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### Publication trends on proportional reasoning research: A bibliometric analysis using Scopus database

Rani Sugiarni<sup>1\*</sup>, Khairul Hafezad Abdullah<sup>2</sup>

<sup>1\*</sup>Departements of Mathematics, Universitas Suryakencana, West Java, Indonesia, [ranisugiarni@gmail.com](mailto:ranisugiarni@gmail.com)

<sup>2</sup>School of Business Management, UUM College of Business, Universiti Utara Malaysia, [hafezad@uum.edu.my](mailto:hafezad@uum.edu.my)

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## Publication trends on proportional reasoning research: A bibliometric analysis using Scopus database

Rani Sugiarni<sup>1\*</sup>, Khairul Hafezad Abdullah<sup>2</sup>

<sup>1</sup>Departements of Mathematics, Universitas Suryakencana, West Java, Indonesia, [ranisugiarni@gmail.com](mailto:ranisugiarni@gmail.com)

<sup>2</sup>School of Business Management, UUM College of Business, Universiti Utara Malaysia, [hafezad@uum.edu.my](mailto:hafezad@uum.edu.my)

\*Correspondence: [ranisugiarni@gmail.com](mailto:ranisugiarni@gmail.com)

### Abstract

Proportional reasoning ability is an important ability for students to understand mathematical concepts. Much research has been conducted on this capability, but it is necessary to map existing research to provide a clearer picture of future research topics. This research aims to provide a bibliometric overview of trends in the use of proportional reasoning skills in mathematics teaching research. The method in this research is bibliometric analysis, which aims to analyze and classify bibliographic material by presenting a representative summary of literature in the Scopus database. The search was carried out using the keyword "proportional reasoning" in the search menu in the Scopus.com database. ScientoPy software analyzes the author's name, number of document citations, document title, publication year, document source, publisher, and document type. Research trends in proportional reasoning show a significant increase, with 356 publications in Scopus, peaking at 32 in 2023. Major contributors include the United States, Turkey, and Spain, with recent studies focusing on "teacher knowledge." Influential works by Liberali et al., Atkinson et al., and Tobin & Capie address numeracy, multimedia learning, and logical thinking, respectively. These findings suggest that improving teacher knowledge and using effective multimedia tools could enhance instruction and research in proportional reasoning. Future research should explore innovative teaching strategies and technologies to further advance proportional reasoning ability.

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## 1. Introduction

Proportional reasoning is understood as the ability to establish a multiplication relationship between two quantities and extend this relationship to other pairs of quantities (Lamon, 2007). Proportional reasoning is included in the mathematical ability component, which is logical thinking and is important for students and teachers to master (Pişkin & Çakıroğlu, 2022). Proportional reasoning is important for understanding many situations in mathematics and in everyday life (Arıcan, 2019). Daily problems that require proportional reasoning include comparison in pricing, the use of scale in maps, solving problems about percentages, the use of scale in designing a building, and many more.

Proportional reasoning describes different types of reasoning that focus on the relationship between two ratios and require complex ideas. According to Boyer & Levine (2012) proportional reasoning requires some understanding of scale relationships and appears in everyday problems. Proportional reasoning includes fraction equivalence, division, place value, percentage calculations, and measurement conversions (Scheibling-Sève et al., 2022). Therefore, understanding the concept of comparison requires proportional reasoning (Burgos et al., 2020)

Proportional reasoning underpins many math and science concepts and has wide applications in everyday life. For students, it facilitates an understanding of fractions, percentages, scales and ratios, all of which are crucial in the math curriculum. Proportional reasoning also supports critical and analytical

thinking skills, helping students solve complex problems and make data-driven decisions. For prospective teachers and math teachers, mastering proportional reasoning is important to teach these concepts effectively. They need to be able to explain and model the use of ratios and proportions in ways that students can easily understand, as well as identify and address conceptual errors that students may encounter.

However, many students, prospective teachers, and math teachers face challenges in developing and teaching proportional reasoning. Students often struggle to understand abstract concepts involving proportions and ratios, which can hinder their progress in mathematics. Prospective teachers may not receive adequate training in teaching these skills effectively, while experienced teachers may face challenges in finding innovative and engaging teaching methods. Therefore, continuous improvement in the teaching and learning process of mathematics is essential. This includes curriculum development that emphasizes proportional reasoning, professional training for teachers, and the use of educational technology and learning aids that support the understanding and application of proportional concepts.

Proportional reasoning is becoming increasingly popular in the mathematics education sector because it is the basis for learning other mathematics. Proportional reasoning supports various disciplines such as math, physics, and economics. Bibliometric analysis can provide benefits for us to see the development of research on the topic of proportional reasoning, such as knowing affiliations, finding potential collaborators, obtaining information about relevant journals, and productive contributors (Jumareng et al., 2024). In addition, we can also utilize published articles to find out trends and patterns in proportional reasoning research. In the study of bibliometric analysis in the field of mathematical ability, several studies have been conducted. These studies include bibliometric analysis of mathematical reasoning (Çoban & Tezci, 2022), science reasoning (Khoeriah et al., 2022), spatial thinking (de Queiroz, 2021), problem-solving (Suseelan et al., 2022), mathematical literacy (Ahyan et al., 2021; Mahmudin et al., 2023), and computational thinking (Muhammad et al., 2024). This research shows potential through bibliometric analysis, in particular, to provide insights into the development of proportional reasoning in the mathematics education sector. Thus, understanding the current landscape of proportional reasoning research through bibliometric analysis can significantly inform educational practices, improve curriculum design, and drive forward the development of interdisciplinary learning.

However, there is no clear research on the bibliometric analysis of proportional reasoning. Therefore, this study will examine in depth the trends in the use of proportional reasoning in mathematics learning research. In general, this study aims to provide a bibliometric analysis of the scientific literature focusing on proportional reasoning, assess trends and patterns of research in this area, and identify potential research gaps. Specifically, this research formulates four questions as follows:

RQ1: What is the total number of research publications on proportional reasoning, and how has it evolved chronologically?

RQ2: Which countries have made notable progress in the investigation of proportional reasoning?

RQ3: What are the main areas of investigation and recurring motifs of the literature on proportional reasoning?

RQ4: What are the main and influential papers that have proportional reasoning citation counts?

## 2. Method

This investigation, entitled "Publication Trends On Proportional Reasoning Research: A Bibliometric Analysis Using Scopus Database," aims to create a catchy and descriptive title by the authors to effectively capture proportional reasoning in previous research. The running title effectively communicates the idea of uncovering hidden insights and highlighting proportional reasoning from a bibliometric perspective. The title is carefully crafted using relevant keywords to succinctly convey the main focus and approach of the bibliometric analysis. Moreover, the use of the term "uncovered" implies the uncovering of new insights through a systematic examination of the literature. The authors strive to formulate an impactful title to capture the reader's interest and accurately summarize the importance of shedding light on trends and patterns related to proportional reasoning research.

## 2.1 Software and database

Bibliometric analysis involves examining bibliographic data to generate descriptive information across various research domains. In this study, bibliometric analysis was conducted using ScientoPy. The software uses Python scripts to automate the generation of reports on important parameters such as authors, countries, and documents, following the research questions or objectives formulated by the researchers. To conduct a bibliometric analysis of proportional reasoning, the Scopus database was used. This database is widely recognized as the most extensive collection of abstracts and citations in scientific research literature on a global scale. The criteria for including the dataset did not delineate any temporal scope or linguistic restrictions. The document types selected included articles and the English language. The search keywords used the term "proportional reasoning." The current investigation was conducted on the title, abstract, and Scopus keywords. The dataset was obtained on June 24, 2024, using the specified search criteria. The search resulted in a total of 546 documents retrieved from the Scopus database.

## 2.2 Data collection and analysis

This section presents the outcome data and bibliometric analysis of proportional reasoning in Figure 1. This analysis examines the most common topics covered in publications, the most prolific authors and institutions, the most prolific source titles and cited articles, and the most significant growth trends in research. This bibliometric analysis provides an overview of the status of proportional reasoning in mathematics education and describes research efforts to explore its potential.

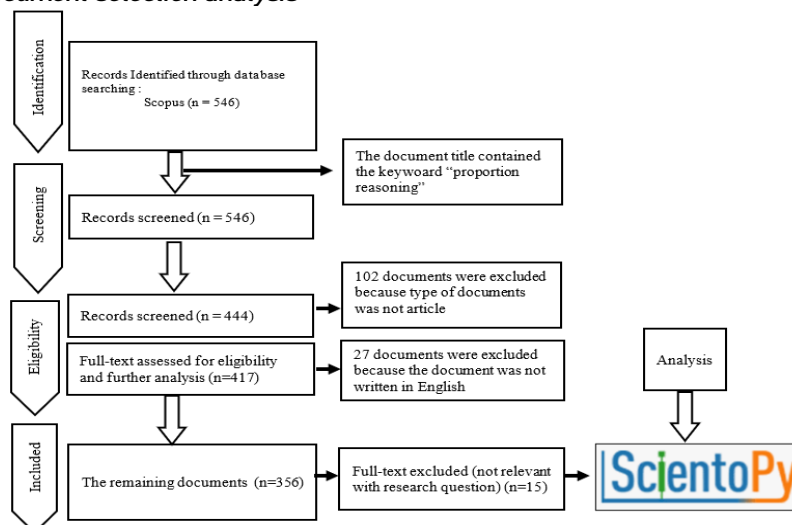
The document selection process for analysis, as illustrated in Figure 1, follows a structured approach using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram. In the identification phase, an initial search was conducted in the Scopus database, resulting in 546 documents with titles containing the keyword "proportion reasoning." Subsequently, during the screening phase, these 546 documents were further reviewed for relevance. In this process, 102 documents were excluded because they were not articles (e.g., conference papers, book chapters, etc.), leaving 444 articles.

In the eligibility phase, a further screening of the 444 articles was conducted, focusing on language eligibility. At this stage, 27 documents were excluded because they were not written in English, resulting in 417 articles eligible for full-text assessment. Then, in the inclusion phase, the full texts of the remaining 417 documents were carefully assessed for relevance to the research question. During this analysis, 15 articles were found not relevant to the research question and were excluded.

After completing the entire screening process, a total of 356 documents remained for further analysis. These remaining documents were then analyzed using ScientoPy, a bibliometric analysis tool that helps visualize and analyze scientific trends in selected research areas. This process demonstrates a systematic approach to narrowing down a large set of documents to those most relevant for an in-depth bibliometric analysis on the topic of "proportion reasoning." (See Figure 1).

Figure 1

### *The process of document selection analysis*



### 3. Results and Discussion

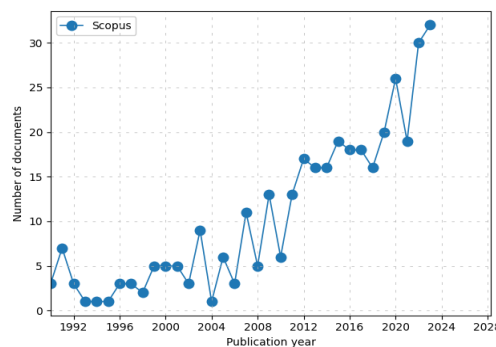
Results This bibliometric analysis illustrates descriptive information about the growth and evolution of publications, countries, research areas, and most-cited papers. An interesting additional task is to explain the importance of author keyword evolution to inspire potential research efforts regarding proportional reasoning research.

#### 3.1 Total Number of Research Publications on Proportional Reasoning and Its Chronological Evolution

The outcome data describes the collection of research publications on proportional reasoning. It shows the growth or evolution of the topic over time, as depicted in Figure 2 which illustrates the evolution and trend of publications on the Scopus database, from 1999 to 2023. The quantity analysis provides a big picture of how proportional reasoning research has progressed over the past two decades based on the volume of publications indexed in major databases (See Figure 2).

Figure 2

*Growth in the number of proportional reasoning publications from year to year*



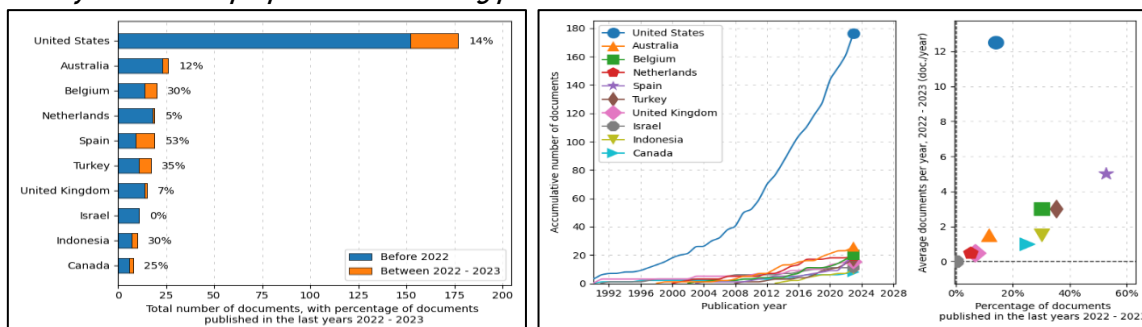
The publication data on "proportional reasoning" in Scopus shows a trend that tends to increase from year to year. Initially, the number of publications was relatively low, with only a few publications published each year in the early years of the 1990s. However, starting around 2003, the number of publications began to increase significantly, with nine publications in 2003 and increasing sharply in the following years. 2007 and 2009 were the peak years, with 11 and 13 publications, respectively. This increase continued, reaching 17 publications in 2012 and remaining stable with 16 publications in the following years until 2016. Entering 2020, the number of publications increased further to 26, and in 2022, the number of publications reached 30. In 2023, the number of publications increased again to 32, indicating a growing interest in research on proportional reasoning. Overall, this trend reflects the increased interest and intensified research into this topic in the past two decades.

#### 3.2 Trends in Leading Countries for Proportional Reasoning Research

This section, "Countries of Note," relates to countries with which the authors are affiliated and have prolifically published papers on proportional reasoning. This parameter is crucial in determining the regions where this topic has received significant attention. This can be important in determining appropriate strategies to address proportional reasoning issues, which may facilitate future collaboration between researchers or attract research funding. Figure 3 displays the top ten countries that have produced academic work on proportional reasoning, ranked by level of activity.

Figure 3

*Country trends with proportional reasoning publications*



The trend graph of the topic "proportional reasoning" based on data from several countries shows variations in the number of publications, h-index, and percentage contribution, especially in 2022–2023. The United States has the highest number of publications, with a total of 177, an h-index of 35, and a contribution of 14% in the last two years. Australia recorded 26 publications with an h-index of 12 and a contribution of 12% over the same period. Belgium, with 20 publications and an h-index of 11, showed a significant increase with a 30% contribution in 2022–2023. The Netherlands has 19 publications, h-index 13, but the contribution has been only 5% in the last two years. Spain also has 19 publications, but with a lower h-index of 9, its contribution reached 53%. Turkey, with 17 publications and an h-index of 6, showed a 35% contribution in the period. The UK recorded 15 publications with an h-index of 10 and a 7% contribution. Israel has 11 publications and an h-index of 8 but has shown no contribution in the last two years. Indonesia, with 10 publications and an h-index of 5, showed a 30% increase. Finally, Canada has eight publications with an h-index of 5 and a 25% contribution in 2022–2023. This data shows how each country contributed differently to "proportional reasoning" research in the period under review.

### 3.3 Key Themes and Focus Areas in Proportional Reasoning Research

The main research areas can be identified based on keywords related to proportional reasoning. The specific keywords used by authors have been previously identified by researchers. This study analyzes the keywords used in published research to identify recurring motifs. According to Abdullah [17], keywords are precise terms or phrases that summarize the main concepts or themes of a research article. By analyzing the frequency and prominence of keywords used in a given corpus of literature, researchers can gain valuable insights regarding the main research domains and central themes that have been explored. Identifying the ten most used keywords by previous proportional reasoning researchers will yield significant insights into key research areas. This information can guide future research efforts on proportional reasoning issues. Figure 4 displays the ten main areas of study that have been the subject of research on correlates of proportional reasoning.

Figure 4

*Keyword trends with proportional reasoning publications*

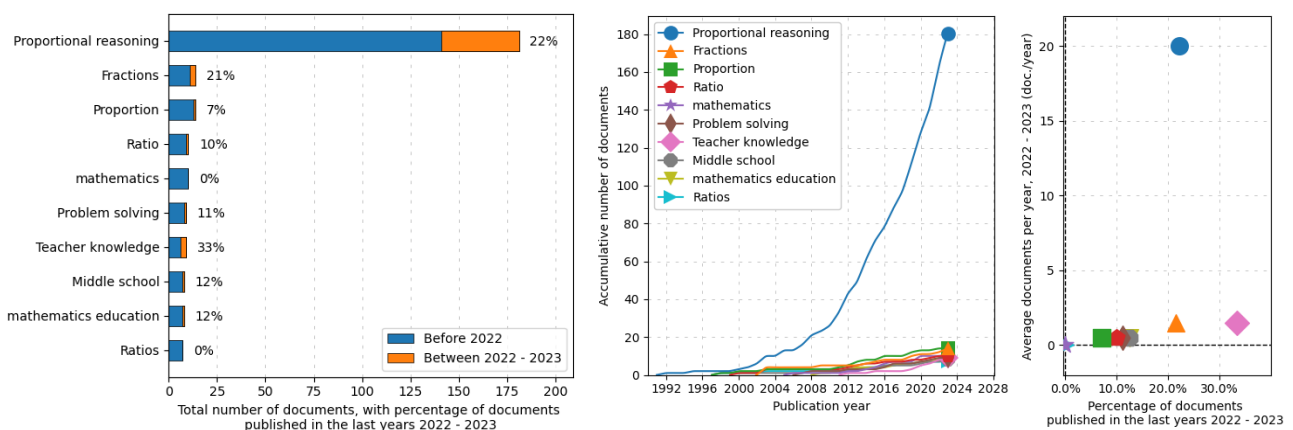


Figure 4 shows the total number of documents published on various topics in mathematics education, as well as the percentage of documents published between 2022 and 2023. The topic with the largest number of documents is "proportional reasoning," with a total of about 200 documents, of which 22% were published between 2022 and 2023. Other topics that also have a significant number of documents include "fractions," with a total of about 75 documents and 21% published between 2022 and 2023, as well as "problem-solving," with 11% of documents published in that period. It is also noticeable that "teacher knowledge" has the highest percentage of documents published between 2022 and 2023, at 33%, even though it has fewer total documents than other topics. Other topics such as "middle school," "mathematics education," and "ratios" have a relatively low number of documents with varying percentages of recent publications.

### 3.4 Influential Papers in Proportional Reasoning Research

Table 1 shows the trend of articles that received the highest number of citations. This citation analysis is based on the Scopus database. It should be noted that the number of citations presented in this study may differ significantly from other databases, such as Google Scholar. The above papers have made important contributions to proportional reasoning.

Table 1

#### *Citation trends with proportional reasoning publications*

References	Title	Source Title	Citation	Affiliations
Liberali J.M.; Reyna V.F.; Furlan S.; Stein L.M.; Pardo S.T.	Individual Differences in Numeracy and Cognitive Reflection, with Implications for Biases and Fallacies in Probability Judgment	Journal of Behavioral Decision-Making	234	Cornell University, Ithaca, NY, United States
Atkinson R.K.; Mayer R.E.; Merrill M.M.	Fostering social agency in multimedia learning: Examining the impact of an animated agent's voice	Contemporary Decision-Making Educational Psychology	234	Louisiana State University, Shreveport, LA, United States
Tobin K.G.; Capie W.	The development and validation of a group test of logical thinking	Educational and Psychological Measurement	223	University of Georgia, United States
Boyer T.W.; Levine S.C.; Huttenlocher J.	Development of Proportional Reasoning: Where Young Children Go Wrong	Developmental Psychology	176	University of Chicago
Van Dooren W.; De Bock D.; Hessels A.; Janssens D.; Verschaffel L.	Not everything is proportional: Effects of age and problem type on propensities for overgeneralization	Cognition and Instruction	120	University of Leuven, Belgium
Booth J.L.; Newton K.J.; Twiss-Garrity L.K.	The impact of fraction magnitude knowledge on algebra performance and learning	Journal of Experimental Child Psychology	113	University, Philadelphia, United States
Jeong Y.; Levine S.C.; Huttenlocher J.	The development of proportional reasoning: Effect of continuous versus discrete quantities	Journal of Cognition and Development	111	University of Chicago, United States
Hansen N.; Jordan N.C.; Fernandez E.; Siegler R.S.; Fuchs L.; Gersten R.; Micklos D.	General and math-specific predictors of sixth-graders' knowledge of fractions	Cognitive Development	110	University of Delaware, United States
Spinillo A.G.; Bryant P.	Children's Proportional Judgments: The Importance of Half	Child Development	109	University of Oxford, United Kingdom
Warshauer H.K.	Productive struggle in middle school mathematics classrooms	Journal of Mathematics Teacher Education	103	University Drive, United States
Hoyles C.; Noss R.; Pozzi S.	Proportional Reasoning in Nursing Practice	Journal for Research in Mathematics Education	103	University of London, United Kingdom

The research trends in proportional reasoning can be seen in the 10 most cited articles. Liberali et al. (2012) explore individual differences in numeracy and cognitive reflection and their impact on biases and fallacies in probability judgment (234 citations, Journal of Behavioral Decision Making). This article

emphasizes that Proportional reasoning is included in the numeracy dimension so that it becomes an important and widely cited topic (Liberali et al., 2012). Atkinson et al. (2012) investigate the impact of an animated agent's voice on social agency in multimedia learning (234 citations, Contemporary Educational Psychology). This study supports social agency theory by demonstrating that students who studied proportional reasoning through an animated agent with a human voice showed better performance and response compared to those using a machine-synthesized voice (Atkinson et al., 2005). Tobin and Capie focus on the development and validation of a group test for logical thinking (223 citations, Educational and Psychological Measurement). The paper introduces the Test of Logical Thinking (TOLT), which measures proportional reasoning along with other formal reasoning modes, showing high reliability and strong criterion-related validity across grades 6 through college (Tobin & Capie, 1981).

In addition, Boyer et al focus on exploring the development of proportional reasoning in young children and the common mistakes they make (176 citations, Developmental Psychology). Children typically struggle with proportional reasoning involving discrete units until around ages 10 to 12, whereas they can manage similar tasks involving continuous quantities by age 6, indicating specific challenges in processing discrete quantity proportions and an overextension of numerical equivalence concepts in these contexts (Boyer et al., 2008). Van Dooren et al discuss the effects of age and problem type on the propensity to overgeneralize in proportional reasoning (120 citations, Cognition and Instruction). Research has highlighted that, due to the extensive emphasis on proportional reasoning in elementary and secondary mathematics education, many students tend to overapply proportional methods across various mathematical domains (e.g., geometry, probability) (Van Dooren et al., 2005). Booth et al examine the impact of fraction magnitude knowledge on algebra performance and learning (113 citations, Journal of Experimental Child Psychology), suggesting that proportional reasoning skills might serve as an important link between fraction knowledge and learning algebra (Booth et al., 2014).

Furthermore, Jeong et al discuss the development of proportional reasoning and the effects of continuous versus discrete quantities (111 citations, Journal of Cognition and Development). The study investigates children's development of proportional reasoning, highlighting how their ability differs when reasoning about proportions that involve discrete entities versus continuous amounts (Jeong et al., 2007). Hansen et al investigate general and math-specific predictors of sixth-graders knowledge of fractions (110 citations, Cognitive Development). In the study, predictors such as whole number line estimation and non-symbolic proportional reasoning significantly contributed to both students' general understanding of fraction concepts and their procedural skills in sixth-grade (Hansen et al., 2015). Spinillo and Bryant study the importance of the concept of "half" in children's proportional judgments (109 citations, Child Development). The experiments consistently demonstrate the pivotal role of the "half" boundary in children's early proportional reasoning, showing that crossings of this boundary significantly enhance their ability to make accurate judgments (Spinillo & Bryant, 1991). In addition Warshauer H.K. Productive struggle in middle school mathematics classrooms (103 citations, Journal of Mathematics Teacher Education).

This study underscores the productive role of student struggles in fostering mathematical understanding, proposing a framework that highlights how these struggles can be supported and integrated into instructional practices to enhance learning outcomes in proportional reasoning tasks for middle school students (Warshauer, 2015).

Hoyles et al. (2001) Proportional Reasoning in Nursing Practice (103 citations, Journal of Mathematics Teacher Education). In investigating drug dosage calculations by expert nurses, we find that they employ diverse proportional reasoning strategies based on drug concentration in clinical practice, diverging from standardized methods taught outside of practical settings (Hoyles et al., 2001). From the analysis of the top cited articles in proportional reasoning, it is evident that research spans various dimensions, emphasizing individual differences in numeracy, the impact of multimedia agents on learning outcomes, development of logical thinking tests, challenges in children's understanding of proportion involving discrete quantities, overgeneralization tendencies, and the crucial role of "half" in early proportional judgments. These studies collectively underscore the multifaceted nature of research in proportional reasoning, addressing critical aspects from cognitive development to educational implications in mathematics.



The review findings regarding data collection in research on "proportion reasoning" provide several key insights. Firstly, the review identifies the most common data collection methods used in existing studies, such as surveys, tests, interviews, and observational studies, which highlight how researchers gather data on students' understanding and application of proportional reasoning. It also sheds light on the specific populations and contexts in which data collection is conducted, such as primary, secondary, or university students in classroom settings or digital learning environments, revealing gaps in current research. Additionally, the review discusses trends in data collection, like the increasing use of digital tools and mixed-method approaches to capture more comprehensive data, while also pointing out limitations, such as biases in survey responses and a lack of longitudinal data.

For future research, there is a clearer picture of several potential topics. One key area is the integration of advanced technology, such as AI-based platforms, simulations, and interactive apps, to collect more dynamic data on proportional reasoning. Another important direction is the need for longitudinal studies to track the development of proportional reasoning skills over time across different educational stages. Exploring diverse educational contexts, including various cultural, socio-economic, and educational settings worldwide, can also provide valuable insights. Future research could also benefit from interdisciplinary approaches combining education, psychology, and cognitive science to develop new frameworks and methodologies for studying proportional reasoning. Furthermore, examining the effectiveness of instructional strategies and teacher training in teaching proportional reasoning, especially with the introduction of new curriculum standards and technological tools, is crucial. These future research directions aim to enhance the understanding and teaching of proportional reasoning in various educational contexts.

#### 4. Conclusion

Research trends in proportional reasoning reveal a significant increase, with 356 publications in Scopus peaking at 32 in 2023. Significant progress in this field has been made by countries such as the United States, Turkey, and Spain. Recent studies have increasingly focused on "teacher knowledge." The most influential research in this area includes those by Liberali et al., Atkinson et al., and Tobin & Capie, which address topics like numeracy, multimedia learning, and logical thinking tests and are highly cited. These findings imply that enhancing teacher knowledge and incorporating effective multimedia tools could significantly improve proportional reasoning instruction and research. Future research should further explore innovative teaching strategies and technologies to advance ability-proportional reasoning.

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#### Author Contribution

Rani Sugiarni: Conceptualization, Writing - Original Draft, Editing and Visualization; Writing - Review & Editing, Formal analysis, and Methodology;  
Khairul Hafezad Abdullah: Validation and Supervision

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#### Conflict of Interest

The authors declare no conflict of interest.

**Additional Information:**

Additional information is available for this paper.

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