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# Mapping the Research Landscape of Mathematical Reasoning: A Bibliometric Study of the Last Decade

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**ABSTRACT**

Mathematical reasoning is recognized as a core competency in mathematics education; however, a comprehensive overview of its research development and thematic evolution remains limited. This study aims to map the research landscape of mathematical reasoning over the last decade in order to identify publication trends, influential contributors, and emerging research themes. A quantitative bibliometric approach was employed using Scopus-indexed journal articles, which were analyzed and visualized through VOSviewer to examine co-authorship networks, keyword co-occurrence, and thematic evolution. The findings indicate a significant growth in publications since 2018, reflecting increasing global attention to mathematical reasoning. The results further reveal that research in this field has developed multidimensionally, integrating cognitive, pedagogical, evaluative, and contextual dimensions, with a recent shift toward assessment practices, problem-based learning, and technology-enhanced instruction. These findings confirm that mathematical reasoning has become a mature and strategically important field in mathematics education, while highlighting opportunities for further research that integrate digital innovation and deep learning-oriented approaches.



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## 1. INTRODUCTION

Mathematical reasoning is a cognitive ability that involves logical, systematic, and reflective thinking to understand, connect with, and manipulate mathematical concepts and representations to draw valid conclusions [1]. This ability involves activities such as identifying patterns and relationships, making conjectures, constructing arguments, providing justifications or proofs, and evaluating the truth of a mathematical statement based on evidence and applicable principles [2]. In the context of education, mathematical reasoning is not only understood as the result in the form of a correct answer, but also as a thinking process evident in the way students explain, interpret, and defend their mathematical solutions [3]. Therefore, mathematical reasoning plays a major role as the foundation for the development of conceptual understanding, problem solving, and higher-order thinking skills, and is an important indicator of the quality of meaningful mathematics learning.

Despite its strategic importance, various studies report that students' mathematical reasoning abilities remain underdeveloped in many educational contexts [4], [1], [2]. Learning practices often emphasize procedural fluency, algorithmic steps, and routine exercises with single correct answers, thereby limiting students' opportunities to justify their solutions, explore alternative strategies, and reflect on their thinking processes. This condition reveals a discrepancy between curriculum demands that promote higher-order thinking skills and the reality of classroom implementation [5]. Consequently, the development of mathematical reasoning remains a significant educational challenge.

In recent years, scholarly attention to mathematical reasoning has increased considerably, as reflected in the growing number of scientific publications on this topic [6]. Previous studies have examined mathematical reasoning from multiple perspectives, including the types of reasoning (inductive, deductive, and analogical), its relationship with problem-solving and mathematical representation, and the influence of specific learning approaches on strengthening reasoning skills [7], [8]. Although these studies contribute substantially to understanding instructional strategies and theoretical frameworks, most are either empirical or conceptual and focus on specific classroom contexts.

However, research that systematically maps the development of mathematical reasoning studies, such as publication trends, influential authors, collaboration networks, citation structures, and thematic evolution, is still relatively limited [6], [9]. Existing reviews generally describe findings narratively without providing a quantitative mapping of the research landscape. This indicates a research gap at the meta-analysis level, particularly in understanding how mathematical reasoning research has evolved and identifying potential directions for future development. Therefore, a comprehensive bibliometric study is needed to fill this gap.

To address this problem, this study employs a bibliometric analysis approach. Bibliometric analysis enables quantitative exploration of scientific publications to identify patterns of productivity, collaboration networks, citation relationships, and the evolution of research themes over time [10], [11]. Through this method, the structure of knowledge in mathematical reasoning research can be mapped objectively and systematically. The author plans to analyze publications over the last ten years to obtain a comprehensive overview of research development, identify dominant themes, highlight influential contributors, and detect underexplored research areas.

Based on this background, the objectives of this study are

1. to analyze publication trends in mathematical reasoning research over the last ten years;
2. to identify influential authors, institutions, and countries contributing to this field;
3. to examine collaboration networks and citation structures; and
4. to identify dominant and emerging research themes as well as existing research gaps.

This study is theoretically grounded in the perspective that scientific knowledge development can be understood through patterns of publication, citation, and collaboration

[10], [11]. While conceptually rooted in the theoretical framework of mathematical reasoning as a higher-order cognitive process in mathematics education [1], [2], [3]. By integrating these perspectives, this research provides a meta-level analysis of the evolution and intellectual structure of mathematical reasoning research.

The results of this study are expected to provide a comprehensive scientific map of mathematical reasoning research and offer strategic insights for future investigations. The findings are anticipated to benefit researchers by identifying promising research directions, assist educators in understanding current research trends, and support policymakers in designing mathematics learning innovations to strengthen students' mathematical reasoning. Thus, this study contributes both theoretically and practically to the advancement of mathematics education research.

## 2. METHOD

### 2.1 Research Design

This study uses a quantitative-descriptive research design and a bibliometric analysis to map the development and structure of research on mathematical reasoning over the past 10 years. The bibliometric approach was chosen for its ability to systematically and objectively analyze publication metadata in order to identify research trends, patterns of scientific collaboration, and the thematic structure of a scientific field [12], [13]. This design is suitable for providing a comprehensive overview of the dynamics of mathematical reasoning research, which continues to evolve in international literature [14].

### 2.2 Data Acquisition

The research data were obtained exclusively from the Scopus database, which is known for its extensive coverage of international journals, high indexing quality, and comprehensive metadata that supportibliometric analysis [15]. Data collection was carried out using the single keyword "mathematical reasoning" applied to the title–abstract–keywords field. To maintain the relevance of the research context, the search was limited to the fields of Social Sciences and Mathematics, so that the publications analyzed were truly related to mathematical reasoning in the context of education.

In addition to limiting the fields of study, this study included only journal articles, while conference papers, book chapters, review articles, and other document types were excluded. This restriction aims to ensure that the data analyzed come from publications that have undergone rigorous peer review. Furthermore, only English-language articles are included to maintain metadata consistency and facilitate comparative analysis between publications, as recommended in previous bibliometric studies.

### 2.3 Research Procedure

Chronologically, this research procedure consists of several main stages as follows[16]:

1. Identification and collection of data from the Scopus database based on predetermined search criteria.

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2. Export of selected article metadata in RIS (Research Information Systems) format, which includes information on authors, affiliations, titles, abstracts, keywords, publication years, and number of citations.
3. Processing and mapping of data using bibliometric analysis software.
4. Manual validation and screening to ensure the relevance of article content.
5. Interpretation of visualization results and thematic analysis to identify research patterns and trends.

This sequence of procedures is designed to ensure that the analysis is conducted systematically and can be replicated, as recommended in the methodological guidelines for bibliometric research [17].

### 2.4 Data Analysis Technique

The data exported in RIS format were analyzed using VOSviewer, a widely used software for bibliometric network visualization [18]. VOSviewer was chosen for its ability to map knowledge structures using various analysis techniques, such as co-authorship, co-occurrence, co-citation, and bibliographic coupling [17]. In this study, the analysis focused on three main types of visualization, namely network visualization, overlay visualization, and density visualization, which were used to describe the relationships between authors, keyword distribution, research intensity, and the evolution of topics over time.

### 2.5 Data Validation and Interpretation

After the initial mapping was completed, a manual screening stage was conducted to improve data validity. This stage aimed to eliminate articles that mentioned the term' mathematical reasoning' only marginally or were irrelevant to the context of mathematics education. This manual screening is important, as keyword-based searches canroduce false positives, and has been recommended in various bibliometric studies to maintain the quality and accuracy of findings [19].

The final stage of the research is the interpretation of the analysis results, which is done by examining patterns of relationships among keywords, term density, annual publication trends, and the contributions of the most influential authors and institutions. These interpretation results are used to identify the dominant topic clusters in mathematical reasoning research and to reveal research gaps that could serve as directions for future studies.

## 3. RESULTS AND DISCUSSION

A bibliometric analysis of publications on mathematical reasoning from 2016 to 2025 yielded 387 documents based on the specified search criteria, namely: (a) the fields of Social Sciences and Mathematics, (b) articles only, (c) English as the main filter, and (d) using the keywords mathematical reasoning, mathematics, and reasoning. All data were retrieved from Scopus in RIS format and analyzed using VOSviewer, which produced three types of visualizations: networks, overlays, and densities.

### 3.1. Results

This section presents the results of a bibliometric analysis of scientific publications discussing mathematical reasoning indexed in the Scopus database. The analysis focuses on the distribution of articles by year of publication, country of origin, journal source, author, and the most productive institutions or universities in this field. The presentation of these results aims to provide an empirical overview of the development and patterns of productivity in mathematical reasoning research globally, while identifying the actors and sources of publications that have made significant contributions to this study over the past decade.

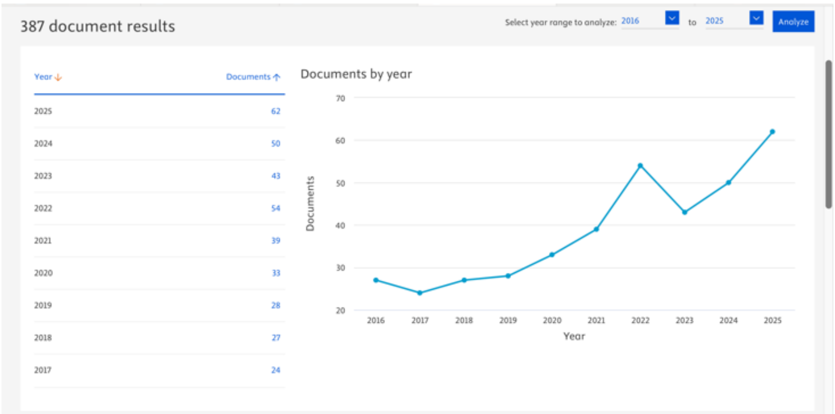


Figure 1. Distribution of mathematical reasoning articles published per year (2016-2025)

The graph in Figure 1 illustrates the dynamics of scientific publications on mathematical reasoning indexed by Scopus during the period 2016–2025. In the early phase, the number of publications was relatively limited, reaching its lowest point in 2017, indicating that mathematical reasoning studies during that period were not yet a major focus in mathematics education research. Since 2018, the publication trend has shown a more consistent increase, indicating growing academic attention to mathematical reasoning, in line with the strengthening of discourse on higher-order thinking skills in the curriculum and in learning practices. Despite fluctuations, including moderate declines in 2021 and 2023, the overall trend remains positive. The most significant surge occurred in the 2024–2025 period, with the number of publications peaking in 2025, reflecting an escalation in interest and the intensity of research on mathematical reasoning. Overall, this temporal pattern confirms that mathematical reasoning research has experienced increasingly strong, stable, and sustainable development over the past decade, while also positioning it as a strategic focus in contemporary mathematics education studies [20].

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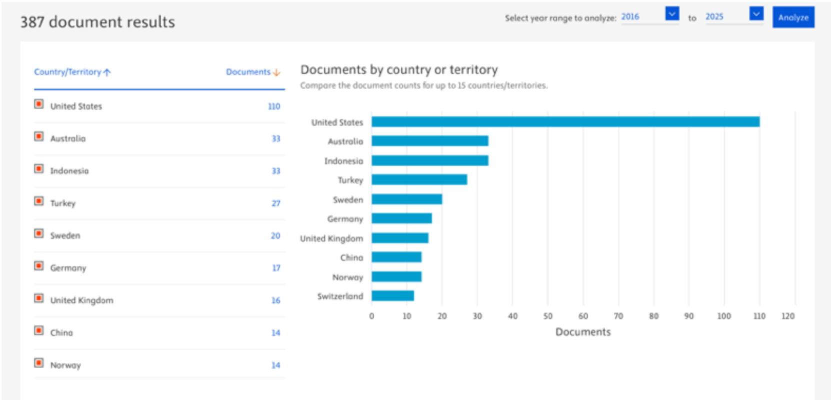


Figure 2. Distribution of mathematical reasoning articles published by country

Figure 2 shows the distribution of scientific publications on mathematical reasoning by country or region indexed by Scopus during the period 2016–2025. The analysis shows that the United States leads in research productivity, with 110 publications, confirming the country's central role as a global center for the development of mathematics education research and studies of mathematical reasoning. The next-largest contributions come from Australia and Indonesia, each with 33 publications, followed by Turkey (27) and Sweden (20). Indonesia's position alongside Australia indicates significant developments in mathematical reasoning research, which can be attributed to strengthened national curriculum policies, increased focus on the development of higher-order thinking skills, and the promotion of international publications in mathematics education. Meanwhile, the involvement of European countries such as Germany, the United Kingdom, Norway, and Switzerland reflects a relatively even distribution of research interest across regions. Overall, these findings show that research on mathematical reasoning is not only concentrated in developed countries such as the United States but is also experiencing significant growth in developing countries, particularly Indonesia, which signals the increasing globalization and diversification of scientific contributions in the field of mathematics education [21].

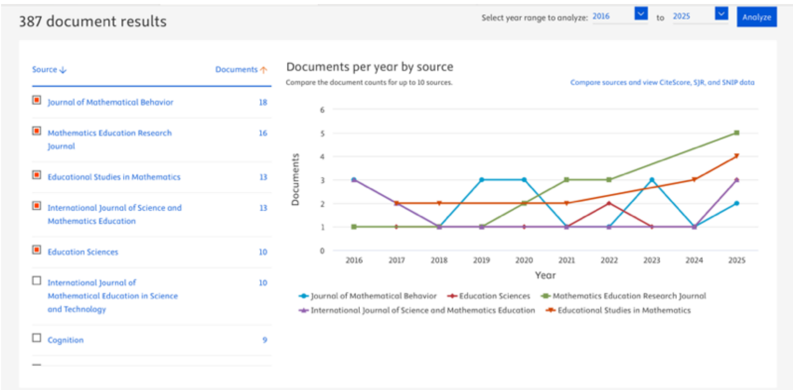


Figure 3. Distribution of mathematical reasoning articles published by the source

Based on Figure 3, research publications on mathematical reasoning during 2016–2025 show a strong concentration in core journals in mathematics education. The Journal of Mathematical Behavior emerged as the most productive source, with 18 publications, followed by the Mathematics Education Research Journal (16 publications), Educational

Studies in Mathematics, and the International Journal of Science and Mathematics Education, each with 13 publications. The pattern of publication distribution per year in these journals is relatively volatile, but shows an upward trend in the second half of the analysis period, especially after 2020. This indicates that the study of mathematical reasoning is increasingly positioned as a strategic issue in mathematics education research, covering cognitive, pedagogical, and learning design development dimensions [22]. The conclusion of this analysis confirms that the topic of mathematical reasoning has a well-established and sustainable publication ecosystem in reputable international journals, which serve as the main centers for disseminating developments in mathematical reasoning research [10].

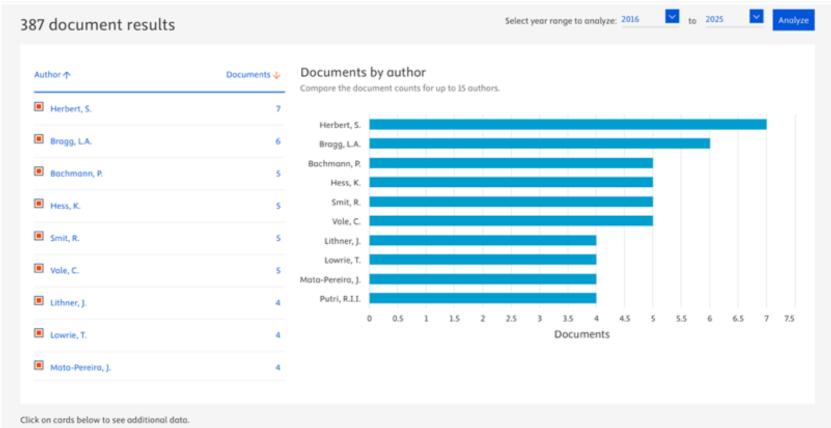


Figure 4. Distribution of mathematical reasoning articles published under the author's name

Figure 4 shows the ten most productive authors in mathematical reasoning research publications during the period 2016–2025. Based on this data, Herbert, S. ranks first with 7 publications, followed by Bragg, L.A. with 6 publications. Next, Bachmann, P., Hess, K., Smit, R., and Vale, C. each published 5 papers, indicating a relatively balanced level of productivity among the core group of authors. Additionally, Lithner, J., Lowrie, T., Mata-Pereira, J., and Putri, R.I.I. contributed significantly with 4 publications each. This distribution pattern indicates that a single author does not dominate mathematical reasoning research, but rather develops through the continuous contributions of a number of key researchers across countries and institutions. In conclusion, the existence of a productive group of authors with relatively equal contributions reflects that mathematical reasoning studies have formed a stable, collaborative, and structured research community that supports the sustainability and strengthening of this field's position in global mathematics education research [23].

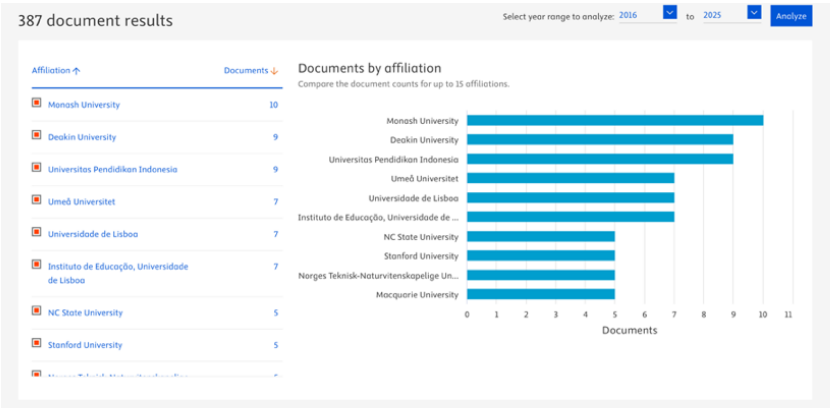


Figure 5. Distribution of mathematical reasoning articles published by the institution

Figure 5 shows the most productive institutional affiliations in mathematical reasoning research publications during the period 2016–2025. The analysis shows that Monash University ranks first with 10 publications, followed by Deakin University and the Indonesian University of Education, each with 9 publications. Next, Umeå Universitet, Universidade de Lisboa, and Instituto de Educação, Universidade de Lisboa, show relatively balanced contributions with 7 publications each, while other institutions, such as NC State University, Stanford University, and Macquarie University, contribute moderately. This pattern indicates that the development of mathematical reasoning studies is supported by institutions from various regions, particularly Australia, Europe, the United States, and Indonesia, which have strong research ecosystems in mathematics education and a commitment to international publications. In conclusion, this distribution of affiliations confirms that mathematical reasoning research is developing globally and collaboratively, with significant involvement from institutions ineveloping countries such as Indonesia, further strengthening this field's position in the international discourse on mathematics education [24].

Table 1. Articles with the highest citations per year from 2016 to 2025

| No | Title | Authors | Source | Year | Citation |
|---|---|---|---|---|---|
| 1 | A conceptual model of mathematical reasoning for school mathematics | Jeannotte, D. Kieran, C. | Educational Studies in Mathematics | 2017 | 158 |
| 2 | Developing an AI-based chatbot for practicing responsive teaching in mathematics | Lee, D. Yeo, S. | Computers and Education | 2022 | 134 |
| 3 | The effects of computer programming on high school students' reasoning skills, mathematical self-efficacy, and problem-solving | Psycharis, S. Kallia, M. | Instructional Science | 2017 | 125 |
| 4 | The Impact of a Professional Development Program on Teachers' Mathematical Knowledge for Teaching, Instruction, and Student Achievement | Jacob, R. Hill, H. Corey, D. | Journal of Research on Educational Effectiveness | 2017 | 110 |
| 5 | How creativity, autonomy, and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module | Thuneberg, H.M. Salmi, H.S. Bogner, F.X. | Thinking Skills and Creativity | 2018 | 101 |

Based on Table 1, the articles with the highest number of citations in the 2016–2025 period were dominated by publications on mathematical reasoning in the context of learning and the development of students' cognitive competencies. The article with the highest number of citations, namely "A conceptual model of mathematical reasoning for school mathematics," published in 2017, shows that conceptual studies of mathematical reasoning frameworks have a strong and lasting influence in the mathematics education literature [25]. In addition, the existence of other articles focusing on technology integration, such as the development of AI-based chatbots and computer programming in mathematics learning, indicates a shift in research focus toward innovative approaches that strengthen reasoning and problem-solving skills [26]. The dominance of publications in reputable international journals such as Educational Studies in Mathematics, Computers & Education, and Instructional Science indicates that articles with high citation impact are generally published in journals with broad readership and strong academic reputations. In conclusion, this citation pattern indicates that conceptual, innovative, and practice-relevant mathematical reasoning research has a significant influence and serves as a key reference in the development of contemporary studies in mathematics education[7].

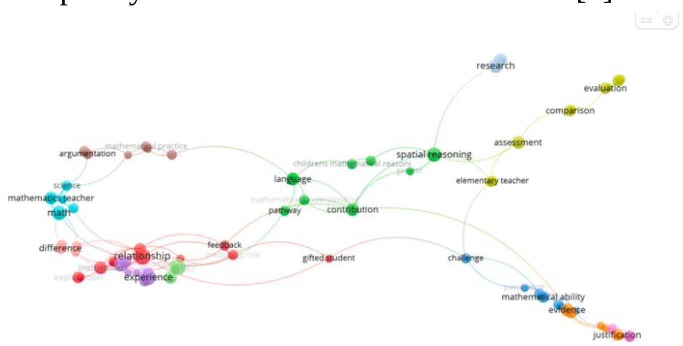


Figure 6. Results of network visualization analysis using VosViewer for mathematical reasoning from 2016 to 2025, sourced from Scopus

Figure 6 shows a map of the keyword network resulting from co-occurrence analysis in VOSviewer for mathematical reasoning research. This visualization shows that the topic of mathematical reasoning is distributed into several interconnected thematic clusters. One of the main clusters focuses on cognitive and conceptual aspects, marked by keywords such as mathematical ability, evidence, and justification, which represent mathematical reasoning as a process of proof, logical decision-making, and argument validation. Another cluster highlights the pedagogical dimension, including keywords such as mathematics teacher, elementary teacher, experience, and assessment, indicating the roles of teachers, learning practices, and evaluation in developing students' mathematical reasoning abilities. In addition, there are clusters related to specific domains of reasoning, such as spatial reasoning, comparison, and problem-solving, reflecting the research focus on types of mathematical reasoning in the context of learning. The interrelationships between clusters show that mathematical reasoning research is developing in an interdisciplinary manner by integrating cognitive, pedagogical, and contextual aspects of mathematics learning. In conclusion, this map confirms that the study of mathematical reasoning does not stand as a single concept, but rather as a multidimensional construct that develops through the interaction between reasoning theory, learning practices, and educational contexts, thereby

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strengthening its position as a core competency in contemporary mathematics education [22], [27].

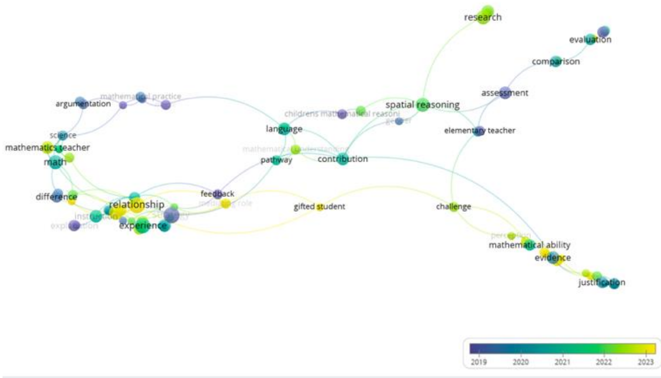

Figure 7. Results of the overlay visualization analysis of mathematical reasoning per year from 2016 to 2025, sourced from Scopus.

Figure 7 presents an overlay visualization of the temporal dynamics of the development of mathematical reasoning research topics, based on the emergence of keywords over time. Keywords displayed in darker colors—such as mathematics teacher, teacher knowledge, argumentation, and experience—indicate that in the early phase of the analysis period (around 2016–2019), mathematical reasoning research focused more on conceptual and pedagogical aspects, particularly the role of teachers, professional knowledge, and mathematical argumentation processes in learning. Meanwhile, keywords that appear in lighter colors—such as spatial reasoning, assessment, evaluation, mathematical ability, evidence, and justification—represent more recent themes (around 2021–2023), which indicate a shift in research focus toward strengthening students' mathematical reasoning abilities, evidence-based evaluation, and more systematic measurement of reasoning abilities. This shift indicates that the study of mathematical reasoning is no longer limited to theoretical foundations but is increasingly directed toward implementation, assessment, and the development of reasoning competencies in the context of modern learning. In conclusion, this overlay map confirms the evolution of mathematical reasoning research from a conceptual-pedagogical to a more applied and evaluative approach, reflecting responses to demands to improvehe quality of mathematics learning and an emphasis on higher-order thinking skills in contemporary education [28].

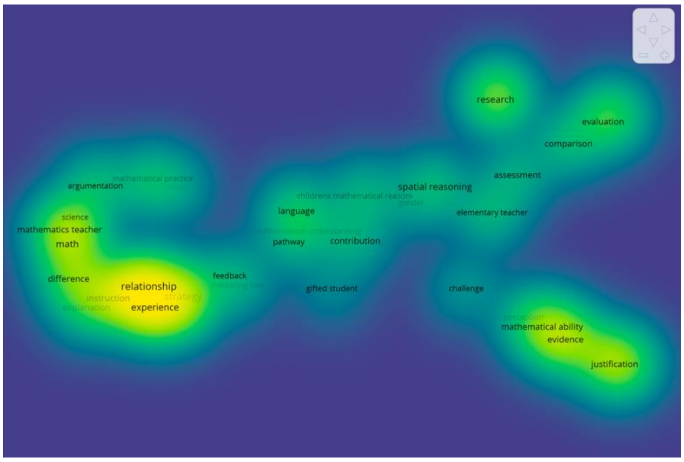

Figure 8. Results of density visualization analysis using VosViewer mathematical reasoning for the period 2016-2025, sourced from Scopus.

Figure 8 shows a density visualization that illustrates the intensity of keyword occurrence in mathematical reasoning research during the analysis period. Areas in yellow to bright green indicate the most frequently occurring terms with high relevance in the literature. On this map, keywords such as relationship, experience, mathematical ability, evidence, and justification cluster in the highest-density areas, indicating that mathematical reasoning research is dominated by studies emphasizing relationships among concepts, student learning experiences, and processes of mathematical proof and justification. In addition, the emergence of terms such as mathematics teacher, assessment, and spatial reasoning indicates that the development of mathematical reasoning is widely studied in the context of learning practices and student ability evaluation. This density pattern indicates that the main focus of research is not only on learning outcomes but also on the cognitive and pedagogical processes underlying mathematical reasoning abilities. In conclusion, this density visualization confirms that the study of mathematical reasoning is developing strongly at the intersection of students' cognitive processes, learning experiences, and pedagogical and assessment practices, thereby strengthening the position of mathematical reasoning as a core competency in modern mathematics education [22], [28].

### 3.2. Discussion

The results of bibliometric mapping using VOSviewer show that research on mathematical reasoning has undergone significant development and become increasingly structured over the past decade 6]. Network visualization shows that studies of mathematical reasoning are divided into several main, interconnected thematic clusters, covering cognitive aspects (such as mathematical ability, evidence, and justification), pedagogical aspects (such as mathematics teachers, experience, and assessment), and specific reasoning domains (e.g., spatial reasoning and comparison). The interconnection between these clusters confirms that mathematical reasoning research is developing multidimensionally by integrating reasoning theory, learning practices, and evaluation contexts. Furthermore, overlay visualization shows a clear temporal dynamic: early-phase research emphasized the role of teachers and the conceptual foundations of mathematical reasoning, while more recent research has shifted towards measuring reasoning abilities, the use of evidence, and students' mathematical justification processes. These findings indicate a shift in research focus from a conceptual-pedagogical approach to a more applicative and evaluative approach. Meanwhile, the density visualization confirms that terms related to conceptual relationships, learning experiences, and mathematical proof processes have the highest frequency, indicating that the core of mathematical reasoning research centers on understanding students' mathematical thinking processes. Overall, these three visualizations show that mathematical reasoning research has developed into a mature, integrated, and sustainable field of study, with a strong orientation towards strengthening reasoning skills as a key competency in contemporary mathematics education [8].

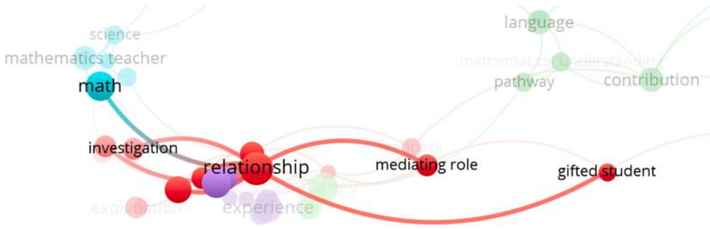


Figure 9. Cluster 1 groups related to mathematical reasoning

Cluster 1 is the most dominant and has the highest density in the mathematical reasoning keyword network map, as shown in Figure 9. This cluster includes key words such as instruction, feedback, experience, relationship, mediating role, self-efficacy, primary student, and gifted student, which collectively represent the pedagogical and psychopedagogical dimensions in the development of mathematical reasoning. The dominance of the keywords' relationship' and 'experience' indicates that mathematical reasoning research emphasizes the relationships among student learning experiences, pedagogical interactions, and teachers' mediation in building reasoning skills. The presence of the terms instruction and feedback indicates that teaching strategies and feedback are key factors in facilitating students to develop arguments, understand mathematical relationships, and reflect on their thinking processes. In addition, the emergence of the keywords "self-efficacy" and "gifted student" confirms that studies of mathematical reasoning also consider differences in students' individual characteristics, both in terms of self-confidence and cognitive potential, during the learning process. In conclusion, the red cluster confirms that mathematical reasoning research strongly emphasizes the role of pedagogy and learning experiences as theoundation for the development of mathematical reasoning, with teachers acting as central mediators who meaningfully connect learning strategies, student characteristics, and mathematical thinking processes [22].


Figure 10. Cluster 2 groups related to mathematical reasoning

Cluster 2 represents the cognitive-conceptual dimension in mathematical reasoning research, as shown in Figure 10. This cluster includes keywords such as children's mathematical reasoning, mathematical understanding, spatial reasoning, question, language, contribution, gender, and pathway, which collectively describe the research focus on students' internal processes in constructing mathematical reasoning. The presence of the terms children's mathematical reasoning and mathematical understanding confirms that research in this cluster is oriented toward how students develop conceptual understanding and reason mathematically in meaningful ways from the elementary education level onward. Furthermore, the emergence of spatial reasoning and questions indicates that certain reasoning and questioning strategies are seen as important pathways for developing reasoning abilities. The study of mathematical reasoning also considers linguistic factors and students' individual characteristics that influence how they construct and express their reasoning. The interconnections among keywords in this cluster indicate that the development of mathematical reasoning is understood as a complex cognitive process influenced by the interaction among conceptual understanding, spatial representation, language, and student characteristics. In conclusion, the dark green cluster confirms that mathematical reasoning research centers on students' thinking processes, emphasizing cognitive pathways that support the holistic, sustainable development of mathematical understanding and reasoning[29].

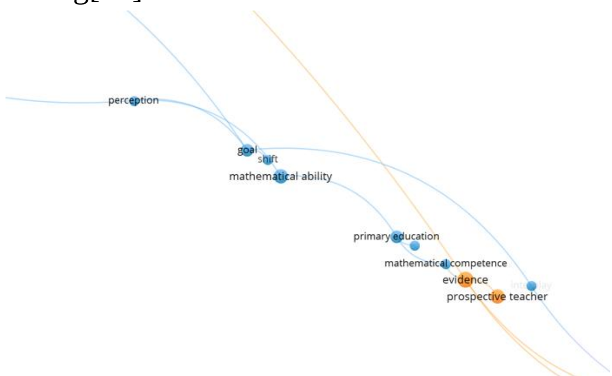


Figure 11. Cluster 3 groups related to mathematical reasoning

Cluster 3 highlights the dimensions of mathematical reasoning ability and development in the context of primary education, characterized by keywords such as mathematical ability, mathematical competence, primary education, perception, goal, shift,

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integration, interplay, and challenge. The focus of this cluster shows that research on mathematical reasoning is largely directed at how these abilities are developed, perceived, and shift in line with changes in learning objectives and educational approaches, particularly at the primary education level. The presence of the terms mathematical ability and mathematical competence confirms that mathematical reasoning is positioned as a core component of mathematical competence that must be systematically developed from the early stages of learning. Meanwhile, the keyword perception reflects the research's attention to how students interpret and understand the reasoning process, which directly affects their engagement and learning success. The terms integration and interplay refer to efforts to link mathematical reasoning with other cognitive aspects, learning goals, and challenges arising in the transition from procedural to conceptual understanding. Overall, this cluster confirms that mathematical reasoning research places the development of reasoning abilities and competencies as a dynamic process influenced by learning objectives, student perceptions, and the integration of various cognitive components in basic education [30], [31].

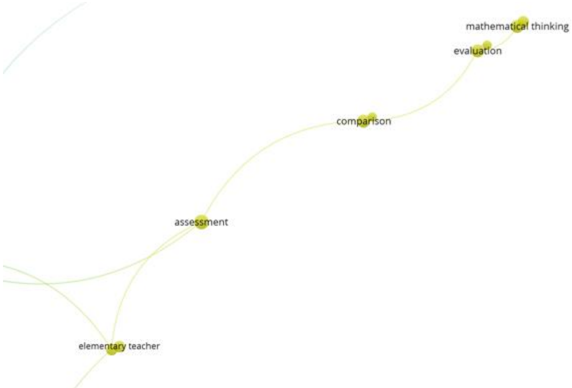


Figure 12. Cluster 4 groups related to mathematical reasoning

Cluster 4 highlights the dimensions of assessment and evaluative practices in the development of mathematical reasoning, characterized by keywords such as assessment, evaluation, comparison, competency, elementary teacher, mathematical thinking, mathematical argument, planning, and insight. The focus of this cluster shows that research on mathematical reasoning is not only oriented towards students' cognitive processes, but also towards how these reasoning abilities are designed, measured, and evaluated systematically in the context of learning, especially at the elementary education level. The presence of the terms assessment and evaluation underscores the importance of assessment instruments in evaluating the quality of mathematical reasoning, including students' ability to construct arguments, draw conclusions, and use mathematical evidence logically. The keyword "comparison" reflects the tendency of research to compare thinking strategies, competency levels, or the effectiveness of learning approaches in supporting mathematical reasoning. In addition, the emergence of the terms "elementary teacher" and "planning" indicates that teachers play a strategic role in designing activities and assessments that encourage mathematical thinking and mathematical argumentation. Overall, this cluster confirms that assessment is positioned as an integral component in mathematical reasoning research, not only to measure learning outcomes, but also as a pedagogical tool to strengthen students' mathematical thinking skills reflectively and sustainably [32], [33].

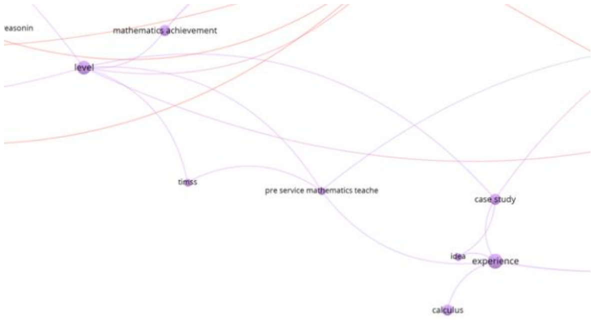


Figure 13. Cluster 5 groups related to mathematical reasoning

Cluster 5 represents the empirical and contextual dimensions in mathematical reasoning research, characterized by keywords such as case study, experience, idea, level, mathematics achievement, calculus, pre-service mathematics teacher, and TIMSS. The focus of this cluster shows that mathematical reasoning studies are largely developed through a research approach based on real contexts and empirical data, particularly to understand variations in the reasoning abilities of students and prospective mathematics teachers. The presence of the terms case study and experience indicates a tendency for research to examine in depth the mathematical thinking processes of individuals or groups in specific learning situations. The keywords level and mathematics achievement reflect efforts to link mathematical reasoning abilities with learning outcomes and students' cognitive development levels. In addition, the emergence of the term calculus shows that mathematical reasoning is not only studied at the basic level but also in advanced mathematics, where formal and abstract reasoning is required. The connection between pre-service mathematics teachers and TIMSS confirms that this cluster is also oriented towards evaluating prospective teachers' readiness and comparing mathematical reasoning abilities in the context of national and international assessments. Overall, this cluster emphasizes that research on mathematical reasoning is developing rapidly through empirical studies grounded in experience, learning outcomes, and evaluative contexts, thereby providing an important foundation for understanding the relationship between mathematical reasoning, achievement, and mathematics education practices [34], [35].

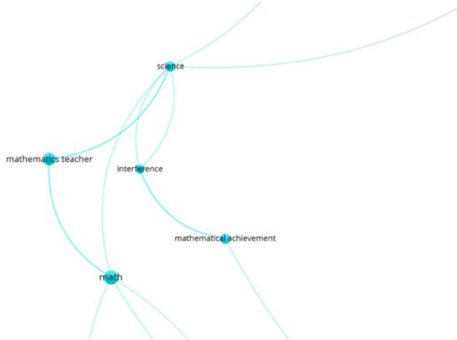


Figure 14. Cluster 6 groups related to mathematical reasoning

Cluster 6 highlights the interdisciplinary and collaborative dimensions of mathematical reasoning research, characterized by keywords such as collaboration, interference, science, scientific theory, mathematics teacher, math, and mathematical achievement. The focus of this cluster shows that the study of mathematical reasoning is not developed in isolation within the domain of mathematics, but rather through interaction with other disciplines, particularly science, and through collaboration among actors in the context of learning. The presence of the term collaboration indicates the research’s attention to collaborative learning as a means of facilitating discussion, exchange of ideas, and social construction of mathematical arguments. Meanwhile, the term interference refers to studies on the influence of cross-concepts or cross-disciplines—for example, between science and mathematics—which can support or hinder students’ mathematical reasoning processes. The emergence of the keyword "mathematics teacher" emphasizes the role of teachers as the primary link between scientific theory, learning practices, and students’ development of reasoning abilities. In addition, the connection to scientific theory shows that the development of mathematical reasoning in this cluster is grounded in a strong theoretical foundation and a systematic scientific approach. Overall, this cluster emphasizes that mathematical reasoning is understood as a cross-disciplinary competency that develops through collaboration, the integration of science and mathematics, and the strategic role of teachers in guiding students' achievement and the quality of theirhematical reasoning [36], [37].

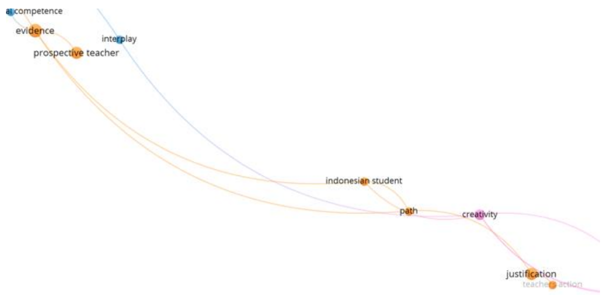


Figure 15. Cluster 7 groups related to mathematical reasoning

Cluster 7 highlights the argumentative and evidentiary dimensions of mathematical reasoning, characterized by keywords such as evidence, justification, path, prospective teacher, teachers’ action, and Indonesian student. The focus of this cluster shows that research on mathematical reasoning pays close attention to how students and prospective teachers construct, evaluate, and communicate mathematical reasoning logically and evidence-based. The presence of the words evidence and justification reflects an emphasis on the process of proof, argument validation, and students’ ability to support mathematical conclusions with accountable reasoning. Meanwhile, the word path indicates the study of the thought process or the sequence of strategies used in problem-solving, an important indicator of the depth of mathematical reasoning. The emergence of the terms prospective teacher and teachers’ action confirms that this cluster also focuses on the role of teachers—especially prospective teachers—in facilitating argumentation and proof in the classroom. In addition, the term Indonesian student indicates a strong empirical grounding in locally based studies, especially in examining the characteristics of students’ mathematical reasoning in Indonesia. Overall, this cluster emphasizes that mathematical reasoning is an argumentative ability that involves evidence, justification, and structured thinking, with teachers playing a key role in shaping the quality of students'easoning [2].

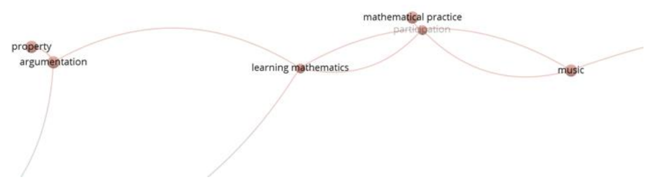


Figure 16. Cluster 8 groups related to mathematical reasoning

Cluster 8 emphasizes aspects of argumentative practice and active participation in mathematical reasoning, as indicated by keywords such as argumentation, learning mathematics, mathematical practice, participation, property, and music. The focus of this cluster shows that mathematical reasoning research is not only understood as an individual cognitive process, but also as a social activity that develops through mathematical practice and students' active involvement in learning. The presence of the words argumentation and mathematical practice indicates attention to how students construct, communicate, and defend mathematical arguments in real learning contexts. Meanwhile, the term participation emphasizes the importance of student interaction and involvement in discussions, explorations, and negotiations of mathematical meaning as part of the development of reasoning. The emergence of the word 'property' reflects a focus on understanding mathematical concepts and properties as the basis for constructing valid arguments, while the presence of music indicates a contextual, interdisciplinary approach to supporting meaningful mathematics learning. Overall, this cluster emphasizes that mathematical reasoning develops optimally through authentic argumentation practices, active student participation, and learning contexts that enable collaborative exploration and communication of mathematical ideas [38].

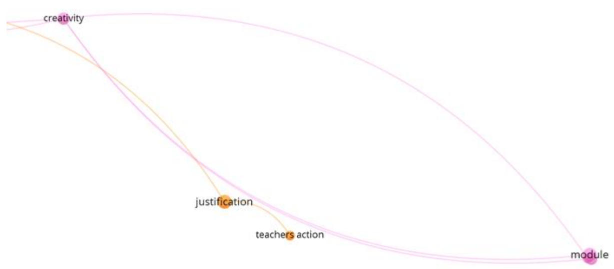


Figure 17. Cluster 9 groups related to mathematical reasoning

Cluster 9 highlights the dimensions of autonomy and creativity in mathematical reasoning, represented by the keywords autonomy, creativity, inquiry, and module. The focus of this cluster shows that research on mathematical reasoning is increasingly directed towards developing students' abilities to think independently, creatively, and reflectively in solving mathematical problems. The presence of the word autonomy indicates attention to students' ability to control their own thinking processes, choose strategies, and make mathematical decisions without excessive dependence on teacher guidance. Meanwhile, creativity reflects efforts to encourage flexibility in thinking, develop alternative solutions, and foster originality in mathematical reasoning. The word inquiry emphasizes an inquiry-based learning approach, in which students are encouraged to ask questions, explore patterns, and build knowledge through an investigative process. The presence of modules indicates the role of structured teaching materials in fostering student autonomy and creativity. Thus, this cluster emphasizes that mathematical reasoning is not only about logical accuracy but also aboutdents' independence of thought and creativity in constructing meaningful mathematical understanding [39], [34].


Figure 18. Cluster 10 groups related to mathematical reasoning

Cluster 10 emphasizes aspects of individual differences and investigative approaches in mathematical reasoning, as indicated by the keywords difference, investigation, mathematical skill, and prospective mathematics teacher. The focus of this cluster is research on mathematical reasoning that largely examines variations in mathematical reasoning abilities among individuals and groups, including students and prospective mathematics teachers. The presence of the term "difference" indicates attention to the heterogeneity of reasoning abilities, cognitive backgrounds, and differences in mathematical thinking strategies. Meanwhile, the word "investigation" reflects the use of exploratory and analytical approaches to understand the reasoning process more deeply, rather than simply measuring the final results. The emergence of mathematical skill shows a close relationship between basic mathematical skills and the quality of reasoning displayed, while prospective mathematics teachers emphasize the importance of mastering mathematical reasoning as a foundation for pedagogical professionalism. Overall, this cluster emphasizes that the development of mathematical reasoning should consider individual differences and be supported by an investigative approach that can comprehensively reveal the dynamics of mathematical thinking[40].


Figure 19. Cluster 11 groups related to mathematical reasoning

Cluster 11 focuses on problem-solving strategies in mathematical reasoning, characterized by the keywords arithmetic word problem, word problem, strategy, and exploratory study. The focus of this cluster shows that mathematical reasoning research often uses story problems as the main context for examining how students interpret problem situations, construct mathematical representations, and design logical solution strategies. The presence of the term strategy emphasizes the importance of selecting, adapting, and evaluating problem-solving strategies as an integral part of mathematical reasoning. Meanwhile, an exploratory study reflects the tendency of research to examine students' thinking processes in depth, including errors in reasoning and misconceptions that arise when solving contextual problems. Thus, this cluster confirms that mathematical reasoning is closely related to the ability to solve contextual problems, particularly through story problems that require integrated understanding, interpretation, and reasoning [41].

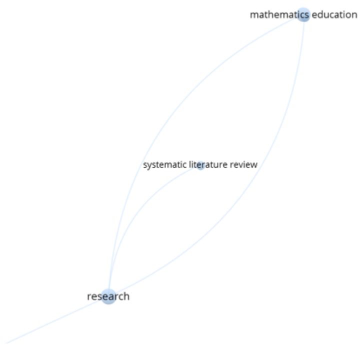


Figure 20. Cluster 12 groups related to mathematical reasoning

Cluster 12 represents the meta-research dimension in mathematical reasoning studies, characterized by the keywords mathematics education, research, systematic literature review, and systematic review. The focus of this cluster shows that, in recent years, there has been an increase in attention to scientific synthesis efforts that systematically map the direction, main findings, and gaps in mathematical reasoning research. The presence of the terms systematic literature review and systematic review indicates a tendency to consolidate previous research findings to obtain a more comprehensive, evidence-based understanding. Meanwhile, the words' research' and 'mathematics education' reinforce the centrality of mathematical reasoning in mathematics education research. This cluster confirms that the study of mathematical reasoning has entered a reflective and integrative stage, in which research focuses not only on development and implementation but also on evaluation and systematic mapping of knowledge to support future theory and practice development [42].

Overall, the twelve clusters that have formed indicate that mathematical reasoning research is developing into a multidimensional field encompassing cognitive, pedagogical, evaluative, and contextual aspects. The interrelationships between clusters confirm that mathematical reasoning cannot be separated from the role of teachers, student learning experiences, language, assessment, and individual differences. Thus, this cluster map reinforces the position of mathematical reasoning as a core competency developed through the comprehensive integration of theory, learning practices, and mathematics education evaluation [6].

In overlay visualization, the temporal dimension of mathematical reasoning research development is more clearly visible through keyword coloring based on the average year of appearance. Darker or bluish colors indicate keywords that were dominant in the early phase of the research period (around 2016–2019), while lighter to yellowish colors represent more recent themes (around 2021–2024). Keywords such as mathematics teacher, experience, instruction, and argumentation tend to be darker in color, indicating that early research on mathematical reasoning focused heavily on pedagogical aspects, the role of teachers, and the conceptual foundations of mathematical reasoning. Conversely, keywords such as assessment, evaluation, spatial reasoning, mathematical ability, evidence, and justification appear in lighter colors, indicating a shift in research focus towards more systematic measurement, validation, and strengthening of students' mathematical reasoning abilities. This pattern indicates that the study of mathematical reasoning has evolved from a conceptual-pedagogical orientation towards a more applicative and evaluative approach, in line with the increasing demand for higher-order thinking skills-based learning [43], [44], [45].

In density visualization, color intensity represents the density of keyword occurrences in the research network. The green to light yellow areas indicate keywords with high frequency of occurrence and relevance. In this map, terms such as relationship, experience, mathematical ability, evidence, and justification are concentrated in the highest-density areas, indicating that the core of mathematical reasoning research centers on understanding mathematical relationships, student learning experiences, and the process of proving and justifying arguments. Surrounding this core area is a zone of medium density that includes keywords such as assessment, spatial reasoning, language, and feedback, indicating the important role of assessment, representation, and pedagogical interaction in supporting the reasoning process. This visualization confirms that mathematical reasoning research is not only oriented toward learning outcomes but also toward the cognitive and pedagogical processes that underlie the formation of mathematical reasoning [22].

An important novelty reflected in this bibliometric map is the increasingly strong shift in mathematical reasoning research towards integration with digital technology and innovative learning approaches. In addition to the emphasis on pedagogical and assessment aspects, the overlay and density visualizations show the emergence of current themes that lead to the use of digital media, technology-based learning environments, and problem-based learning approaches as means to strengthen students' mathematical reasoning. This development opens up great opportunities for integrating immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) into mathematics learning, particularly to support spatial reasoning, the visualization of abstract concepts, and deeper exploration of contextual problems. In addition, deep learning-oriented problem-based learning approaches are increasingly relevant for encouraging students not only to solve problems procedurally but also to build arguments, evaluate evidence, and provide reflective mathematical justifications 46].

Thus, mathematical reasoning is no longer positioned solely as an individual cognitive ability, but as a competency that can be developed through rich, authentic, and challenging digital learning designs. This novelty confirms that the direction of future research is wide open to the development of digital technology-based learning models and to the integration of AR/VR with problem-based learning and deep learning approaches as key strategies for strengthening mathematical reasoning in 21st-century mathematics education.

## 4. CONCLUSION

This study provides a bibliometric mapping of mathematical reasoning research over the past decade based on Scopus-indexed publications. The findings indicate that mathematical reasoning has developed into a structured and multidimensional field, integrating cognitive, pedagogical, evaluative, and contextual dimensions, with an increasing emphasis on strengthening students' reasoning competencies through innovative, evidence-based learning approaches.

Theoretically, this study clarifies the intellectual structure and thematic evolution of mathematical reasoning research. In practice, it offers guidance to researchers and educators for identifying emerging themes and designing reasoning-oriented instructional strategies.

This study is limited to Scopus-indexed English journal articles and bibliometric metadata analysis, which may not fully represent the entire body of related research. Future studies are encouraged to expand database coverage, diversify keywords, and conduct deeper empirical investigations, particularly regarding the integration of digital technology and problem-based learning to enhance mathematical reasoning.

Overall, this research contributes a strategic scientific map that supports the advancement of mathematical reasoning as a core competency in contemporary mathematics education and informs broader educational development in the 21st century.

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