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Development Trends of Mathematical Mindset Research: A Bibliometric Analysis

Sugama Maskar[1,2], **Tatang Herman**[2,*] **& Nicky Dwi Puspaningtyas**[1,3]

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Abstract: Objective: This study aims to assess the development trends of mathematical mindset research. **Methodology:** This investigation employs bibliometric analysis using three critical terms related to mathematical mindset from the Scopus database. The dataset comprises 51 journal articles, proceedings, and reviews published between 2016 and 2023. **Results:** The results indicate an increasing number of published documents on mathematical mindset research but a limited development of research themes. Additionally, there is a decline in article citations. Most published articles are authored by individuals affiliated with institutions in the US, and most research collaborations also involve US-based entities. **Conclusion:** Nevertheless, there are emerging collaborations globally involving multiple countries across different continents, offering promise and a framework for future research in the field of mathematical mindset.

Keywords: Bibliometric Analysis, Mathematical Mindset, Mathematics Education, Mathematical Growth Mindset, Growth Mindset, Students Learning

اتجاهات تطور البحث في العقلية الرياضية: تحليل ببليومتري

سوغامَا ماسكار[1،2]**، وتاتانغ هيرمان**[2،*]**، ونيكي دوي بوسبانينغتياس**[1،3]

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ملخص: تهدف هذه الدراسة الى تقييم اتجاهات تطوير أبحاث العقلية الرياضية. **المنهجية:** يستخدم هذا البحث التحليل الببليومتري باستخدام ثلاث مصطلحات مهمة تتعلق بالعقلية الرياضية من قاعدة بيانات سكوبس. تتكون مجموعة البيانات من 51 مقالة صحفية وإجراءات ومراجعات نشرت بي عامي 2016 و 2023. **النتائج:** تشير النتائج الى زيادة عدد الوثائق المنشورة حول أبحاث العقلية الرياضية ولكن الى تطور محدود في موضوعات البحث بالإضافة الى ذلك هاك انخفاض في الاستشهادات بالمقالات. معظم المقالات المنشورة من تأليف أفراد تابعين لمؤسسات في الولايات المتحدة، ومعظم المقالات البحثية تشمل أيضاً كيانات مقرها الولايات المتحدة. **الخلاصة:** ومع ذلك هناك تعاونيات ناشئة عالمياً تشمل دولاً متعددة عبر قارات مختلفة، مما يوفر وعداً واطارا للبحوث المستقبلية في مجال العقلية الرياضية.

الكلمات المفتاحية: التحليل الببليومتري، العقلية الرياضية، تعليم الرياضيات، عقلية النمو الرياضي، عقلية النمو، تعلم الطلاب

Introduction

Numerous studies have demonstrated the positive impact of a mathematical mindset on students' math performance (Boaler *et al*., 2018, 2021). A growth mindset fosters resilience in learning (Altakhyneh & Aburiash, 2018; Lee *et al*., 2019; Mooghrabi, 2019), increases interest in STEM careers (Degol *et al*., 2018), and is influenced by both teacher and student mindsets (Maskar & Herman, 2024). However, the effectiveness of this approach depends on various factors, including intrinsic motivation, self-efficacy, and attitudes toward failure (Dong *et al*., 2023).

1 Universitas Teknokrat Indonesia, ZA. Pagar Alam Street, Bandar Lampung, Lampung, Indonesia, sugama_maskar@teknokrat.ac.id;
2 Universitas Pendidikan Indonesia, Setiabudhi Street, Bandung, West Java, Indonesia
* Corresponding author email: tatangherman@upi.edu
3 E-mail: nicky@teknokrat.ac.id

1 جامعة تكنوكرات إندونيسيا، ZA. شارع باجار علم، بندر لامبونج، لامبونج، إندونيسيا،
sugama_maskar@teknokrat.ac.id
2 جامعة بنديديكان إندونيسيا، شارع سيتيابودي، باندونج، جاوة الغربية، إندونيسيا
* الباحث المراسل: tatangerman@upi.edu
3 البريد الالكتروني: nicky@teknokrat.ac.id

Implementing a mathematical mindset requires addressing confidence issues, particularly among students from lower socioeconomic backgrounds (Bostwick *et al*., 2017). This shift can enhance perseverance in learning mathematics, which is often linked to grit (Duckworth, 2016; Kaya & Karakoc, 2022). Nevertheless, cultural differences shape how mathematical struggles are perceived (Boaler, 2022; Sun *et al*., 2021), indicating that mindset interventions may require contextual adaptation.

Recent studies have also explored the connection between mathematical mindset and neuroscience. Beliefs about mathematics correlate with brain function (Boaler *et al*., 2023), intrinsic motivation (Ng, 2018), and teacher feedback processing (Puusepp *et al*., 2021). These findings suggest that mindset development extends beyond psychology into biology and education neuroscience (Gutshall, 2020).

Despite the growing body of research, a systematic mapping of global mathematical mindset studies remains limited. The only bibliometric study found on this topic is by Xu *et al*. (2022), which focuses on latent topics and research trends in mathematics education. Given the increasing need for international collaboration in research (Pohl, 2020; Waham *et al*., 2023), it is essential to analyze how mathematical mindset research has evolved globally.

While previous studies, such as those by Xu *et al*. (2022), have examined latent topics within the research on mathematical mindset. However, this study offers a fresh perspective by incorporating the latest publication data from 2023. Doing so captures recent trends, themes, and emerging collaboration networks in mathematical mindset research. As a result, this study provides new insights into the evolution of mathematical mindset research. Additionally, it emphasizes international research collaborations, shedding light on how mathematical mindset research is developing globally. Consequently, the research questions addressed in this study include:

1. To what extent has mathematical mindset research developed?
2. To what extent has the international mathematical mindset developed globally by research collaboration been carried out?

Mathematical Mindset

A mathematical mindset reflects an active approach where students see their role in understanding and interpreting mathematics (Boaler, 2019). A mathematical mindset can help teachers and students understand mathematics at any level (Boaler, 2022). This means that students' mathematical knowledge and imagination can be explained directly and moderately through students' mathematical mindset (Irakleous *et al*., 2022). Mathematical problems formulated according to the mathematical mindset theory can increase student motivation by involving the brain-stimulation reward pathway (Daly, *et al*., 2019).

The concept of mathematical mindset is deeply rooted in Carol Dweck's (Dweck, 2006) growth mindset theory, which states that individuals who believe that intelligence can be developed through effort and persistence are more likely to be able to cope with challenges and persist in learning. In mathematics education, cultivating a growth mindset has been shown to improve students' resilience, problem-solving skills, and overall performance. Individuals with a growth mindset tend to show consistently improving performance and tend to view mistakes as positive (Boaler, 2022; Moser *et al*., 2011). Individuals with a growth mindset also tend to use a more positive approach to learning and

have a greater potential for success (Blackwell *et al*., 2007; Boaler, 2022). In contrast, individuals with a fixed mindset tend to give up easily and have constant performance (Blackwell *et al*., 2007; Boaler, 2022; Duckworth, 2016).

Applying a mathematical mindset in mathematics teaching can improve students' mathematics achievement and change students' beliefs in mathematical identities (Boaler *et al*., 2022). Mathematical identity requires a mathematical mindset mediator in developing STEM career interests Cribbs *et al*., 2021). In addition, a study by Asante Britwum, Ntow, and Smith (2024) related to mathematical mindset shows that students develop a growing mindset when taught using student-centered methods and, conversely, develop a fixed mindset when teacher-centered learning. The indirect effect of a growth mathematical mindset on mathematics achievement is positive and significant, mediated by academic grit (Kaya & Karakoc, 2022). Several studies show that students with a strong mathematical mindset are more innovative in solving problems, and their mathematical knowledge is more rooted and meaningful (Boaler *et al*., 2018; Masitoh & Fitriyani, 2018). Through a growth mathematical mindset, students can grow confidence and self-confidence in mathematical knowledge Aswin & Herman, 2022; Jaffe, 2020).

From a broader perspective in educational psychology, mathematical mindsets align with Vygotsky's (Vygotsky, 1980) Zone of Proximal Development (ZPD). This concept emphasizes the importance of scaffolding and guided learning in promoting intellectual growth. Additionally, mathematical mindsets are connected to Bandura's (Bandura, 1982) Self-Efficacy Theory. Students who possess strong mathematical mindsets generally develop higher self-confidence in their ability to solve complex problems.

In Science, Technology, Engineering, and Mathematics (STEM) education, mathematical mindsets play a critical role in preparing students to solve problems and innovate, enabling them to use mathematics in concrete ways. Studies have shown that students with growth mindsets are more likely to persist in STEM fields, overcoming challenges in mathematics and science courses (Boaler, 2022; Boaler *et al*., 2018). Therefore, understanding the development of mathematical mindset research is essential to shaping instructional strategies that foster student engagement and success in STEM disciplines.

The Impact of Mathematical Mindset on Student Performance

Recent studies have provided empirical evidence on how cultivating a mathematical mindset positively affects student performance (Anderson *et al*., 2018; Boaler, 2019, 2022; Boaler *et al*., 2021; Lee *et al*., 2019). Several studies have shown that students with a growth mindset in mathematics learning tend to find innovative ways to solve problems. If they fail, they will add additional questions and look at books or online sources for ideas so that students' mathematical knowledge can be more easily rooted because students consider their mathematics learning more meaningful (Boaler, 2022; Henningsen & Kay Stein, 1997; Masitoh & Fitriyani, 2018).

In other studies, it was found that mathematical mindsets are related to motivational factors, self-confidence, perceptions, interests and knowledge of students, and teacher encouragement (Aguilar, 2021; Boyer & Mailloux, 2015; Hannula *et al*., 2004; Heinze *et al*., 2005; Tambunan, 2018). Research on the effectiveness of this mindset instilling the idea in students that intelligence is malleable and that struggle is an important part of learning has been conducted at various ages

and different subjects and shows its importance (Blackwell *et al*., 2007; Boaler, 2022; Dweck, 2006).

The Importance of Bibliometric Analysis in Mathematical Mindset Research

Bibliometric analysis provides a systematic approach to charting research development in a particular field, identifying influential works, collaborative networks, and emerging themes (Ellegaard & Wallin, 2015; Merigó & Yang, 2017; Passas, 2024). In addition, bibliometric analysis is also used to explore and reveal the nuances of evolution in a particular field (Donthu *et al*., 2021); in this context, it highlights the study of mathematical mindset. In mathematical mindset research, this method objectively assesses how the field has developed, which theories have gained prominence, which areas require further exploration, and which collaborative networks have been formed and still need further support. Given the increasing attention to developing a growth mindset in mathematics education, understanding the research trajectory in this domain is essential to shaping future studies and informing educational policy.

In addition to tracking the intellectual development of mathematical mindset research, bibliometric analysis also facilitates identifying key research collaborations and geographic trends. Scientific research is becoming increasingly collaborative, and studies show a high correlation between collaboration and research productivity (Subramanyam, 1983). Understanding which institutions and countries contribute most to the field of mathematical mindset provides insight into how knowledge is shared globally and where potential research collaborations can be strengthened. Bibliometric analysis helps identify collaborative networks between authors, universities, and countries involved in joint research projects and publications; it also highlights their structure and dynamics (Erdyneeva *et al*., 2024; Hassan & Duarte, 2024). Furthermore, this method helps highlight areas that are underrepresented in the literature, ensuring that future research addresses a variety of perspectives and contexts. These findings provide valuable insights into current trends and important areas for future research, and by leveraging bibliometric insights, researchers and policymakers can make informed decisions about funding allocation, curriculum design, and intervention strategies to promote mathematical mindset development more effectively (Erdyneeva *et al*., 2024).

Methods

This study uses the bibliometric analysis method. Bibliometric analysis is a method that can be used to analyze large amounts of scientific data to highlight areas that are developing in a particular study (Donthu *et al*., 2021). Bibliometrics is increasingly used as a scientific communication tool to study various aspects of science (Ellegaard, 2018; Ellegaard and Wallin, 2015). Technically, bibliometric analysis and scientific visualization are conducted quantitatively (Derviş, 2020). This study also uses qualitative studies to elaborate data from bibliometric analysis. The data used in this study comes from the Scopus database. In several aspects, the Scopus database is superior to others. The Scopus database includes article data from 1966 (Burnham, 2006; Chadegani *et al*., 2013) and has the availability of individual profiles for all authors, institutes, and serial sources, and also has better impact indicator metrics than Web of Science (Pranckutė, 2021).

The data used in this study comes from the Scopus database. Scopus was chosen as the primary database due to its comprehensive coverage of peer-reviewed journals and its robust indexing of multidisciplinary research,

including mathematics education (Burnham, 2006; Chadegani *et al*., 2013). Compared to other databases, Scopus provides robust citation metrics, author affiliations, and collaboration networks, making it well-suited for bibliometric analysis. Scopus database also has the availability of individual profiles for all authors, institutes, and serial sources and also has better impact indicator metrics than the others (Pranckutė, 2021). Although Scopus is a well-established database, it may not comprehensively cover all relevant studies in education and psychology, particularly those related to mathematical mindset. Some articles may be indexed exclusively in Web of Science, ERIC, or Google Scholar databases. Therefore, future research should consider combining multiple databases to ensure broader coverage of relevant literature.

Data Collection

Data was taken from the Scopus database via www.scopus.com for 2016 – 2023. Figure 1 depicts the data collection process from beginning to end. Keywords used in the search include (1) "mathematic AND growth AND mindset," (2) “growth mindset” AND mathematics AND students,” and (3) “growth mindset” AND mathematics AND education.” The selection of keywords was based on an initial review of relevant literature and common terminology used in mathematical mindset research. The combination of the terms “growth mindset,” “mathematics,” “education,” and “students” ensured that studies that fall into aspects of mathematical mindset, such as psychological and educational, were included.

Alternative search terms, such as “mindset theories in mathematics” and “student beliefs in mathematics learning,” were contemplated but ultimately not utilized due to their broad scope, which could encompass studies outside the specific realm of mathematical mindset research. By narrowing the search to keywords pertinent to mathematical mindset terminology, we ensured that the results would be directly relevant to the impact of mindset on student learning outcomes while excluding studies focused on teacher perspectives or general psychological theories that do not specifically pertain to mathematics education.

To validate the selection of keywords, an initial search was performed to evaluate the relevance of the retrieved articles. The final combination of keywords was carefully selected to enhance the breadth of the search results while minimizing irrelevant findings, thereby ensuring that the search dataset accurately reflects the theme of mathematical mindset research.

There was a total of 188 articles found using these three keywords, consisting of 42 articles found using keywords (1), 102 articles found using keywords (2), and 44 articles found using keywords (3). Filtering articles was carried out to sort out articles that were relevant to the mathematical mindset, resulting in 18 articles that were relevant to keywords (1), 36 articles that were relevant to keywords (2), and 17 articles that were relevant to keywords (3).

From the initial 188 retrieved articles, a screening process was conducted to refine the dataset to a final 51 articles. Several exclusion criteria were applied to ensure that only the most relevant and high-quality studies were included in the analysis. Irrelevant Scope: Studies that mentioned ‘growth mindset’ or ‘mathematical mindset’ but focused primarily on general psychology, neuroscience, or non-mathematical educational contexts were excluded. In addition, non-empirical studies, such as opinion articles, editorial notes, and non-research discussions that did not provide empirical findings or theoretical advances in mathematical mindset, were excluded. Then, all relevant articles were collected to obtain 71 articles. Due to their occurrence in multiple

keywords, duplicate articles were also excluded, so 51 articles were obtained for further analysis using bibliometric analysis.

The selection process followed a structured approach, as illustrated in Figure 1, ensuring that the final dataset included studies that directly contributed to understanding mathematical mindset in educational contexts.

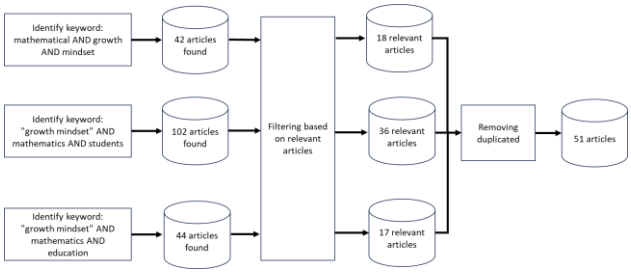

Figure (1): Data Collection Flow.
Source: prepared by the author.

Data Analysis

A search for Scopus articles related to mathematical mindset resulted in 51 articles analyzed using bibliometric analysis with R-Studio software. The software is open-source, written in the R package, and has 16,000 software packages (Derviş, 2020). In addition, R-Studio is powerful software for performing bibliometric analysis (Bhat *et al*., 2023). Bibliometric analysis was carried out to answer two research questions in this study. The first research question is about the extent to which mathematical mindset research has been developed (RQ1), and the second is about how mathematical mindset research developed globally by international collaboration has been carried out (RQ1). To answer RQ1, bibliometric analysis related to trends in mathematical mindset articles published in 2016 – 2023 was carried out. These trends are analyzed based on several indicators, namely keywords, distribution of articles in sources, distribution of publications based on country and affiliation, and analysis of themes used by authors. To answer RQ2, an analysis of articles written by several authors from different countries and institutions was carried out. Apart from that, an analysis was also carried out on the growth of articles written by several authors across countries and an analysis of the collaboration clusters between countries and institutions.

This study also examines qualitative factors that may affect regional collaboration patterns to enhance the quantitative analysis of co-authorship networks. Through a contextual literature review and analysis of institutional reports, the study identifies structural and policy barriers, including funding gaps, research infrastructure deficiencies, and language accessibility issues. By incorporating these qualitative insights, the goal is to provide a more comprehensive understanding of the factors influencing international collaboration in mathematical mindset research.

Results

Overview and Sources

The articles analyzed were 51 articles from 2016 to 2023. These articles comprised 42 journal articles, five conference proceedings articles, and four review articles. Figure 2 shows that the average growth of articles per year is 25.85% from 2016 to 2023, meaning that the growth of articles with the mathematical mindset theme is quite large. Apart from that, the growth of articles was also represented by 185 authors in that period. The number of plus keywords (ID) is 131 words, and author keywords (DE) is 164. Furthermore, the number of single authors is only three documents, and the number of co-authors per document is 4.24, and 9,804% are international co-authors.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2016:2023
Sources (Journals, Books, etc)	41
Documents	51
Annual Growth Rate %	25.85
Document Average Age	2.24
Average citations per doc	22.02
References	1
DOCUMENT CONTENTS	
Keywords Plus (ID)	131
Author's Keywords (DE)	164
AUTHORS	
Authors	185
Authors of single-authored docs	3
AUTHORS COLLABORATION	
Single-authored docs	3
Co-Authors per Doc	4.24
International co-authorships %	9.804
DOCUMENT TYPES	
article	42
conference paper	5
review	4

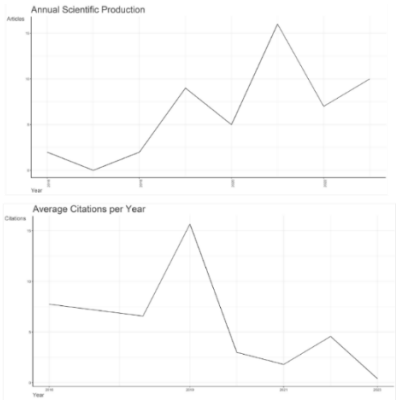

Figure (2): Summary Statistics and Trends in The Article and Citations.
Source: prepared by the author, using RStudio Software.

Figure 2 illustrates the publication trend in mathematical mindset research from 2016 to 2023, showing a steady increase in research output, with a significant increase in 2019. This growth reflects the growing academic interest in fostering a growth mindset in mathematics education, influenced by both theoretical advances and practical interventions. However, despite the increase in publications, citation rates peaked between 2016 and 2019 before declining. This suggests that while foundational studies continue to be cited, newer works face greater competition for citations as the field matures.

Several factors may contribute to this trend. First, the initial surge in citations was likely driven by foundational studies that established the theoretical foundation for mathematical mindset research. As these works became established, newer studies had less opportunity to attract similar levels of citations. Second, the research focus has diversified into related areas such as self-efficacy, math anxiety, and productive struggle, leading to a spread of citations across themes. The emergence of open-access platforms and alternative publication formats has also influenced how academic work is accessed and cited, potentially changing citation patterns. These trends suggest that while the mathematical mindset remains a growing area of research, its integration with broader educational psychology and Science, Technology, Engineering, and Mathematics (STEM) education topics is shaping its future trajectory.

Another interesting thing to analyze is sources. One indicator that can be used as a reference is the h-index value. The H-Index compares the number of articles produced and the number of citations for each published article (Hirsch and Buela-Casal, 2014). Figure 3 shows the top 10 sources based on the h-index level. The top source is occupied by three sources with an h-index value of 2, among them Contemporary Educational Psychology, Frontiers in Education, and Frontiers in Psychology. Seven other sources have an h-index value of 1.

Element	h_index
CONTEMPORARY EDUCATIONAL PSYCHOLOGY	2
FRONTIERS IN EDUCATION	2
FRONTIERS IN PSYCHOLOGY	2
9TH RESEARCH IN ENGINEERING EDUCATION SYMPOSIUM AND 32ND AUSTRALASIAN ASSOCIATION FOR ENGINEERING EDUCATION CONFERENCE, REES AAEE 2021: ENGINEERING EDUCATION RESEARCH CAPABILITY DEVELOPMENT	1
AUSTRALIAN JOURNAL OF TEACHER EDUCATION	1
CBE LIFE SCIENCES EDUCATION	1
CONFERENCE ON HUMAN FACTORS IN COMPUTING SYSTEMS - PROCEEDINGS	1
CRITICAL STUDIES IN TEACHING AND LEARNING	1
CURRENT OPINION IN BEHAVIORAL SCIENCES	1
EDUCATION SCIENCES	1

Figure (3): Publications Sources by H-Index.
Source: prepared by the author, using RStudio Software.

Figure 4 depicts the sources of relevant article production from 2016 to 2023. Frontiers in Education consistently published articles related to mathematical mindset in 2018-2023. Teaching and Teacher Education started publishing articles on the theme of mathematical mindset in 2020 – 2023 and PRIMUS (Problems, Resources, and Issues in Mathematics Undergraduate Studies) in 2021 – 2023.

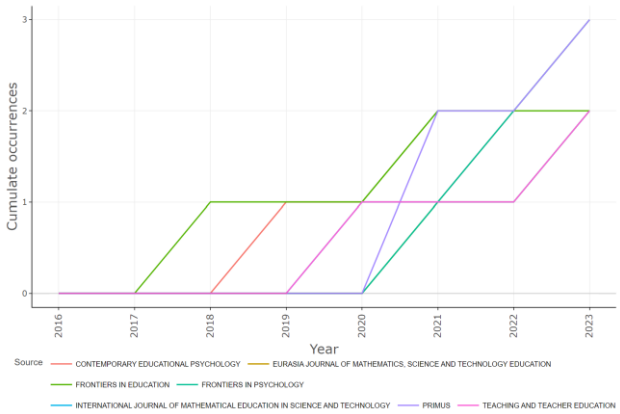

Figure (4): Sources' Production over Time.
Source: prepared by the author, using RStudio Software.

Countries, Affiliations, And Authors

Figure 5 is a three-field plot based on the Sankey diagram Lupton & Allwood, 2017; Riehmann *et al*., 2005), which depicts the relationship between country and keyword authors (DE) and authors. The diagram provides information on the top 15 countries where articles were published, including the US, Ireland, Norway, Finland, Australia, Canada, India, Sweden, Netherlands, Indonesia, Germany, China, Hong Kong, South Africa, and the United Kingdom. These countries contribute to the top 14 keywords, including; "Growth Mindset," "Implicit Theories," "Mindset," "Mathematics," "Beliefs," "Motivation," "Fixed Mindset," "Mathematical Mindset," "Mathematics Education," "Mathematics Achievement," "Anxiety," "Intervention," "Assessment," and "Calculus". Furthermore, the diagram also shows authors based on the number of published articles and the ranking of the five most prominent authors, including Boaler, Buentempo, Downtown, Bobis, and Collie.

The diagram shows that the United States leads in research on mathematical mindsets, contributing significantly more than other countries like the United Kingdom, Australia, Canada, and Germany. This dominance indicates that researchers in the U.S. are at the forefront of studies on growth mindsets in mathematics education. In contrast, countries such as Indonesia, South Africa, and Hong Kong have smaller contributions, reflecting their emerging but limited participation in this field.

The keyword authors (DE) section shows that "growth mindset" is the most frequently studied concept, followed by related terms such as "mindset," "implicit theories," "beliefs," and "motivation." More specific terms such as "mathematics education," "mathematics mindset," and "anxiety" indicate an increasing focus on how mindsets influence student performance and emotional responses to learning. Author keywords (AU) link these research themes to specific authors, revealing key contributors such as Boaler J, Buontempo J, and Downton A. Their work likely played a significant role in shaping discussions about mindset theory in mathematics education. Overall, this visualization demonstrates the interconnected nature of international research collaborations while highlighting regional disparities in contributions to the field.

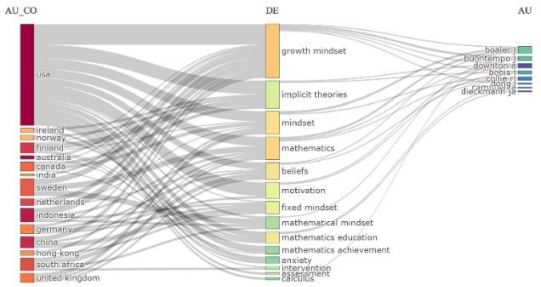

Figure (5): Three-Field Plot Relationship.
Source: prepared by the author, using RStudio Software.

Figure 6 shows the distribution of collaborative article publications between countries (MCP) or only within one country (SCP). The United States is the most prolific contributor, with significantly more SCPs than any other country. This indicates that most research is conducted domestically without international collaboration. Australia follows, contributing many studies, although with a slightly higher proportion of MCPs, indicating more international partnerships. Meanwhile, Indonesia and South Africa show a mix of SCPs

and MCPs, highlighting their growing presence in global research collaboration.

Beyond these leading contributors, several European and Asian countries, including Canada, China, Finland, and Germany, show moderate research output, particularly through SCPs. However, several countries, such as Ireland, Israel, and Korea, show relatively high MCPs, indicating strong international collaboration despite fewer publications. The data suggest that while certain countries, such as the US and Australia, dominate in publication volume, other regions actively engage in cross-border collaboration to contribute to the field. This pattern highlights differences in research independence and varying emphasis on global partnerships across countries.

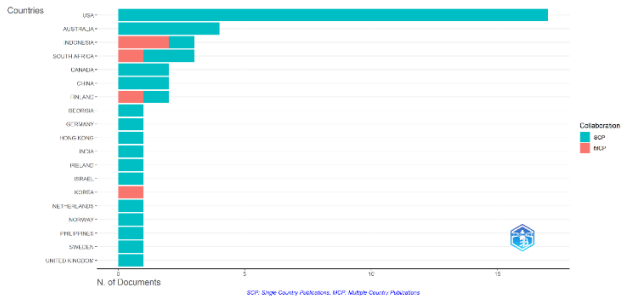

Figure (6): Single Country Publication and Multiple Country Publication.
Source: prepared by the author, using RStudio Software.

Figure 7 shows several productive institutions producing articles relevant to the mathematical mindset. Six are from the US: the University of Texas at Austin, Stanford University, Florida State University, University of California, and Arizona State University. There are also South African, Finland, Canadian, and Indian institutions, namely the University of Cape Town, University of Helsinki, Universite Du Quebec a Montreal, and Kle Technological University.

This distribution pattern suggests that research on mathematical mindset is fairly concentrated in a few leading universities, particularly in the United States and Europe. The University of Texas at Austin has the most publications, which may indicate the presence of research groups actively focused on this area. In addition, universities outside the United States, such as the University of Cape Town and the University of Helsinki, also make strong contributions, reflecting the global nature of this research interest. However, Asian institutions, such as Minzu University of China, have a more limited involvement, which may indicate a research gap in certain regional contexts.

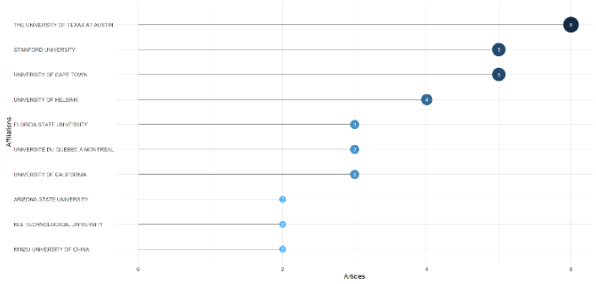

Figure (7): Mathematical Mindset Articles by Most Relevant Affiliations.
Source: prepared by the author, using RStudio Software.

Figure 8 depicts the eight institutions that published the most mathematical mindset articles in 2016 – 2023. The institutions that consistently publish these articles are Stanford University in the 2016 – 2023 period and the University of California in 2019 – 2023. In the 2016 – 2019 period, there is Universite Dua Quebec A Montreal, and in the 2018 – 2023 period, namely the University of Cape Town. In 2020 – 2023, three new institutions published mathematical mindset articles: The University of Texas at Austin, the University of Helsinki, and Florida State University.

The data shows a noticeable increase in research on mathematical mindset in recent years, with certain universities, like The University of Texas at Austin and Université du Québec à Montréal, experiencing a significant spike in publications since 2021. This trend suggests that the global academic community is paying increasing attention to this study area. In contrast, institutions such as Florida State University only began to see an increase in

publications after 2022, indicating a slower but gradually growing interest in related research.

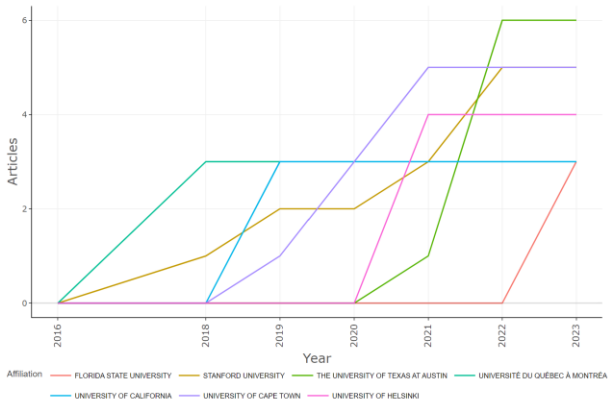

Figure (8): Affiliations' Production Over Time.
Source: prepared by the author, using RStudio Software.

Figure 9 depicts the ten authors with the highest productivity. At least three authors, Boaler, J., Buontempo, J., and Dieckmann, JA, are most consistent in publishing articles. Other authors, namely Bobis, J., Bostwick, KCP., Cambell A., Collie, RJ., Dong, L., and Downtown, A., also published articles during specific periods.

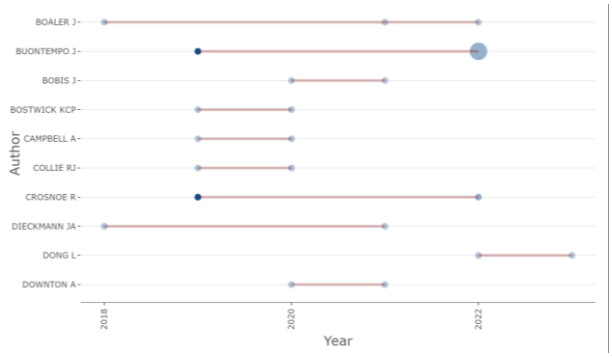

Figure (9): Authors' Production over Time.
Source: prepared by the author, using RStudio Software.

Figure 10 shows the ten authors based on the best H Index. Several authors who have a high H index and also high productivity include Boalaer, J., Buentempo, J., Bobis, J., Bostwick, KCP., Collie, RJ., Crosnoe R., Dieckmann, JA., and Downtown, A. Meanwhile, Duckworth, AL, and Durksen, TL have a high H index but are not included in the top 10 authors with high productivity. All authors in this graph have the same H-index value of 2. This means that each author has at least two articles cited twice. The scores are uniform, indicating that their publications' impact in terms of citations is relatively uniform.

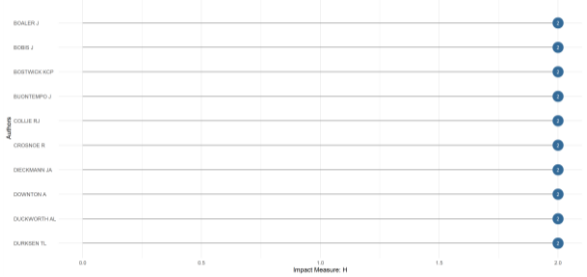

Figure (10): Authors' Local Impact by H-Index.
Source: prepared by the author, using RStudio Software.

Keyword and Thematic Network

Keyword indicators show important concepts of published articles to help readers find the main themes easily and provide more information to guide data collection (Xu *et al*., 2022). Besides author keywords and keyword plus, Figure 11 provides information about abstract keywords and title words. Abstract keywords are words that often appear in abstracts, and title words are words that often appear in article titles relevant to the article. The words that appear most frequently in each keyword are illustrated in larger size in Figure 11. The keyword abstract shows four words that appear frequently, namely "Growth," "Students," "Mindset," and "Mathematics." The words in the author's keyword that appear most frequently are "Growth Mindset," "Mathematics," and "Mindset." Furthermore, in the plus keywords, the words that appear most often are "Human," "Mathematics," and "Female." In the title word, the words that appear most often are "Mindset," "Mathematics," and "Growth". Overall, the words that appear most often of all these keywords are "Growth," "Growth Mindset," and "Mathematics". Other words that appear quite a lot from all the keywords include; “Belief,” “Fixed Mindset,” “Mathematics Education,” “Motivation,” “Male,” “Achievement,” and “Anxiety.”

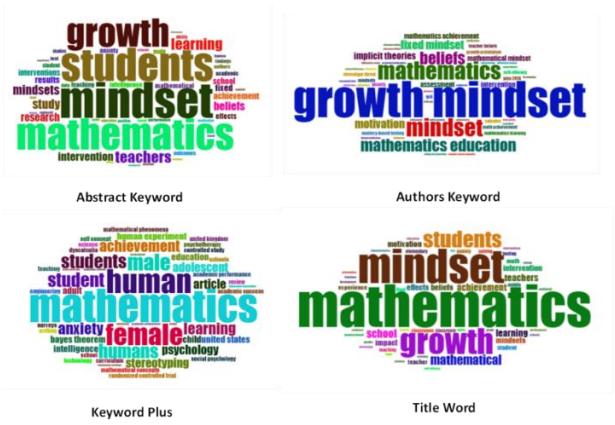

Figure (11): Word Count of Keywords in Mathematical Mindset Articles.
Source: prepared by the author, using RStudio Software.

Based on Figure 12, the themes included in motor themes (quadrant 1) are "Anxiety" and "Self-Efficacy". The themes included in niche themes (quadrant 2) include "Mathematical Mindset" and "Math Achievement." Meanwhile, there are no themes included in emerging or declining themes (quadrant 3). The themes most often found are basic (quadrant 4) or themes with low development but high relevance. Themes included in quadrant four include; “Growth Mindset,” “Mathematical Education,” “Fixed Mindset,” “Motivation,” “Implicit Theories,” “PISA 2018”, “Mathematics Achievement,” “Mathematics,” “Mindset,” and “Belief.” The themes most discussed in mathematical mindset articles are found in quadrant 4. "Growth Mindset," "Mathematics Education," and "Fixed Mindset" are the themes most discussed in relevant articles. "Mathematics," "Mindset," and "Belief" are the second most frequently discussed theme groups.

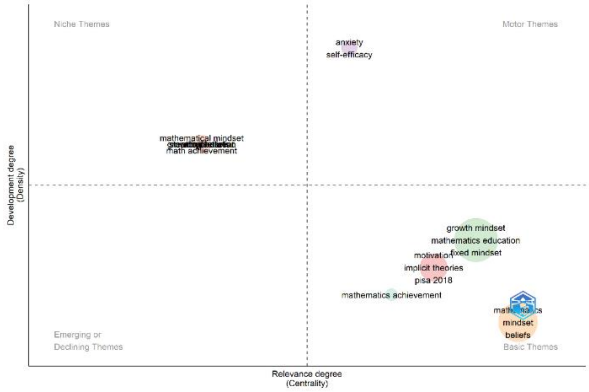

Figure (12): Bubble Chart of Thematic Network.
Source: prepared by the author, using RStudio Software.

Figure 13 shows a diagram of the evolution of theme trends between 2016 – 2021 and the period 2022 – 2023. In Figure 13, the color bars show the differences in these terms, while the size of the bars depicts the normalized proportion of terms in each period. The relationship between periods shows the thematic evolution that occurred (Tassinari, Araújo, and Barbosa, 2023). The diagram in Figure 13 illustrates that the themes for the 2016 – 2021 period are "Growth Mindset" and "Mathematics," and the term "Mathematics" is more widely used than "Growth Mindset". Then, in the 2022 - 2023 period, evolution occurred in the term "Mathematics," which developed into two terms, namely "Mathematics" and "Mindset," so that in the 2022 - 2023 period, the commonly used keywords were "Mathematics," "Growth Mindset," and “Mindset.”

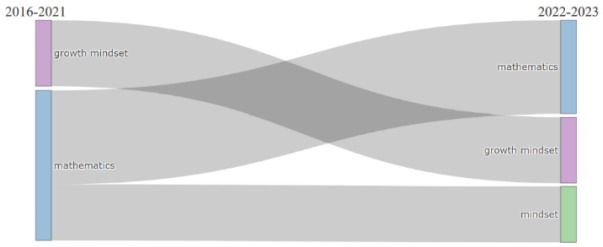

Figure (13): Flow Diagram of Thematic Evolution.
Source: prepared by the author, using RStudio Software.

Research Collaboration

Collaboration is something that needs attention in the current era. Based on (Dusdal and Powell, 2021; Katz and Martin, 1997), there are several motivations for collaboration. The first motivation concerns research support facilities; not all institutions have adequate research facilities, so collaboration is an effective and efficient alternative solution. Furthermore, it is related to technological advances that facilitate the coordination process between institutions, especially those from different countries. The third motivation is the need for experts in different research fields, increasing the need for collaboration.

The final motivation concerns science's need to interact with scientists in other fields to obtain a broader research impact. This section discusses collaborative research related to mathematical mindset in 2016 – 2023.

Figure 14 shows the collaboration in mathematical mindset research based on affiliation. The most extensive collaboration still occurs between institutions in the US and is divided into several clusters. The first cluster (in blue) is a collaboration formed from five institutions: Stanford University, the University of Pennsylvania, Harvard University, The University of Texas at Austin, and the University of Virginia. Meanwhile, the second cluster comprises Arizona State University, the University of Washington, and the University of California. The other clusters come from the Habilitation and Health Institution and the Center for Neurodevelopment Disorders at Karolinska Institut. There is a relationship between the first and second clusters, but the third cluster is still isolated from the others.

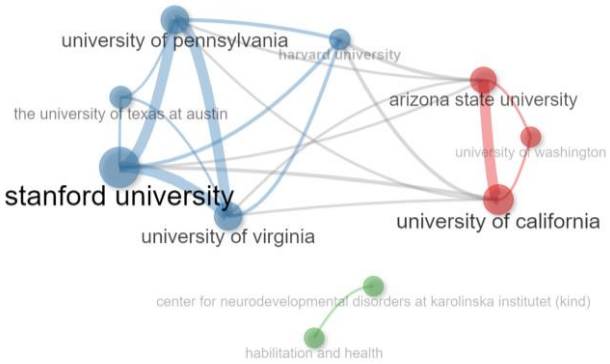

Figure (14): Collaboration Network by Institution.
Source: prepared by the author, using RStudio Software.

Based on the information above, the most extensive collaboration formed came from the US. However, it is essential to analyze the international collaboration that occurs. Figure 15 is an illustration of the collaboration that occurred between countries related to the mathematical mindset article. There are four collaboration clusters formed. The most extensive collaboration occurred between the US and Korea (blue), followed by a collaboration between the Netherlands and South Africa (green), Finland and Lithuania (purple), and the only collaboration occurred between three countries, namely Mexico, Indonesia and Singapore (Red).

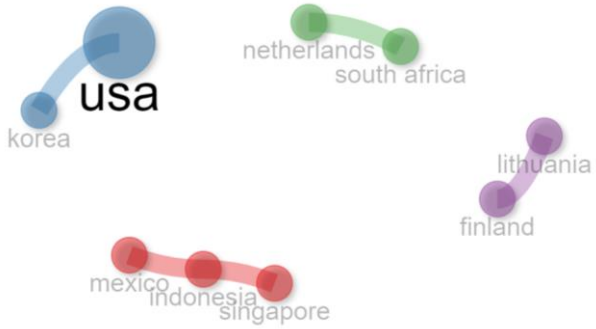

Figure (15): Collaboration Network by Countries.
Source: prepared by the author, using RStudio Software.

Discussion

This section discusses the research results regarding the development of mathematical mindset research and international collaboration.

Development of Mathematical Mindset Research

Figure 2 shows that the development of mathematical mindset articles over the eight years from 2016 to 2023 has increased with an average yearly increase of 25.25%. However, this increase was not matched by an increase in citations. The citation trend increased in 2016 – 2019 and tends to decrease from 2019 to 2023.

Over recent years (2019—2023), the decline in the number of citations can be attributed to several interconnected factors. Firstly, mathematical mindset research may be experiencing saturation as key work, especially those by Dweck (2006). Growth mindsets have been widely cited and established as foundational references. As a result, newer research struggles to achieve the same visibility and citation impact since researchers continue to refer to these influential earlier works. Additionally, the citation cycle of many publications follows a natural trajectory, where papers receive peak recognition shortly after

publication before gradually experiencing a decline in citation rates.

Another possible explanation is the evolving focus of researchers on emerging topics in educational psychology that go beyond the traditional scope of mathematical mindset. Recently, studies have increasingly integrated cognitive science (Schoenfeld, 2016), digital learning environments (Fregola, 2015), and socio-emotional learning (Lechner *et al*., 2019) into mathematics education research. This shift may have led to a wider dispersion of citations across a broader range of topics, which could reduce the relative density of citations within the mathematical mindset domain. Additionally, the rise of open-access preprints and alternative publication platforms has impacted how academic works gain visibility, potentially redistributing citation patterns across various sources that may not be fully captured in bibliometric analyses.

Citations are one of the benchmarks for assessing the quality of an article. Several factors influence the number of citations, including Article substance, source factor (academic publisher), and author factor (Castillo *et al*., 2007). In general, there are also scientific factors consisting of the quality of the article and the characteristics of the methodology used, and non-scientific factors related to the number of article pages, international collaboration, and number of authors Tahamtan *et al*., 2016; Xie *et al*., 2019). The number of article references (Onodera & Yoshikane, 2015) and keyword selection (Corrin *et al*., 2022; Sezer *et al*., 2022) also positively affect citations. These factors will be elaborated on in the following discussion.

The first factor is keywords. Keywords themselves are phrases in an article that reveal the essence of an article (Tripathi *et al*., 2018). In Figure 2, there are two keyword terms: keyword plus (ID), a keyword taken from a reference used in an article and not a keyword in the article, and author's keyword (DE), a keyword created by the author. Article (Zhang *et al*., 2016). Figure 2 shows that the ratio between ID and DE is 0.79, meaning that the number of DE is greater than that of ID. This illustrates that the expansion of mathematical mindset articles tends to be low. The low ID also relates to the number of references used in mathematical mindset articles. In addition, Figures 11 and 12 show that the largest DE is "Growth Mindset," followed by "Mathematics," "Mindset," and "Mathematics Education." Meanwhile, the plus keywords consist of the words "Mathematics," "Human," "Student," "Female," "Anxiety," "Learning," and others. Even though DE data is more prominent than ID, the keyword "Growth Mindset" still dominates DE in terms of distribution. Therefore, the root of the problem lies in expanding the keyword "Growth Mindset." This information is reinforced by Figure 13, which shows that the word "Growth Mindset" has not evolved for eight years from 2016 - 2023. This is understandable because "Growth Mindset" is the theory that underlies mathematical mindset. Figure 12 shows that the keywords developed in mathematical mindset research are "Anxiety" and "Self-Efficacy." Meanwhile, the degree of development for keywords, including DE, tends to be low but highly relevant.

The second factor is the distribution of articles in sources. Sources through academic publications contribute to distributing articles across geographies and different reader groups. Academic publishers also play a role in the production, assessment, reproduction, and distribution stages of scientific articles (Neavill, 1975). The emergence of the internet has resulted in the growth of digital-based library models, which have a positive role in increasing scientific articles that can be reviewed by other authors (Morgan *et al*.,

2012). Figure 3 depicts the top 10 Scopus-indexed sources relevant to the mathematical mindset based on the h-index value. Of the top 10 sources, there are eight journal-type sources and two conference proceedings types. Based on the Scopus website (www.scopus.com), from 8 journal-type sources, the most extensive citations are in the sources entitled Frontiers in Psychology with 91,802 citations, and the lowest are the sources entitled Critical Studies in Teaching and Learning with 86 citations, and the average citation from these eight journals is around 14625 citations. The reasonably large range (917906) does not describe the average value. Therefore, these data illustrate that there is a gap in sources related to mathematical mindset, meaning that mathematical mindset articles are not evenly distributed among sources that have wide access. However, this does not mean that journals that do not have extensive citations are disreputable. Adjei and Owusu-Ansah (2016) show that authors' preference for publishing their articles is other than the journal's reputation and publication costs. Therefore, open-access (OA) journals are cited more often than non-OA journals (Eysenbach, 2006). Judging by academic publishers, of the top 8 sources, the journal is only covered by six academic publishers, namely Elsevier, American Society for Cell Biology, Frontiers Media SA, Multidisciplinary Digital Publishing Institute (MDPI), Social Science Press, and the University of the Western Cape. This indicates the limited scope for mathematical mindset authors in publishing their research results. Based on the scope of sources, mathematical mindset articles are still included in several general sources, especially education and psychology-based ones. This shows the low level of particular sources related to the scope of the mathematical mindset. However, an interesting thing happened with the involvement of a journal based on "Behavioral Neuroscience," which is part of the development of mathematical mindset research.

The third factor related to the development of mathematical mindset research can be seen in the distribution of publications in various countries. Figure 6 shows that the US still dominates the publication of mathematical mindset articles; the large range between the US and other countries illustrates that the development of mathematical mindset article publications is still not significant; this confirms the previous statement that the development of mathematical mindset articles is 25.25% per year. Apart from that, if you look at the publisher's academic country, publishers from the US also dominate the eight sources of the journal types discussed above. The development in terms of author keywords (DE) shown in Figure 5 also shows that the US still dominates the contribution to DE development. However, this is considered normal because the US is the starting place for developing Mindset and Mathematical Mindset research, which Carol Dweck and Joe Boaler pioneered. Figure 12 also confirms this theme's low level of development based on development degree. Therefore, there are many opportunities for research themes in the field of mathematical mindset that can still be developed today. Apart from themes, the US still dominates the contribution of institutions and authors. Figure 7 shows that most of the top 10 institutions producing mathematical mindset articles come from the US, amounting to 60%. Apart from that, article productivity by year is still evenly dominated by US institutions, including Stanford University and the University of California. However, some institutions are consistent with the productivity of creating mathematical mindset articles from outside the US, namely the University of Quebec A Montreal from Canada and the University of Cape Town from South Africa. In addition, Figure 10 depicts the ten authors who

contributed the most based on the h-index value. The h-index value is an indicator that can measure the professional quality of researchers based on the number of publications by researchers and the number of citations to that work (Hirsch & Buela-Casal, 2014). The authors who contributed most consistently from 2018 – 2023 were Boaler, J, Buontempo, J., Crosnoe, R., and Dieckmann, JA. The four authors come from two different institutions in the US, namely Stanford University and the University of Texas at Austin.

The fourth factor is the authors' themes and keywords when publishing their research findings. Themes and keywords are closely related to each other in scientific publications. Keywords provide readers with information to find relevant articles and conduct surveys on specific articles (Sezer *et al*., 2022). There are 131 plus keywords (ID) and 164 authors keywords (DE) for mathematical mindset articles in the 2016 – 2023 time period based on Figure 2. Meanwhile, in Figure 11, most keywords used in DE and ID are five words. This means that the comparison between the most keywords used and the keyword distribution is 2.44% for ID and 3.82% for DE. This data illustrates that the degree of development of the mathematical mindset theme based on keywords is still relatively low, as shown in Figure 11. Figure 11 also shows that "Mathematics" is the most widely used keyword in all types of keywords except for the author's keyword; this is understandable because the domain used by the author is the scope of mathematics education. The most relevant keywords or themes in mathematical mindset research are "Growth Mindset" and "Mindset." This is shown by the flow diagram of thematic evolution in Figure 13. Two themes have a reasonable degree of development and relevance, namely "Anxiety" and "Self-Efficacy" (Figure 12). "Anxiety" and "Self-Efficacy" themselves are close parts of "Mindset" (Cherewick *et al*., 2023; Rhew *et al*., 2018).

Mathematical Mindset Research Collaboration Trends

The following discussion is about collaboration that occurs in mathematical mindset research. Based on Figure 2, collaboration between authors was good in the 51 mathematical mindset articles from 2016 – 2023, with 4.24 co-authors per document and only three articles with a single author. However, the percentage of international authors is still relatively low; only 4 to 5 articles, or 9.8%, collaborate between countries. International research collaboration (IRS) is essential nowadays as the fields of innovation and internationalization develop (Chen *et al*., 2019; Freshwater *et al*., 2006). The low level of collaboration between countries is shown in Figure 6 regarding SCP and MCP. Most MCPs only occur in 4 countries, namely Indonesia, South Africa, Finland, and Korea. The majority of the remainder collaborate locally or SCP. This is reinforced by the picture of collaborative relationships between countries; in 8 years, there were only four collaboration clusters between countries, and all were isolated, meaning there was no relationship between the 4 clusters. The US dominates local collaboration and is starting to build relations with Korea; apart from that, the most extensive collaboration has occurred with Mexico, Indonesia, and Singapore. However, this information shows that the publication of mathematical mindset articles has inspired the world.

The most extensive institutional collaboration also occurs at US-based institutions. An international collaboration between institutions is needed to build constructive working relationships (Peterson, 2001) in research development. Figure 8 shows that the most significant contribution of articles

is still centered in the US, followed by South Africa, Finland, Canada, and India. However, comparing articles in the US and other countries is still very far away. Based on trends, only three institutions outside the US have the potential to increase, namely the University of Cape Town from South Africa, the University of Helsinki from Finland, and the University of Quebec A Montreal from Canada. Figure 14 shows that there are three most significant collaboration clusters between institutions. The two largest clusters formed came entirely from the US (red and blue clusters). This information shows that international collaboration between mathematical mindset research institutions remains relatively low. However, based on the explanation of international research collaboration (IRS) above, there is an embryo of international collaboration between institutions, which has the potential to be the beginning of the development of international collaboration in mathematical mindset research.

While the United States leads in the publication of research on mathematical mindsets, other regions contribute only a small number of publications. Several factors may explain this disparity. First, funding limitations in developing countries can hinder research productivity, as securing grants for educational and psychological research may not be prioritized. For instance, in many African nations, less than 1% of their Gross Domestic Product (GDP) is allocated to research and development (Igiri *et al*., 2021). Additionally, constraints on funding, a lack of highly qualified human resources, and inadequate research facilities are significant challenges faced by researchers in the Southeast Asian region (Supriandi *et al*., 2023). Without sufficient financial support, researchers in these areas may encounter difficulties in conducting large-scale studies or accessing the necessary resources for publication.

Second, limited access to top-tier sources can be a significant barrier. High-impact sources often impose substantial article processing fees, which can hinder researchers from low-income countries from disseminating their work. Additionally, many prestigious sources are associated with institutions in North America and Europe, potentially introducing bias into the review process and reducing the visibility of research from other regions. As illustrated in Figures 3 and 4, journals linked to the US and Europe continue to dominate in terms of both productivity and citations.

Language barriers also limit the international visibility of research on mathematical mindsets. Most high-impact sources are published in English, which can disadvantage researchers from non-English-speaking countries. Even when high-quality research is produced, academic writing and communication challenges may lead to rejection or lower citation rates.

Strategies to Enhance Global Collaboration

To address these challenges, increasing international collaboration is essential (Finger *et al*., 2021; Widmer *et al*., 2015). Universities and research institutions can partner with scholars from underrepresented regions, fostering joint research projects and co-authorship opportunities. Such initiatives can enhance knowledge exchange and give researchers from developing countries better access to funding and publication networks.

Open-access journals play a vital role in democratizing access to publication opportunities (Warlick & Vaughan, 2007; Woszczynski & Whitman, 2016). Encouraging researchers to publish in reputable open-access journals can help close the research dissemination and visibility gap. Additionally, global academic organizations can organize training programs, workshops, and mentorship initiatives to support researchers in enhancing

their academic writing and grant application skills. This support can significantly increase their chances of being published in international journals.

By addressing these barriers and fostering greater global participation, mathematical mindset research can evolve into a more diverse and inclusive field, enriching perspectives and broadening the impact of its findings.

Conclusion

This study provides a comprehensive bibliometric analysis of mathematical mindset research, highlighting publication trends, collaboration patterns, and emerging themes. Although the field has grown, findings suggest that research remains concentrated in a few geographic regions with limited international collaboration. Furthermore, the focus has shifted from basic theories to applied areas such as self-efficacy, math anxiety, and neuroscience.

Future research should emphasize global collaborations, particularly with researchers from underrepresented regions, to advance the field to cultivate a more inclusive knowledge base. We can gain deeper insights into cognitive development and learning outcomes by integrating mathematical mindset research with neuroscience, AI-driven personalized learning, and cross-cultural education studies. Additionally, establishing dedicated publication avenues and enhancing institutional support for mindset-based interventions would help bridge the gap between research and practice. Focusing on these areas would promote theoretical progress and enhance practical applications in mathematics education worldwide.

Disclosure Statement

- **Conflict of interest:** The authors declare no competing interests.
- **Ethical approval and consent to participate:** This study is a bibliometric analysis based on data from published literature. It does not involve human participants, clinical trials, or the use of personal or sensitive data. Therefore, ethical approval and informed consent were not required.
- **Availability of data and materials:** The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.
- **Author contribution: Sugama Maskar** contributed to the conception and design of the study, data collection, analysis, and drafting of the manuscript. **Tatang Herman** provided guidance on the research framework, methodological validation, and critical revisions of the manuscript. **Nicky Dwi Puspaningtyas** supported the data analysis process and contributed to the interpretation of results and refinement of the final manuscript. All authors read and approved the final version of the manuscript.
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