



Analysis bibliometrics study reasoning mathematical in mathematics education: trends, structures, and implications for elementary school education

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Article info	Abstract
Keywords: bibliometric analysis, elementary education, mathematical reasoning, mathematics education, problem solving.	Mathematical reasoning is a fundamental competency in mathematics education that supports students' logical, critical, and systematic thinking skills. Along with technological advancements and the growing demands of twenty-first-century learning, research on mathematical reasoning has expanded significantly and become increasingly multidisciplinary. This study employed a bibliometric analysis to map the global development of research on mathematical reasoning in mathematics education. Data were retrieved from the Scopus database using the keywords "mathematical reasoning" and "learning". A total of 685 documents published between 1979 and 2026 were analyzed using Biblioshiny. The analysis focused on identifying publication trends, thematic structures, collaboration patterns, and the geographical distribution of research contributions. The results reveal a substantial increase in publications, particularly since 2006, with research productivity peaking in 2023. The field is organized around three major domains: pedagogical aspects of mathematics learning, mathematical modeling development, and technology integration, including artificial intelligence and machine learning. Furthermore, research contributions are predominantly led by the United States and China, supported by strong international collaboration networks. This study concludes that mathematical reasoning research has evolved into a global, interdisciplinary, and technology-oriented field. However, its implementation in elementary mathematics education remains relatively limited. The findings provide a comprehensive overview of the development of research on mathematical reasoning and offer insights for designing more contextually grounded and practice-oriented mathematics learning approaches at the elementary school level.

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1. Introduction

Mathematical reasoning is widely recognized as a fundamental competency in mathematics education because it enables students to think logically, analytically, systematically, and reflectively when engaging with mathematical ideas. Within contemporary mathematics education, reasoning is viewed not only as a learning outcome but also as an intellectual process through which learners construct, test, justify, and validate mathematical knowledge (Jeannotte & Kieran, 2017). Consequently, international educational organizations have identified reasoning as a core competency that should be fostered through mathematics instruction to support higher-order thinking skills and mathematical literacy (OECD, 2021).

A growing body of research has demonstrated that strong reasoning skills are positively associated with problem-solving ability, academic achievement, learning motivation, and critical thinking (Supriadi et al., 2024; Xue et al., 2023). Similarly, Lathifah et al. (2021) found that students' ability to understand problems, select appropriate solution strategies, and verify the validity of their solutions plays a crucial role in successful mathematical problem solving at the elementary school level. These findings suggest that mathematical reasoning serves as a foundational component for the development of more advanced mathematical thinking throughout subsequent stages of education.

At the elementary school level, mathematical reasoning plays a strategic role as a foundation for the development of higher-order thinking skills required in subsequent stages of education. Students who are accustomed to making generalizations, constructing arguments, identifying patterns, and drawing logical conclusions tend to demonstrate a deeper understanding of mathematical concepts than those who rely primarily on procedural memorization. Research by Cindyana et al. (2022) found that differentiated instruction, supported by geometry teaching materials grounded in the Realistic Mathematics Education (RME) approach, significantly improved elementary students' mathematical reasoning abilities. This finding suggests that the development of mathematical reasoning requires learning experiences that are contextual, meaningful, and aligned with students' cognitive development. Similarly, Agustina et al. (2021) reported that cooperative learning provides opportunities for students to engage in discussion, exchange ideas, and actively construct mathematical understanding, thereby fostering logical thinking and mathematical problem-solving skills.

Beyond its role in conceptual understanding, mathematical reasoning is closely associated with the development of twenty-first-century competencies, particularly the 4C skills of critical thinking, creativity, collaboration, and communication. Kurniawan (2021) found that the implementation of Higher-Order Thinking Skills (HOTS)-based assessment integrated with 4C competencies significantly enhanced elementary students' critical thinking skills. This finding highlights the close relationship between mathematical reasoning and critical thinking, as both require learners to analyze information, evaluate arguments, and make logically justified decisions. Furthermore, studies conducted in elementary school settings have shown that collaborative learning activities and group discussions provide opportunities for students to articulate mathematical ideas, negotiate meaning, and refine their understanding through social interaction, thereby supporting the development of stronger mathematical reasoning abilities (Agustina et al., 2021). Therefore, fostering mathematical reasoning should be considered an essential component of mathematics education, as it contributes not only to mathematical proficiency but also to broader competencies required for lifelong learning and active participation in an increasingly complex, technology-driven society.

In response to these educational demands, various instructional approaches have been developed to foster students' mathematical reasoning abilities. Approaches such as Realistic Mathematics Education (RME), Problem-Based Learning (PBL), project-based learning, and inquiry-based learning have been widely reported to support the development of mathematical reasoning by actively engaging students in problem-solving processes, mathematical argumentation, and reflective thinking (Jäder et al., 2017). Such learning environments encourage students to formulate conjectures, justify their reasoning, and evaluate alternative solution strategies, all of which are fundamental components of mathematical reasoning. As noted by Conner et al. (2014), problem-solving activities that require students to explain their thinking, construct arguments, and defend their solutions contribute not only to stronger reasoning skills but also to deeper conceptual understanding of mathematics. At the elementary school level, students' success in solving mathematical problems is closely related to their ability to interpret available information, connect it with relevant mathematical concepts, and select appropriate solution strategies (Lathifah et al., 2021). Consequently, mathematical reasoning is increasingly recognized as a key indicator of effective mathematics learning, particularly within instructional frameworks that promote higher-order thinking and meaningful conceptual understanding.

At the same time, advances in digital technology and Artificial Intelligence (AI) have broadened the scope of research on mathematical reasoning. The integration of technology into mathematics education enables students to engage in more interactive learning experiences through dynamic visualizations, mathematical simulations, adaptive feedback, and personalized learning environments. According to Jeannotte & Kieran (2017), technology can support mathematical exploration, representation, and justification, which are central processes in the development of mathematical reasoning. The rapid growth of digital learning and AI has also created new opportunities to design data-informed, adaptive mathematics learning environments, leading to increased interdisciplinary research across education, technology, and computer science. However, the educational value of technology depends largely on how it is integrated into meaningful learning activities. Technology alone does not automatically enhance students' mathematical reasoning; rather, its effectiveness depends on pedagogical approaches that actively promote mathematical exploration, argumentation, reflection, and conceptual understanding. Therefore, current discussions on mathematical reasoning increasingly emphasize not only technological innovation but also the pedagogical conditions necessary to support meaningful mathematical learning.

Despite the growing body of research on mathematical reasoning, existing studies have primarily examined the effectiveness of specific instructional interventions, including innovative learning models, problem-solving approaches, critical thinking development, cooperative learning, and technology-enhanced instruction. While these studies have provided valuable insights into factors influencing students' mathematical reasoning, their findings are generally limited to particular educational settings and intervention contexts. As a result, the broader development of mathematical reasoning as a research field remains insufficiently understood. In particular, there is still limited evidence regarding how research trends have evolved, how key themes are interconnected, which countries and institutions have contributed most significantly, and what emerging directions may shape future investigations. Therefore, a more comprehensive and systematic approach is needed to map the intellectual structure, thematic evolution, and research trends within the field of mathematical reasoning. Such an approach can provide a broader perspective on the field's development while identifying research gaps and future opportunities that may inform both mathematics education research and educational practice.

Bibliometric analysis has been widely employed to map the development of scientific knowledge across various disciplines, including mathematics education. Previous bibliometric studies have primarily examined broad themes such as mathematics learning, educational technology, STEM education, and mathematical literacy (Cevikbas et al., 2024; Harahap et al., 2025; Hungo et al., 2025). However, studies specifically focusing on mathematical reasoning as an independent research domain remain relatively limited. Existing bibliometric investigations have generally focused on publication trends or thematic distributions, without providing an integrated analysis of the field's conceptual structure, thematic evolution, scientific collaboration patterns, and the geographical distribution of research contributions. Moreover, the implications of these developments for elementary mathematics education have received little attention. Consequently, a gap remains in understanding how mathematical reasoning research has evolved globally and how its development may inform teaching and learning practices in elementary school contexts. Addressing this gap, the present study adopts a multidimensional bibliometric approach that integrates analyses of annual scientific production, thematic trends, co-occurrence networks, collaboration patterns, influential sources, highly cited documents, factorial structures, and country-level scientific contributions. By combining these indicators within a unified analytical framework, this study not only maps the intellectual development of mathematical reasoning research but also discusses its relevance to advancing mathematics learning at the elementary education level.

Despite the growing interest in mathematical reasoning, several research gaps remain. First, bibliometric studies specifically examining the development of mathematical reasoning at a global scale are still relatively scarce. Second, existing studies often focus on a limited set of bibliometric indicators and therefore provide only a partial understanding of the field's intellectual structure, thematic evolution, collaboration patterns, and geographical distribution. As a result, a comprehensive picture of how mathematical reasoning research has developed over time remains underexplored. Third, limited attention has been given to the implications of bibliometric findings for elementary mathematics education, despite substantial evidence indicating that mathematical reasoning plays a critical role in supporting students' problem-solving abilities, critical thinking, and conceptual understanding (Agustina et al., 2021; Cindyana et al., 2022; Lathifah et al., 2021). Addressing these gaps is important not only for advancing the scholarly understanding of mathematical reasoning as a research field but also for informing future efforts to strengthen mathematics learning in elementary school settings.

The novelty of this study lies in its multidimensional bibliometric approach, which integrates annual scientific production, trend topics, co-occurrence networks, collaboration networks, most relevant sources, most globally cited documents, factorial analysis, and country scientific production within a unified analytical framework. Unlike previous bibliometric studies that have primarily focused on broad themes in mathematics education or general publication trends, this study specifically examines mathematical reasoning as an independent field of inquiry. Furthermore, it not only maps the intellectual, thematic, and collaborative development of mathematical reasoning research at the global level but also interprets its relevance to elementary mathematics education. By linking bibliometric findings with pedagogical implications, this study extends beyond descriptive mapping and provides a comprehensive understanding of research trends, emerging themes, and future directions for strengthening mathematical reasoning in elementary school mathematics learning. Consequently, the study offers both a scientific overview of the field's development and an empirical basis for designing

instructional strategies, mathematical learning activities, and future research agendas in elementary mathematics education.

Mathematical reasoning is regarded as a core competency in mathematics education that develops through the interaction of instructional processes, learner characteristics, and the use of educational technology. In elementary education, mathematical reasoning enables students to understand mathematical concepts, make generalizations, construct arguments, and solve problems logically. Accordingly, this study positions mathematical reasoning as a conceptual bridge connecting mathematics learning, educational technology, and elementary mathematics education. Within this framework, mathematics learning serves as the context for developing reasoning skills, educational technology functions as a tool to support and enhance learning processes, and elementary education serves as the setting in which these competencies are cultivated and applied. This conceptual framework provides the foundation for interpreting the research trends, thematic structures, and knowledge networks identified through the bibliometric analysis.

In light of the conceptual framework and research gaps identified above, a comprehensive bibliometric investigation is needed to systematically map the development of research on mathematical reasoning. Accordingly, this study aims to: (1) identify global publication trends in mathematical reasoning research; (2) analyze dominant research themes based on keywords and the conceptual structure of the field; and (3) examine patterns of scientific contribution and international collaboration among countries involved in mathematical reasoning research. Through these objectives, the study seeks to provide a comprehensive overview of the evolution of mathematical reasoning as a research domain, while identifying emerging directions and potential implications for advancing mathematics teaching and learning in elementary education.

2. Method

This study employed a quantitative, descriptive, bibliometric approach to map the global development of research on mathematical reasoning in mathematics education. Bibliometric analysis enables the systematic examination of scientific publication metadata to identify research trends, conceptual structures, and patterns of scholarly collaboration within a particular domain (Donthu et al., 2021). The unit of analysis consisted of publication metadata, including article titles, abstracts, keywords, authors, publication sources, and citation counts. By analyzing this metadata, the study provides a comprehensive overview of the intellectual development and thematic evolution of mathematical reasoning research over time.

Data were retrieved from the Scopus database through a search conducted in the title, abstract, and keyword fields using the search string TITLE-ABS-KEY ("mathematical reasoning" AND "learning"). The data collection process was carried out in January 2026. The inclusion of 2026 publications reflects Scopus's indexing status at the time of data retrieval. Therefore, the publication range reported in this study follows the metadata available in Scopus, while the interpretation of the most recent year is treated cautiously because indexing for 2026 may still be incomplete. To ensure relevance and consistency, the search was limited to English-language journal articles related to mathematics learning contexts. The initial search yielded 1,230 documents. Following a multi-stage screening process based on predefined inclusion and exclusion criteria, a final dataset of 685 articles was retained for analysis. The selected search terms were intended to capture publications that explicitly addressed mathematical reasoning

within learning and educational contexts. The search was conducted globally, without restricting educational level, thereby enabling the identification of research trends across different educational settings.

To ensure the quality and relevance of the dataset, inclusion and exclusion criteria were established prior to the screening process. The inclusion criteria comprised Scopus-indexed journal articles that addressed mathematical reasoning in learning and educational contexts, were published in English, and were published between 1979 and 2026. The exclusion criteria included conference papers, book chapters, editorials, notes, errata, publications not directly related to mathematical reasoning in educational settings, and documents published in languages other than English.

The data selection procedure was adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which consists of four stages: identification, screening, eligibility, and inclusion. During the identification stage, all records were retrieved from the Scopus database using the predefined search query. In the screening stage, documents were evaluated based on the relevance of their titles and abstracts to the research topic. The eligibility stage involved removing duplicate records and excluding publications that did not meet the inclusion criteria. Following this process, a final dataset of 685 documents was retained and subsequently analyzed using bibliometric techniques. The document selection process is summarized in Table 1.

Table 1. Document selection process based on the PRISMA framework

Selection Stage	Number of Documents	Description
Identification	1030	Initial records retrieved from Scopus
Screening	987	Records with titles and abstracts relevant to the research topic
Eligibility	712	Records remaining after duplicate removal and relevance assessment
Inclusion	685	Final dataset included in the bibliometric analysis

Documents were excluded if they were not directly related to mathematical reasoning within educational contexts, were identified as duplicate records, or did not satisfy the predefined inclusion criteria. After completing all selection stages, the final dataset was exported in BibTeX format and analyzed using Biblioshiny. This procedure ensured that only relevant, valid, and high-quality publications were included in the bibliometric analysis, thereby enhancing the reliability and consistency of the findings.

The data were analyzed using Biblioshiny, a web-based interface of the Bibliometrix package in R (Aria & Cuccurullo, 2017). A comprehensive bibliometric analysis was conducted to examine the intellectual structure and development of mathematical reasoning research. The analysis included descriptive performance indicators, such as main information and annual scientific production, to identify publication trends and research growth over time. Thematic development was explored through trend topics, co-occurrence network analysis, and tree map visualization. Scholarly influence was assessed using the most relevant sources and most globally cited documents, while collaboration network analysis was employed to examine patterns of scientific collaboration among researchers and institutions (Donthu et al., 2021). Furthermore, conceptual structure analysis was performed using Multiple Correspondence Analysis (MCA)-based

factorial analysis to identify relationships among research themes and conceptual clusters (Zhang et al., 2023). Finally, the country's scientific production was used to investigate the global distribution of research contributions in the field of mathematical reasoning.

The validity and reliability of the dataset were enhanced by using the Scopus database, which employs rigorous indexing and quality control procedures. In addition, data cleaning was conducted systematically to minimize metadata inconsistencies, duplicate records, and potential retrieval errors. Data validity was further strengthened through manual verification during the screening and eligibility stages to ensure each publication's relevance to the research focus. The use of Biblioshiny, a widely adopted tool in bibliometric research, also contributed to the consistency and accuracy of the analytical process (Aria & Cuccurullo, 2017). Furthermore, all analytical procedures were conducted using transparent, replicable workflows within the Biblioshiny environment, thereby enhancing the transparency, consistency, and reliability of the study's findings.

3. Results

This section presents the findings of the bibliometric analysis of mathematical reasoning research. The results cover publication characteristics, publication trends, thematic development, conceptual structure, influential publications, collaboration patterns, and country contributions. Interpretations and broader implications of these findings are presented in the Discussion section.

3.1 General characteristics of the documents

The main analysis revealed that the dataset comprised 685 documents published between 1979 and January 2026. This publication period was consistently determined based on the metadata retrieved from the Scopus database at the time of data collection. The documents were distributed across 362 publication sources and involved 2,119 authors. Of the total publications, 93 were single-authored, while the majority were collaborative.

The international co-authorship rate was 18.54%, with an average of 3.42 authors per document. The average age of the documents was 11.3 years, and the average number of citations per document was 24.36. Figure 1 summarizes the main characteristics of the dataset analyzed in this study.



Figure 1. Main information

3.2 Research topic development

The trend topics analysis revealed a shift in research focus from foundational themes, such as mathematical reasoning, learning, and students, toward more application-oriented topics. In subsequent periods, keywords such as problem solving, critical thinking, and mathematics education became increasingly prominent. This pattern indicates that mathematical reasoning has frequently been examined in relation to higher-order thinking skills and problem-solving processes.

In the most recent period, technology-related keywords, including digital learning, artificial intelligence, and machine learning, have emerged more prominently within the literature. The appearance of these themes reflects the growing presence of technology-oriented topics in mathematical reasoning research. Figure 2 illustrates the temporal evolution of research topics and keywords across the study period.

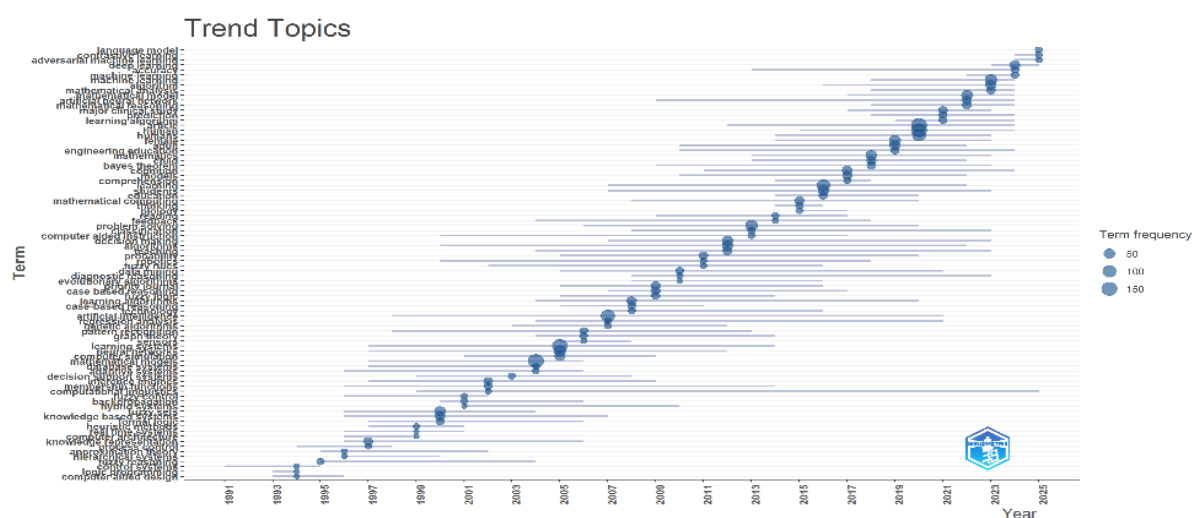


Figure 2. Trend topics

3.3 Conceptual structure of the research field

The co-occurrence network analysis identified three major thematic clusters within the mathematical reasoning literature. The first cluster was centered on mathematics learning and included keywords such as 'learning' and 'students'. The second cluster comprised higher-order thinking skills, as reflected in keywords such as problem-solving and critical thinking. The third cluster was associated with educational technology and included keywords such as digital learning, artificial intelligence, and machine learning.

The network visualization also revealed strong connections among mathematical reasoning, problem solving, and critical thinking. In addition, technology-related keywords formed a distinct thematic cluster within the broader research network. Figure 3 illustrates the relationships among keywords and the conceptual structure of mathematical reasoning research based on keyword co-occurrence patterns.

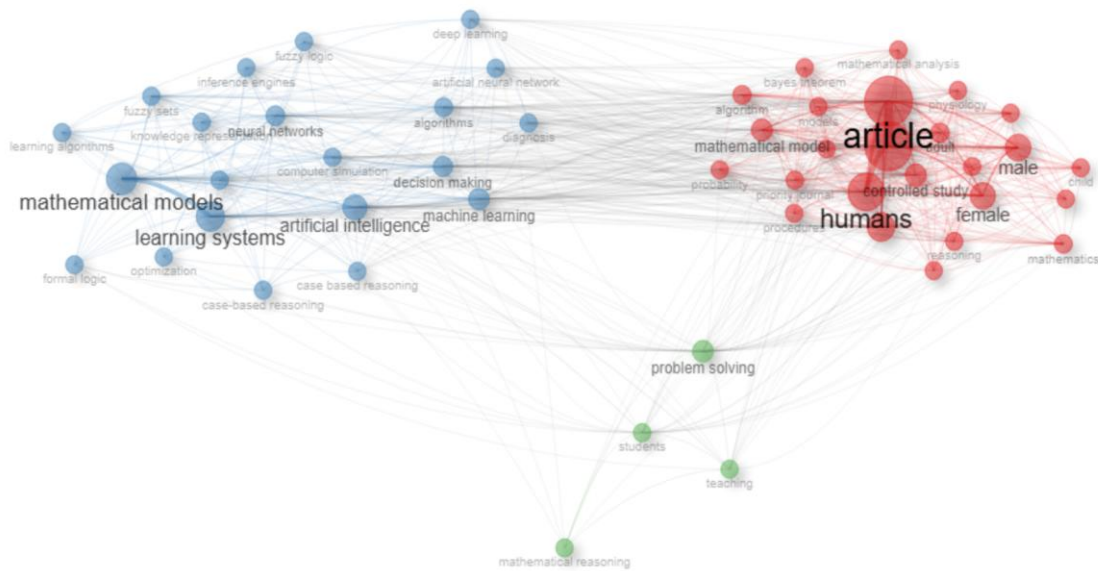


Figure 3. Co-occurrence network

3.4 Most relevant source

The analysis of the most relevant sources identified Education Sciences as the most productive publication source, contributing 25 documents. Other prominent sources included Expert Systems with Applications, Artificial Intelligence, and IEEE Journal of Biomedical and Health Informatics, each publishing 12 documents. School Science and Mathematics contributed 10 documents, while several additional sources also appeared among the leading publication outlets within the dataset. This distribution indicates that mathematical reasoning research is published not only in mathematics education journals but also in interdisciplinary outlets related to artificial intelligence, expert systems, and digital learning, as shown in Figure 4.

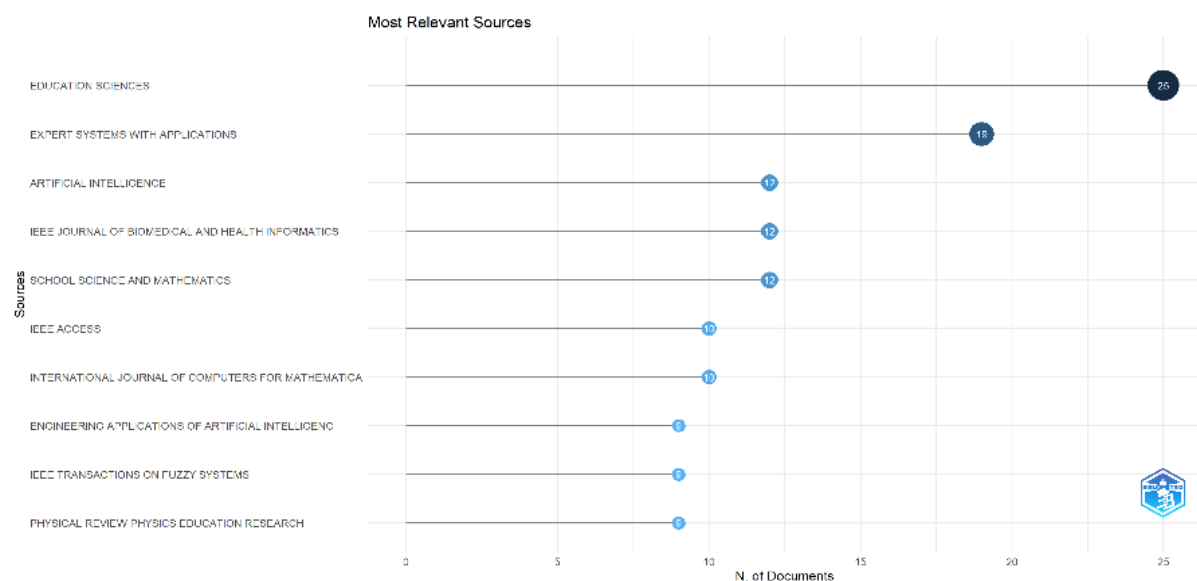


Figure 4. Most relevant sources

3.5 Most globally cited documents

The analysis of the most globally cited documents identified several highly influential publications within the dataset. The most cited document was authored by Kuipers (1991), with 590 global citations, followed by Umeda (1996) with 517 citations, Richens et al. (2020) with 470 citations, and Tavtigian et al. (2018) with 405 citations. These publications represent some of the most influential works in the dataset and have received substantial scholarly attention, as evidenced by their global citation counts. Table 2 presents the distribution of the most-cited documents in mathematical reasoning research.

Table 2. Most globally cited documents

Paper	DOI	Total Citations	TC per Year	Normalized TC
Kuipers Bj, 1991, Rob Autom Syst	10.1016/0921-8890(91)90014-C	590	16.86	3.70
Umeda Y, 1996, Artif Intell Eng Des Anal Manuf	10.1017/s0890060400001621	517	17.23	8.75
Richens Jg, 2020, Nat Commun	10.1038/s41467-020-17419-7	470	78.33	9.23
Tavtigian Sv, 2018, Gen Med	10.1038/gim.2017.210	405	50.63	8.03
Champagne Ab, 1980, Am J Phys	10.1119/1.12290	309	6.72	1.00
Xu DL, 2007, Expert Sys Appl	10.1016/j.eswa.2005.11.015	285	15.00	4.14
Novick Lr, 1991, J Exp Psychol Learn Mem Cogn	10.1037/0278-7393.17.3.398	285	8.14	1.79
Van Den Bergh D, 2020, Annee Psychol	10.3917/anpsy1.201.0073	254	42.33	4.99
Magesh Pr, 2020, Comput Biol Med	10.1016/j.compbiomed.2020.104041	238	39.67	4.67
Mercer N, 2006, Lang Educ	10.2167/le678.0	231	11.55	5.00

3.6 Collaboration network

The collaboration network analysis revealed that several interconnected author clusters characterize the field of mathematical reasoning research. Each cluster represents a group of researchers linked by co-authorship and shared publications. The network visualization also showed several authors occupying central positions that connect different clusters within the collaboration network. These findings indicate that collaborative authorship is a common characteristic of mathematical reasoning research. Figure 5 illustrates the structure of the author collaboration network and the relationships among research groups within the dataset.

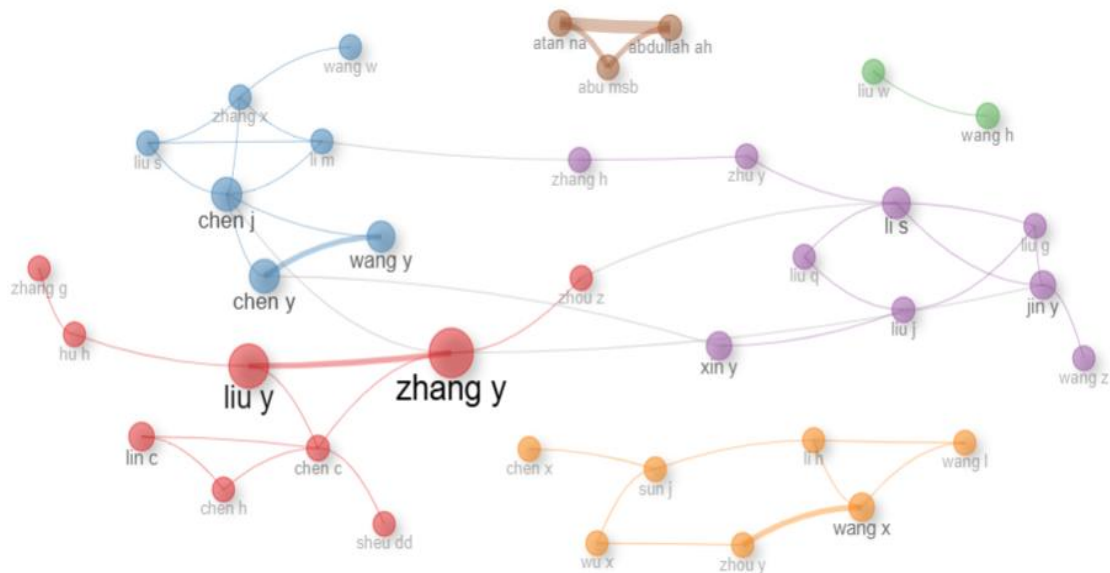


Figure 5. Collaboration network

3.7 Annual scientific production

The annual scientific production analysis revealed that publications on mathematical reasoning remained relatively limited and stable during the early years of the study period. A sustained increase in publication output became evident after 2006, followed by a continuous upward trend that culminated in the highest number of publications in 2023. In the subsequent years, publication output showed some fluctuations, particularly for the most recent period, as document indexing and database updates were still ongoing at the time of data collection.

Overall, the annual publication pattern demonstrates a marked growth in the volume of mathematical reasoning research over the study period. Figure 6 illustrates the annual distribution of publications from 1979 to January 2026.

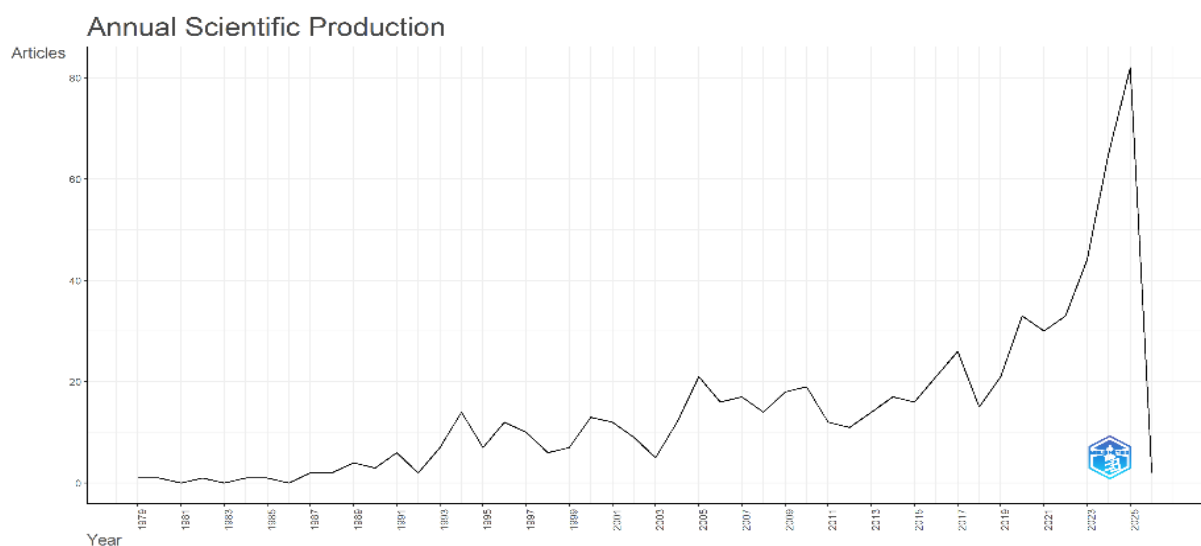


Figure 6. Annual scientific production

3.8 Dominant theme distribution

The tree map analysis identified several highly represented categories within the dataset. The most frequent categories were article (152 documents), mathematical models (151 documents), human (147 documents), and learning systems (137 documents). Other notable categories included problem solving (71 documents) and neural networks (70 documents). Overall, the distribution illustrates the relative prominence of topics and subject areas in mathematical reasoning research. Figure 7 presents the thematic distribution by frequency of occurrence in the dataset.

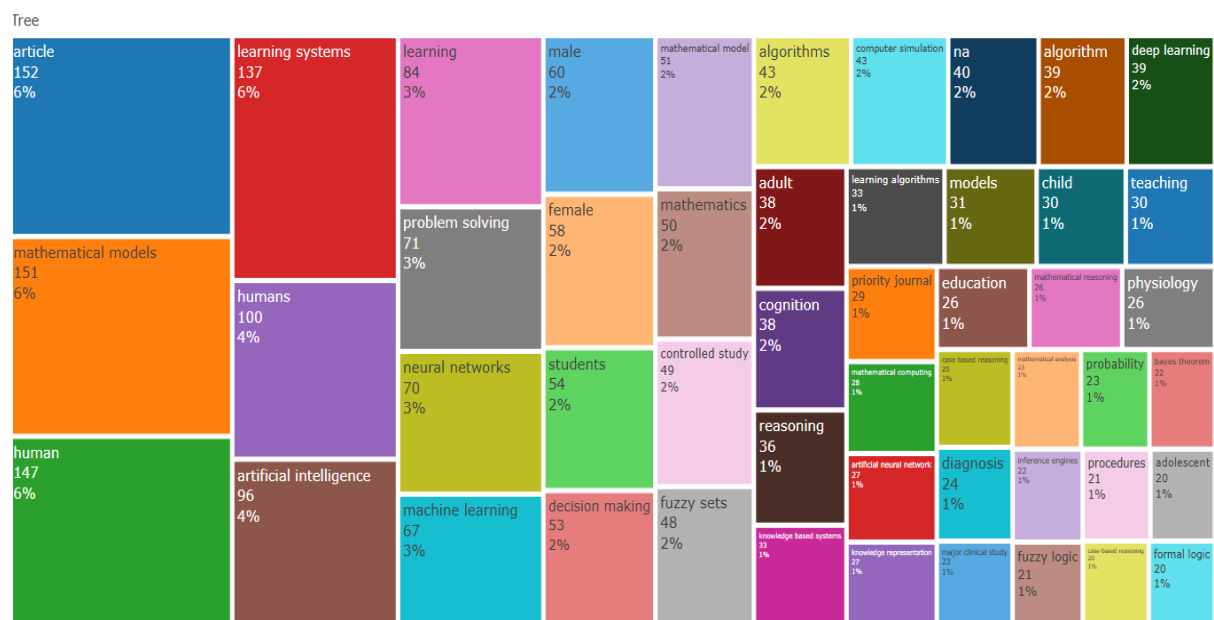


Figure 7. Tree map

3.9 Conceptual structure based on factorial analysis

The factorial analysis, generated through the conceptual structure map, revealed two principal dimensions underlying the research field. The first dimension accounted for 73.63% of the total variance and differentiated clusters associated with computational and technology-related topics from those more closely linked to learning-related themes. The second dimension explained 16.93% of the variance and reflected the separation between pedagogical themes and technical-oriented topics.

The conceptual structure map illustrates the distribution of research themes according to their conceptual proximity and association within the mathematical reasoning literature. Figure 8 presents the results of the factorial analysis based on Multiple Correspondence Analysis (MCA).

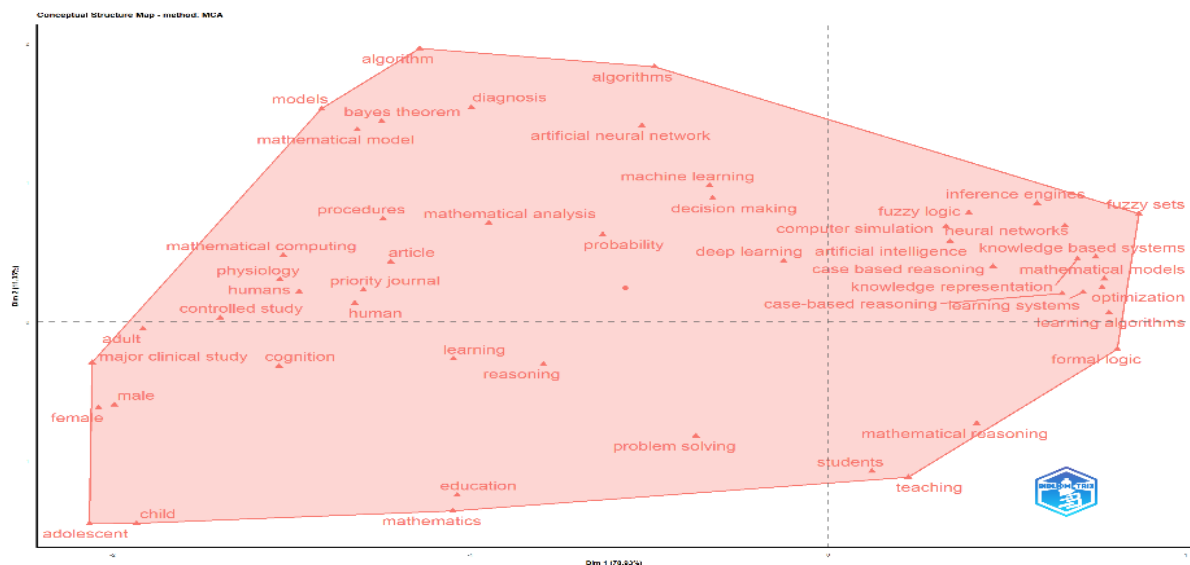


Figure 8. Factorial analysis

Table 3. Country scientific production

Country	Freq
Usa	465
China	244
Uk	83
Germany	61
Spain	51
Italy	50
India	40
France	38
Indonesia	36
Canada	32

3.10 Country scientific production

The country-level analysis of scientific production identified the United States as the leading contributor, with 465 publications, followed by China with 244. Other countries with notable publication outputs included the United Kingdom (83 publications), Germany (61 publications), Spain (51 publications), Italy (50 publications), India (40 publications), France (38 publications), Indonesia (36 publications), and Canada (32 publications), as presented in Table 3. The distribution of publications across countries indicates varying levels of research output within the mathematical reasoning literature. Table 3 summarizes the publication contributions of the most productive countries included in the dataset.

4. Discussion

Mathematical reasoning is understood as a cognitive process that involves constructing arguments, formulating conjectures, validating relationships among mathematical concepts,

and drawing logical conclusions based on mathematical evidence (Alakayleh, 2025; Bosch et al., 2024). This competence is not developed solely through procedural mastery; rather, it emerges through students' active engagement in mathematical exploration, representation, argumentation, and reflection. This perspective serves as the foundation for interpreting the bibliometric findings of the present study.

The results indicate that research on mathematical reasoning has grown steadily since 2006, reaching its peak in 2023. This growth reflects a broader shift in mathematics education research from a predominantly procedural orientation toward the development of more sophisticated forms of mathematical thinking (Diniyarti & Agustika, 2023; Rabbani & Puspita, 2025). From a thematic perspective, the field has evolved from an emphasis on learning and problem-solving to a broader focus on educational technology, artificial intelligence, and machine learning. This transition suggests that mathematical reasoning has increasingly developed into a multidisciplinary area of inquiry that extends beyond the traditional boundaries of mathematics education.

However, it is important to note that many highly cited publications, particularly those in neural networks, expert systems, and computational research, do not directly address mathematics learning in elementary school settings. Therefore, these thematic patterns should be interpreted as indicators of the broader intellectual structure of mathematical reasoning research rather than as direct representations of classroom practices in elementary mathematics education. This interpretive boundary is maintained throughout the discussion of the findings.

The dominance of the United States (465 publications) and China (244 publications) reflects the strong research ecosystems of both countries and their active engagement in integrating digital technologies into educational contexts. Recent studies suggest that technology-enhanced learning environments can support the development of mathematical reasoning when they are embedded within appropriate pedagogical frameworks. For example, Nugraha and Susanti (2025) found that AI-based applications such as Symbolab can assist students in formulating problems, manipulating mathematical symbols, and constructing logical conclusions. Similarly, Alakayleh (2025) reported that AI-supported tutoring systems significantly improved students' abilities in conjecturing, mathematical justification, representation, and metacognitive awareness compared with conventional instructional approaches.

Nevertheless, it is important to acknowledge that most of these studies were conducted in broader educational contexts and did not specifically target elementary school students. Consequently, their applicability to elementary mathematics education requires further empirical validation. Li and Manzari (2025) emphasized that the successful integration of artificial intelligence in mathematics education depends largely on teacher readiness and supportive learning environments, both of which remain significant challenges in many elementary schools. This suggests that the use of technology in elementary mathematics classrooms should be designed to enhance students' reasoning processes rather than merely accelerate the production of correct answers.

In contrast, the contributions of European countries, particularly the United Kingdom (83 publications), Germany (61 publications), and Spain (51 publications), reflect a complementary perspective that emphasizes the pedagogical dimensions of mathematical reasoning. Research in this context has focused extensively on mathematical argumentation, proof, and knowledge construction. Bosch et al. (2024) argued that argumentation and proof play a central role in geometry and algebra learning because they enable learners to construct, test, and validate

relationships among mathematical concepts. This perspective is particularly relevant to elementary mathematics education, as it highlights that the development of mathematical reasoning does not necessarily depend on advanced technologies but can be fostered through instructional practices that position reasoning and sense-making at the core of learning.

Extending this global perspective, Indonesia (36 publications) demonstrates a distinct research trajectory compared with countries that dominate publication output. While the global literature increasingly incorporates artificial intelligence and computational approaches, Indonesian research has focused more on instructional models designed to promote students' mathematical reasoning. A prominent example is the widespread use of Problem-Based Learning (PBL), which has been shown to support higher-order thinking skills within relatively resource-constrained educational settings (Julyasary et al., 2024). Similarly, Prastitasari et al. (2022) reported that integrating Problem-Based Learning with the Simultaneous Roundtable and Quick on the Draw strategies enhanced student engagement, critical thinking, and mathematics achievement at the elementary level. These findings suggest that the development of mathematical reasoning in Indonesia is primarily driven by pedagogical innovation and classroom-based instructional improvement rather than by the adoption of advanced technological systems.

Indonesia's position among the ten most productive countries in mathematical reasoning research offers a valuable opportunity to advance studies more closely aligned with the needs of elementary mathematics education. A growing body of research suggests that developing students' mathematical competencies is more effective when learning and assessment are connected to meaningful experiences. For example, Saputro and Anugraheni (2020) reported that Discovery Learning and Problem-Solving approaches effectively enhanced elementary students' mathematical problem-solving abilities. Similarly, Rahartiningsih et al. (2025) developed an ethnomathematics-based numeracy assessment instrument aligned with the Minimum Competency Assessment (AKM), which was found to be valid, practical, and effective for elementary school students. The incorporation of local cultural contexts into assessment practices demonstrates that numeracy and mathematical reasoning can be strengthened through contextualized learning experiences without relying on sophisticated technological interventions. These findings suggest that the development of mathematical reasoning in Indonesia has considerable potential to be advanced through pedagogical innovations responsive to students' cultural backgrounds and learning needs.

Taken together, the patterns identified across these regions reveal a significant imbalance in the current development of mathematical reasoning research. While a substantial proportion of recent studies have increasingly focused on artificial intelligence, machine learning, and computational modeling, research that explicitly examines the development of mathematical reasoning within the context of elementary mathematics education remains comparatively limited. This disparity suggests that advances in technological and computational domains have progressed more rapidly than pedagogical research aimed at understanding how mathematical reasoning develops in young learners. Consequently, a critical research gap persists regarding the design of learning environments that are developmentally appropriate and capable of fostering mathematical reasoning in elementary classrooms.

Evidence from elementary mathematics education indicates that the development of mathematical reasoning is strongly influenced by the quality of students' learning experiences rather than by the adoption of particular technologies or instructional models alone. Studies involving GeoGebra-assisted learning (Supriyadi et al., 2023), Discovery Learning and Problem

Solving (Saputro & Anugraheni, 2020), Problem-Based Learning (Herliati, 2022), and mathematical representation through Problem-Based Learning (Islamati et al., 2021) consistently demonstrate that exploration, discussion, representation, argumentation, and problem-solving are central processes through which students construct mathematical understanding. Across these studies, mathematical reasoning emerges not as an isolated skill but as a product of active engagement with mathematical ideas. This pattern suggests that effective reasoning development depends on learning environments that encourage students to formulate conjectures, justify solutions, evaluate arguments, and communicate mathematical thinking meaningfully.

Beyond instructional and cognitive dimensions, findings from elementary education research also point to the importance of affective factors, which remain largely absent from the dominant themes identified in the global bibliometric landscape. Marisa et al. (2023) reported that mathematical disposition, including self-confidence, perseverance, and curiosity, was closely associated with students' performance in mathematical problem-solving. Similarly, Rabbani and Puspita (2025) found that self-efficacy contributed significantly to differences in students' mathematical reasoning achievement, even when the same instructional approach was implemented. Fajri and Taufina (2020) demonstrated that the REACT strategy, which connects mathematical concepts to real-life contexts, not only enhanced critical thinking but also strengthened students' confidence in engaging with mathematical tasks. These findings suggest that a complex interaction among cognitive, pedagogical, and affective factors shapes the development of mathematical reasoning in elementary education. Therefore, future research should move beyond an exclusive emphasis on technological innovation and place greater attention on how instructional design, learner characteristics, and classroom interactions collectively support the growth of mathematical reasoning in elementary school settings.

These findings imply that efforts to strengthen students' mathematical reasoning cannot be maximized by selecting appropriate instructional models alone. Equally important are establishing a supportive classroom climate, providing constructive feedback, and gradually introducing challenges aligned with students' developmental levels and learning needs. Given that this affective dimension remains largely underrepresented in the mainstream global bibliometric literature, future research that bridges affective factors and the development of mathematical reasoning in elementary school contexts represents a critical direction.

Taken together, the findings of this study point to a consistent conclusion: the development of mathematical reasoning among elementary school students is influenced more by the quality of learning experiences than by the complexity of the technologies employed. Various instructional approaches, including Realistic Mathematics Education (RME), Teaching at the Right Level, Discovery Learning, Problem-Based Learning, the REACT strategy, cooperative learning, and Higher-Order Thinking Skills (HOTS)-based assessment, have consistently demonstrated their effectiveness in supporting the development of students' mathematical reasoning abilities (Agustina et al., 2021; Diniyarti & Agustika, 2023; Fajri & Taufina, 2020; Kurniawan, 2021; Saputro & Anugraheni, 2020). A common characteristic shared by these approaches is the opportunity they provide for students to explore ideas, construct representations, evaluate arguments, and connect mathematical concepts to meaningful real-world situations. Therefore, the future direction of elementary mathematics education should not depend solely on the adoption of emerging technologies, but rather on teachers' capacity to design learning experiences that actively promote reasoning processes.

Educational technology can serve as a valuable support tool; however, its implementation should align with students' developmental characteristics and the intended learning objectives. Rahartiningsih et al. (2025) demonstrated that ethnomathematics-based assessment can effectively support the development of mathematical reasoning by integrating local cultural contexts without requiring sophisticated technological infrastructure. Accordingly, future research and instructional development in elementary mathematics education should focus on achieving a balanced integration of mathematical reasoning, problem-solving, representation, and appropriate educational technologies, rather than merely following global technological trends that may not align with the contextual realities and institutional capacities of elementary schools in Indonesia.

This study makes a contribution that distinguishes it from previous bibliometric studies in three respects. First, by focusing specifically on mathematical reasoning rather than mathematics education in general, this study provides a more targeted mapping of the field's intellectual structure and its most relevant research gaps. Second, the integrated use of eight bibliometric indicators, namely annual scientific production, trend topics, co-occurrence network, collaboration network, most relevant sources, most globally cited documents, factorial analysis, and country scientific production, provides a more comprehensive overview than studies that rely on only one or two indicators. Third, the most distinctive contribution of this study lies in its systematic effort to bridge global bibliometric findings with the practical needs of elementary mathematics education, a perspective that has rarely been explicitly addressed in bibliometric studies of mathematics education.

Thus, the main contribution of this study lies not only in mapping the global development of mathematical reasoning research but also in identifying the gap between international research trends and the actual needs of mathematics learning in elementary schools. This gap provides a basis for formulating a more contextually grounded research agenda and for promoting pedagogical innovation aligned with the characteristics of elementary mathematics learning. In addition, this study shows that the global development of mathematical reasoning research does not always correspond directly to the needs of elementary mathematics education. Therefore, future studies should be more strongly oriented toward pedagogical contexts and students' cognitive development.

Several limitations should be considered when interpreting the findings of this study. First, the data were drawn exclusively from Scopus; therefore, relevant publications indexed in Web of Science, ERIC, or other regional databases were not included in the analysis. Second, the search strategy, which used the keywords "mathematical reasoning" and "learning," may have excluded publications that address similar concepts using different terminology. Third, the restriction to English-language articles may introduce language bias and limit the representation of research contributions from non-Anglophone countries, including Indonesia. Fourth, because bibliometric analysis relies on metadata and citation patterns, this method is not designed to assess the substantive quality, practical effectiveness, or methodological rigor of each reviewed article. Fifth, because the dataset reflects Scopus's indexing status at the time of retrieval in January 2026, the most recent publications should be interpreted cautiously, as indexing for the latest year may still be incomplete. This limitation should be acknowledged to avoid overinterpreting publication trends in the most recent period.

5. Conclusion

This study mapped the development of mathematical reasoning research in mathematics education through a bibliometric analysis of Scopus-indexed publications from 1979 to January 2026. The findings indicate a steady growth in publications, particularly after 2006, with the highest research output recorded in 2023. Thematically, the field has shifted from a primary focus on learning and problem solving toward a more multidisciplinary orientation, marked by stronger connections with educational technology, artificial intelligence, and digital learning. These findings suggest that mathematical reasoning has developed into a broad and increasingly interdisciplinary research domain, although its specific application in elementary mathematics education remains relatively limited.

The findings also confirm the close connection among mathematical reasoning, problem-solving, critical thinking, and the mathematics learning processes. Pedagogical dimensions remain central to the development of this field, while technology serves as a supporting medium to strengthen mathematical exploration, argumentation, representation, and reflection. Therefore, technology should not be viewed as a replacement for pedagogy, but as a deliberately designed tool to enrich the quality of mathematics learning. In elementary education, strengthening mathematical reasoning remains essential as a foundation for developing students' logical, analytical, systematic, and critical thinking skills.

The main contribution of this study lies in its use of a multidimensional bibliometric approach that integrates several analytical indicators, including annual scientific production, trend topics, co-occurrence network, collaboration network, most relevant sources, most globally cited documents, factorial analysis, and country scientific production within a unified analytical framework. Unlike previous bibliometric studies that have generally mapped mathematics education more broadly, this study specifically focuses on the development of research on mathematical reasoning and interprets its findings within the context of elementary mathematics education. Therefore, this study provides a more comprehensive understanding of the developmental direction of mathematical reasoning research while offering an empirical basis for improving mathematics learning at the elementary school level.

Methodologically, this study has several limitations. First, the data were obtained from a single database, namely Scopus. Second, the search strategy used a limited set of keywords, which may have excluded relevant publications that use different but conceptually related terms. Third, the restriction to English-language articles may introduce language bias. Fourth, bibliometric analysis relies primarily on metadata and citation patterns; therefore, it does not assess the substantive quality, practical effectiveness, or methodological rigor of the individual articles included in the analysis. These limitations should be acknowledged to avoid interpreting the findings beyond the scope of the data used.

Based on these limitations, future studies are recommended to expand the databases used, employ a broader range of search keywords, and combine bibliometric analysis with systematic literature review or content analysis. Further research should also focus more specifically on the implementation of mathematical reasoning in elementary education through approaches such as Problem-Based Learning, Discovery Learning, REACT, inquiry-based learning, and cooperative learning, supported by educational technology appropriate to the developmental characteristics of elementary school students. In this direction, research on mathematical reasoning would move beyond trend mapping and make more concrete contributions to improving mathematics learning in elementary schools.

6. Implications

The findings of this study highlight the need to strengthen mathematical reasoning in elementary mathematics education through contextualized and problem-solving-based approaches. In classroom practice, teachers should design learning activities that encourage students to articulate and justify their solution strategies, compare alternative approaches with peers, identify mathematical patterns, construct logical arguments, and critically reflect on the validity of their reasoning. These activities can be integrated into pedagogical models such as Problem-Based Learning, Discovery Learning, REACT, cooperative learning, and inquiry-based learning, as these approaches provide opportunities for students to actively explore mathematical ideas, discuss reasoning processes, and develop deeper conceptual understanding.

In addition, digital tools should be used selectively to support mathematical visualization, provide feedback, and document students' reasoning processes. Technology should not be positioned as a replacement for teacher-guided mathematical discussion, but rather as a supportive medium that enriches learning interactions and helps students represent mathematical ideas more clearly. Therefore, the integration of technology in elementary mathematics classrooms should remain developmentally appropriate, pedagogically meaningful, and aligned with the cognitive characteristics of elementary school students.

Future research should further examine the effectiveness of these instructional models in fostering mathematical reasoning among elementary school students. Further studies may also investigate how digital technology can be integrated into classroom practices to support reasoning, problem solving, argumentation, and conceptual understanding in more concrete and measurable ways. This direction is important to ensure that the development of mathematical reasoning research is not limited to global trend mapping, but also contributes directly to improving mathematics learning practices in elementary schools.

Credit authorship contribution statement

Yunni Arnidha: Conceptualization, original draft preparation, editing, data analysis, visualization, writing, review, and editing. **Agus Suyatna:** Supervision, writing, review and editing, and formal analysis. **Sugeng Sutiarto:** Methodology, supervision, validation, and academic supervision.

Declaration of competing interest

The authors declare that there is no conflict of interest related to the publication of this manuscript. In addition, the authors have complied with all applicable ethical standards, including ensuring that the manuscript is free from plagiarism, ethical misconduct, data fabrication or falsification, duplicate submission, and research duplication.

Ethical Declaration

This study did not involve human participants, personal data, or experimental intervention. The analysis was conducted using bibliographic metadata retrieved from the Scopus database. Therefore, formal informed consent was not required.

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