, clusters featuring instructional quality, STEM education, and home learning environment fall under instructional and environmental dimensions. This categorisation highlights the integrated nature of current research, which spans psychological, pedagogical, and sociocultural domains within mathematics education.

The overlay visualisation in Figure 11 reveals that themes in the literature have evolved over time, with blue nodes (e.g., executive functions and working memory) representing topics frequently discussed early in the analysis period (2021–2022). In contrast, yellow nodes (e.g., growth mindset, gender, and test anxiety) indicate emerging topics in recent research. Current research trends emphasise social-emotional factors, such as equity and gender stereotypes. The density visualisation in Figure 12 confirms that topics like mathematics, academic achievement, and math achievement have high density, signifying significant frequency and interconnectedness in the literature. Conversely, themes such as spatial ability and gender stereotypes have low density, suggesting limited attention or connections in research. These visualisations provide insights into dominant research trends, the development of new themes, and potential areas for further exploration within mathematical proficiency research.

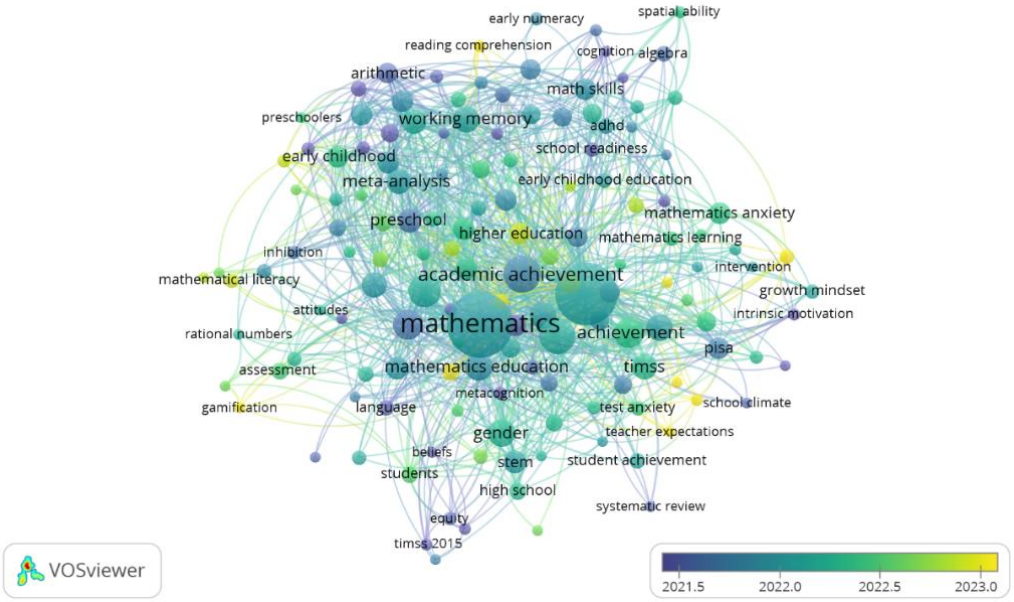


Figure 11: Authors' keywords overlay visualisation

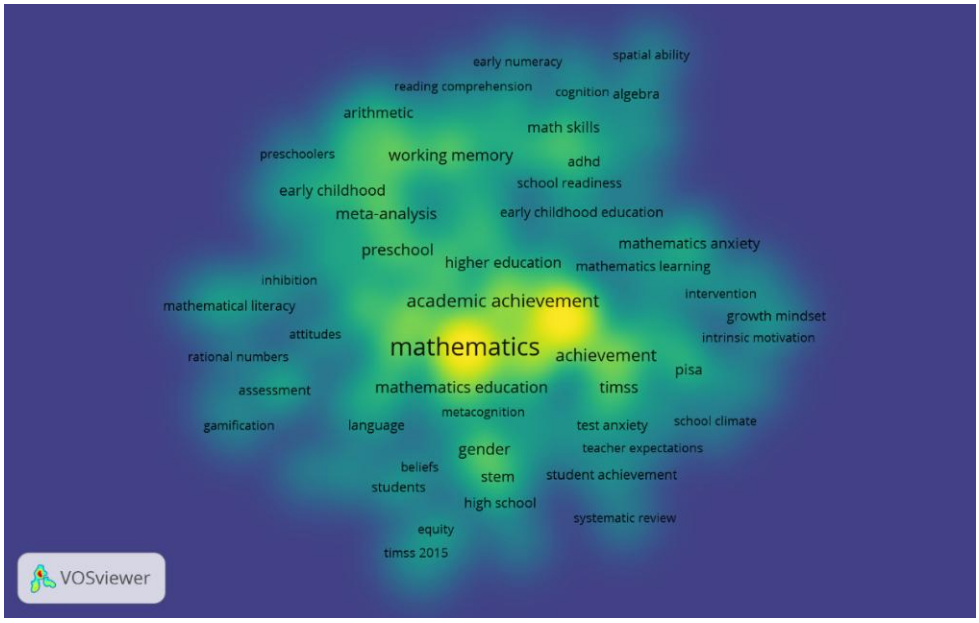


Figure 12: Authors' keywords density visualisation

4. Discussion

The bibliometric analysis conducted in this study provides critical insights into global trends in the field of mathematical proficiency. The findings reveal that global research in this topic is dominated by publications from developed countries such as the United States, Germany, and the United Kingdom. Key topics include mathematics (Berger et al., 2020; Fischer & Thierry, 2022; Henner et al., 2021; Niemivirta et al., 2024; Outhwaite et al., 2023), academic achievement (Bishara, 2023; Hwang & Fitzpatrick, 2021; Lynn et al., 2023), and mathematics anxiety (DiStefano et al., 2023; Quintero et al., 2022; Szczygieł & Sarı, 2024), highlighting the focus on the interconnection between mathematical proficiency,

academic performance, and cognitive and affective factors in education. These findings address the research question on the role of key actors shaping the literature, with the United States, through institutions such as the University of Pittsburgh, taking the lead in reputable international journals. This aligns with the overall dominance of U.S. publications and citations in mathematics education research (Gökçe & Güner, 2021). This leadership is underpinned by strong research networks, access to resources, and an interdisciplinary focus on theory and practice development. The U.S.'s prominence emphasises that robust research capacity, supported by influential institutions, is vital for building high-quality, impactful scientific literature on a global scale (MacLeod & Urquiola, 2021).

The study also highlights the central role of interdisciplinary approaches integrating education, psychology, and child development in global mathematical proficiency research. This is evidenced by numerous articles published in journals such as Frontiers in Psychology and the Journal of Experimental Child Psychology. Keywords such as executive functions (Bernal-Ruiz et al., 2024; Magalhães et al., 2020; Marks et al., 2024) and working memory (Hamidi et al., 2024; McGonnell et al., 2024; Miller-Cotto et al., 2024) are frequently associated with mathematical ability.

These findings are consistent with previous research emphasising the significance of cognitive factors in mathematics achievement (Abín et al., 2020; Bernal-Ruiz et al., 2024; Ellis et al., 2021). Meanwhile, socio-emotional themes such as gender stereotypes (Justicia-Galiano et al., 2023; Lee et al., 2021; McCoy et al., 2022; Mejía-Rodríguez et al., 2021) and growth mindset (Chen et al., 2024; Ershova et al., 2021; Kaya & Karakoc, 2022; Lee et al., 2021; Saefudin et al., 2023) have emerged as key areas of recent research, reflecting efforts to understand non-cognitive influences on mathematics learning.

The keyword co-occurrence and thematic cluster analyses further demonstrate the complex, multidimensional nature of mathematical proficiency. Visualisation of these clusters reveals how themes such as academic achievement, math anxiety, and instructional quality are interconnected, indicating a systemic view of mathematics learning. Emerging topics, such as growth mindset, reflect the field’s responsiveness to broader psychological and educational discourse. The evolution of research themes, as seen in the overlay visualisations, also suggests a shift from purely cognitive models towards more holistic frameworks that incorporate motivational, emotional, and contextual variables. This shift opens new directions for research that are more inclusive of diverse student experiences and educational environments.

The shift in thematic focus from purely cognitive constructs toward socio-emotional and motivational variables also reflects an evolution in instructional methods. Traditional approaches to teaching mathematical proficiency, such as rote memorisation and procedural drills, are increasingly being supplemented or replaced by student-centred strategies including flipped classrooms, gamification, and socio-emotional learning frameworks. This transition aligns

with the broader educational shift towards more holistic, inclusive, and motivational learning environments.

These findings are broadly consistent with previous bibliometric studies on mathematics education that emphasised the dominance of cognitive factors such as academic achievement, working memory, and executive functions. However, unlike earlier reviews that primarily focused on specific themes—such as augmented reality, flipped classrooms, or computational thinking—this study highlights a more holistic trend. Socio-emotional factors such as growth mindset, mathematics anxiety, and gender stereotypes emerged as integral components of the research landscape, indicating a shift in scholarly interest towards non-cognitive influences. Additionally, while some bibliometric studies concentrated on pedagogical or technological innovations, the present study integrates psychological, instructional, and contextual dimensions under the broader umbrella of mathematical proficiency, offering a more interdisciplinary perspective.

Analysis of institutional and country-level productivity highlights the dominance of well-funded research ecosystems in advancing the field. Institutions in the United States and Europe contribute disproportionately to publication and citation counts, largely due to strong research infrastructure, interdisciplinary collaboration, and access to global networks. Countries with higher levels of international collaboration, as reflected in higher MCP ratios, tend to produce more visible and impactful research. These findings reaffirm that fostering international collaboration is not only beneficial for citation metrics but also essential for advancing collective understanding of mathematical proficiency across cultural and educational contexts.

Notably, countries such as the United States, the United Kingdom and Germany not only demonstrated high publication counts but also formed central nodes in international collaboration networks. These countries function as global research hubs, facilitating cross-border knowledge exchange and multi-institutional authorship. Such collaborations are often associated with higher citation impact and greater research visibility, reinforcing the relationship between international partnerships and the overall quality of research outputs.

These findings carry important implications for shaping international education policies aimed at enhancing mathematical proficiency. Global research trends have increasingly emphasised the need to consider not only cognitive aspects but also socio-emotional factors such as executive functions, mathematics anxiety, and growth mindset. Integrating these factors into education systems can help design more holistic policies that are responsive to diverse student needs across contexts.

Executive functions—encompassing working memory, attention regulation, and self-control—have been consistently identified as key predictors of students' mathematical performance. Studies have found strong positive correlations between executive function and mathematics achievement across educational

levels (Geary et al., 2021; Zhong et al., 2022). Furthermore, students with strong executive functioning tend to perform better on mathematical tasks, highlighting the importance of embedding cognitive skills training in curriculum design (Han et al., 2024). Similarly, mathematics anxiety has been shown to significantly impede performance, particularly among students with otherwise adequate skills (Maldonado Moscoso et al., 2020; Piccirilli et al., 2023). Addressing this challenge through inclusive teaching approaches and emotional support strategies is essential (Niu et al., 2022; Živković et al., 2023).

In addition, promoting a growth mindset plays a vital role in helping students persist through academic challenges. Students who adopt a growth mindset are more likely to engage deeply with learning processes and display resilience in the face of difficulty (Abín et al., 2020; Kismiantini et al., 2021). Educational policies that prioritise fostering such mindsets have demonstrated positive effects on student motivation and achievement, particularly when paired with interventions designed to mitigate the effects of anxiety and build confidence (Juniati & Budayasa, 2022). Therefore, the integration of cognitive and socio-emotional components into international education policies can create more supportive and adaptive learning environments, ultimately enhancing students' mathematical proficiency (Cui et al., 2022; Zhang et al., 2023).

Overall, this study offers a comprehensive view of the global landscape of mathematical proficiency research. It highlights the importance of interdisciplinary approaches, identifies dominant research themes, and suggests directions for future inquiry. Researchers are encouraged to build on this foundation by further investigating underexplored socio-emotional factors, enhancing cross-country collaboration, and continuing to refine theoretical frameworks that capture the multifaceted nature of mathematical proficiency. These efforts will help ensure that the field remains responsive to both academic and practical demands in mathematics education worldwide.

Future research may consider investigating underrepresented themes that did not emerge prominently in the current bibliometric mapping. These include the role of pedagogical content knowledge (PCK) in shaping instructional quality, the influence of local and national cultural contexts on mathematics education practices, the potential of internet-based communication and social networks in enhancing mathematical proficiency, and comparative studies between traditional and modern instructional approaches. Exploring these areas could provide a richer understanding of how contextual, pedagogical, and technological factors interact with cognitive and socio-emotional dimensions to influence mathematical learning outcomes across diverse educational settings.

5. Conclusion

This bibliometric analysis provides a comprehensive overview of global research trends in mathematical proficiency from 2020 to 2024. The findings reveal that research in this field is primarily concentrated in countries with strong academic infrastructures and high levels of international collaboration, particularly the United States and several European nations. Key themes emerging from the

literature include mathematics achievement, executive functions, math anxiety, and growth mindset, which reflect an increasing shift towards interdisciplinary and socio-emotional perspectives in understanding mathematical proficiency. The co-occurrence of keywords and clustering of themes indicate that cognitive and affective factors are often studied in tandem, highlighting the importance of holistic educational models. This study also observes that high-impact publications tend to integrate concepts from psychology, education, and child development, suggesting the need for further cross-disciplinary collaborations. This study has several limitations. It focuses solely on Scopus-indexed articles and English-language publications, which may exclude relevant research from other databases or in other languages.

Additionally, keyword-based search strategies may miss studies using alternative terminology. Future research could address these gaps by incorporating multiple databases, diversifying search approaches, and examining underexplored themes such as pedagogical content knowledge (PCK), cultural influences, and digital learning environments. However, this study provides a roadmap for future inquiry. Researchers are encouraged to further investigate the roles of executive function, emotional regulation, and motivational beliefs in mathematics learning. Education policymakers should consider embedding socio-emotional learning in curricula to promote student engagement. By synthesising current evidence and identifying emerging directions, this study enhances our understanding of how mathematical proficiency can be developed through comprehensive, interdisciplinary approaches.

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