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Fraction Understanding in Children: Bibliometric Analysis

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Abstract. This study used a bibliometric analysis approach to investigate the literature on children's development of fraction understanding. Fraction understanding is crucial in early mathematics education because it is the foundation for more advanced concepts. Bibliometric analysis gives a comprehensive data-driven assessment of research trends, significant contributors, and emerging themes in this field. The data were sourced from the Scopus journal database, encompassing 228 articles from 1975 to 2023. Analytical and visualization tools, including VOS Viewer and the Bibliometrix R-Package, were utilized to map connections among journals, authors, countries/regions, and keywords. The findings indicated a trend of increasing publication volume over the past 15 years, with a yearly growth in articles on this topic. Keyword analysis revealed that, within these publications, "fraction" was the most frequently encountered term, followed by "mathematics" and "decimals". Moreover, there has been a shift in research focus from studying the challenges in conceptual understanding of fractions among children to investigating alternative interventions designed to address these challenges. This study is a foundational reference for future research on the progression of fraction understanding in children.

Keywords: bibliometric analysis; children; fraction comprehension; mathematics

Introduction

Understanding of mathematical concepts is essential to a child's cognitive growth (Sidney et al., 2019). This understanding can develop through formal education in schools, where mathematical symbols are applied for computation, and through informal daily settings, where children apply mathematical concepts to practical tasks (Baiduri, 2020). While school learning emphasizes procedural skills, everyday experiences often promote a conceptual understanding of math. Nevertheless, mastering arithmetic operations, such as fractions, remains a significant challenge for children, indicating a need for effective strategies to improve their comprehension (Baiduri, 2020; Siegler & Lortie-Forgues, 2015; Tian & Siegler, 2017). Fractions, encompassing the concepts of decimals, percentages, ratios, rates, and proportions, are fundamental to mathematical literacy as they lay the groundwork for later

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understanding in algebra and advanced mathematics (Siegler & Lortie-Forgues, 2015). Expertise in these concepts is critical because they provide foundation for comprehensive mathematical thinking and problem-solving. It highlights the need for teaching approaches that include all the steps involved in mathematical operations and a grasp of fundamental mathematical concepts.

Research has shown that a child's grasp of fractional magnitudes can influence their future mathematical skills (Schiller et al., 2022; Spitzer & Moeller, 2021; Stelzer et al., 2023). Moreover, Stafylidou and Vosniadou (2004) examined children's understanding of fractions. They found that students often struggle with this topic due to a paradigm shift in their knowledge, as fractional properties and meanings diverge significantly from whole numbers. Fractions become more complex due to their unique characteristics; including the infinite quantity of fractions existing between any two numbers and the non-intuitive rules governing the multiplication and division of fractions, which differ from those of whole numbers (Lewis et al., 2015). Exploring and developing innovative teaching methods that address children's specific challenges with fractions is crucial to enhancing their fundamental mathematical skills (Braithwaite et al., 2019; Spitzer et al., 2024). Hence, continued research and analysis into how children understand fractions are vital.

A methodical strategy to integrate diverse studies and insights in this area is needed to understand the complexities of fraction comprehension in children. One practical approach for gaining insights into this matter is bibliometric analysis, a well-established method for systematically exploring and analyzing vast scientific data to uncover patterns, key themes, and pivotal research contributions (Donthu et al., 2021). Furthermore, bibliometric analysis is a comprehensive approach that offers more in-depth insights than standard literature reviews because it relies on quantitative data and objective measures to reduce potential subjectivity (Bhattacharyya & Verma, 2020). This analytical tool enables academics to track the growth and trends in fraction-related research while highlighting significant contributions made by scholars in the study area.

By identifying rising trends and undiscovered aspects, bibliometric analysis can guide future studies and assist the development of evidence-based approaches in fraction studies. However, a lack of systematic reviews focused on trends in this subject has hampered efforts to synthesize data and identify key research gaps correctly. This limitation emphasizes the necessity for a systematic way to evaluate the progress and focus of fraction-related research. Therefore, this study aimed to analyze current research trends and define the frontiers of children's fraction comprehension using bibliometric analysis. This study sought to improve fraction understanding and solve the obstacles to building children's higher cognitive comprehension by providing a more precise roadmap for future research.

Methods

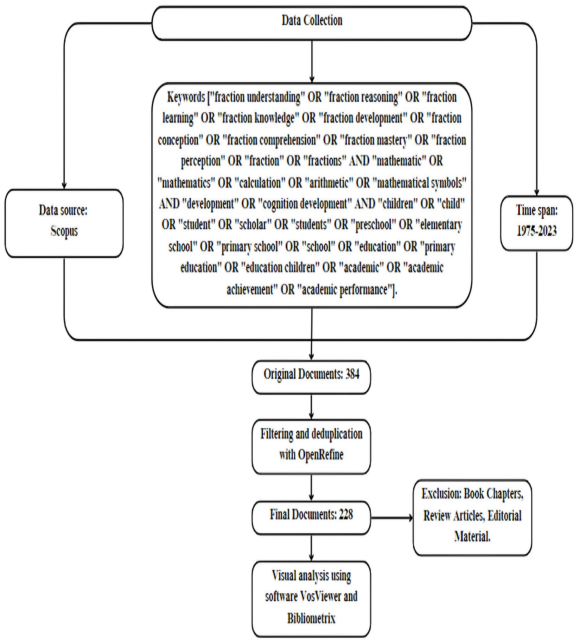
Data Source and Retrieval Strategy

Data for this comprehensive bibliometric study were methodically gathered from the Scopus database. It utilized several search terms designed to capture the broad spectrum of research about fraction comprehension and development in children. The search keywords, meticulously

formulated to encompass key terms [“fraction understanding” OR “fraction reasoning” OR “fraction learning” OR “fraction knowledge” OR “fraction development” OR “fraction conception” OR “fraction comprehension” OR “fraction mastery” OR “fraction perception” OR “fraction” OR “fractions” AND “mathematic” OR “mathematics” OR “calculation” OR “arithmetic” OR “mathematical symbols” AND “development” OR “cognition development” AND “children” OR “child” OR “student” OR “scholar” OR “students” OR “preschool” OR “elementary school” OR “primary school” OR “school” OR “education” OR “primary education” OR “education children” OR “academic” OR “academic achievement” OR “academic performance”]. The gathered corpus comprised 384 documents, providing a robust foundation for the bibliometric analysis. The documents encompass a substantial period range, with publications from 1975 to 2023, presenting an outlook of the field’s evolution in nearly five decades. See Figure 1

Figure 1

Research Design Flow Diagram



Literature Inclusion and Exclusion Criteria

Documents examined in this study were complete research articles. The researchers included articles written in English and published from 1975 to August 2023. Documents excluded from this study were book chapters, review articles, editorial materials, and abstract-only articles. Additionally, the researchers conducted a filtering process to ensure the relevance of the documents to the research topic. This process involved reviewing the title, abstract, and keywords of each document encountered. The

researchers excluded 156 papers, leaving 228 articles for further analysis. The researchers downloaded all documents that met the inclusion criteria in .csv format. Subsequently, the team used OpenRefine software to conduct data cleansing, which ensured no corrupt data within the keywords, authors' names, or institutions/organizations. This process allowed further processing with more validated data. This study used the VOSviewer software and the Bibliometrix R package for visual analysis tools. The primary outcomes of this visual analysis were keyword analysis, author analysis, analysis of countries/regions and institutions, and publication trends.

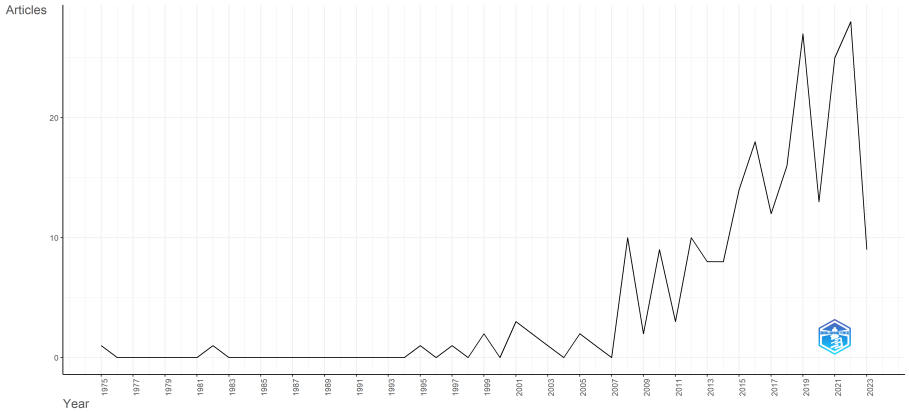
Results

Publication Trends

Based on the visual analysis of annual scientific production using the Bibliometrix R package, the researchers observed a rising trend in publication volume from 1975 to 2023 (Figure 2). The range of publication years was then divided into three categories: the first period (1975–1993), the second period (1994–2007), and the third period (2008–2023). The number of publications displayed a relatively flat graph during the first period (1975–1993) (Figure 2). Throughout the second period (1994–2007), publication volume tended to fluctuate, even though the numbers were not significant ($N \leq 10$). The publication trend on fraction understanding also fluctuated during the third period (2008–2023), with substantial volume changes from year to year. Year 2022 recorded the highest number of publications throughout the entire range, with 28 articles published.

Figure 2

Publication Productivity in 1975–2023



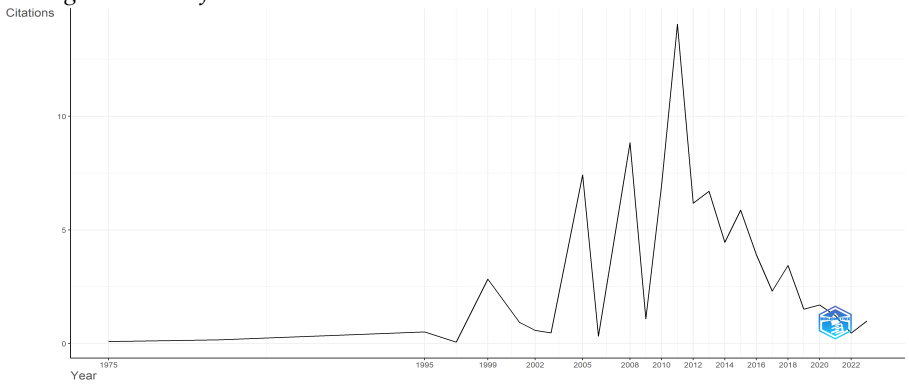
Average Article Citation per Year

Figure 3 depicts the average number of citations per article from 1975 to 2023. The higher the chart in a given year, the greater the number of citations of articles from that year have received. The citation

timeframe for these articles was divided into two periods: the first (1975–1995) and the second period (1996–2023). The citation count graph tends to be flat during the first period (1975–1995). Meanwhile, the graphs fluctuated in the second period (1996–2023). The highest average citation for this topic occurred in 2011, with an average of 14.05 citations per article.

Figure 3

Average Number of Article Citations in 1975–2023



Most Relevant Sources

The analysis results presented in Table 1 showcase the top 10 journals with the highest volume of publications of the target topic out of the total 102 journals included in this study. The Journal of Experimental Child Psychology has the most publications, boasting 14 research articles on children's fractional understanding, followed by the Journal of Physics Developmental Science (9 articles), and the Journal of Educational Psychology (8 articles).

Table 1

Ten Journals with the Most Published Articles

Rank	Journal	Publications
1	Journal of Developmental Psychology	14
2	Journal of Physics Developmental Science	9
3	Journal of Educational Psychology	8
4	Developmental Psychology	7
5	Journal of Mathematics Teacher Education	7
6	Developmental Science	6
7	International Journal of Science and Mathematics	6
8	Educational Studies in Mathematics	4
9	Learning and Individual Differences	4
10	Mathematics Education Research Journal	4

Most Globally Cited Documents

Table 2 presents the ten articles with the most global citations out of the 228 research articles analyzed in this study. The results indicate that the article by Halberda et al. (2008), published in the Journal of Developmental Psychology, holds the record for the most global citations, having been cited 644 times. The second most globally cited article is by Piazza et al. (2010), which appeared in Cognition, with citations accruing 550 times. The article by Siegler et al. (2012), published in the Journal of Psychological Science, ranks third with 447 citations. See Table 2

Table 2

Ten Articles with the Most Citations

Rank	Journal	Publications
1	Halberda et al. (2008), Developmental Psychology	644
2	Piazza et al. (2010), Cognition	550
3	Siegler et al. (2012), Journal of Psychological Science	447
4	Siegler et al. (2011), Cognitive Psychology	438
5	Reyna and Brainerd (2008), Learning and Individual Differences	344
6	Siegler et al. (2013), Trends in Cognitive Sciences	195
7	Martin and Schwartz (2005), Cognitive Science	185
8	Jordan et al. (2013), Journal of Experimental Child Psychology	182
9	Mix et al. (2016), Journal of Experimental Child Psychology	165
10	Bailey et al. (2012), Journal of Experimental Child Psychology	153

Thematic Evolution

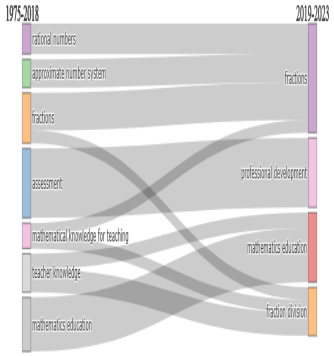
The visual analysis of thematic evolution illustrates the shifts in themes within articles on fraction understanding from 1975 to 2023 (Figure 4). There was a transition in the mention of specific themes from 1975–2018 to 2019–2023. Under a broader theme of fractions, sub-themes like rational numbers, the approximate number system, and fractions had begun to be encompassed. Research on assessments also tends to transition into the theme of professional development. Mathematics education results from merging themes like teacher knowledge and mathematics education. In contrast, fraction division is an amalgamation of themes, e.g., fractions, mathematics knowledge for teaching, and teacher knowledge.

Keywords Co-Occurrence Analysis

The co-occurrence analysis of keywords, performed in VOSviewer software, aids in identifying the research focus of articles or authors and highlights general research trends. Keywords that appeared at least four times were included in the analysis. Of 575 keywords, 34 met this criterion and were displayed. The total link strength for each keyword was calculated, reflecting its connections with other keywords and the frequency of occurrences. "Fractions" emerged with the most considerable total link strength (117) and an occurrence count of 76, followed by "mathematics" with a total link

Figure 4

Thematic Evolution



strength of 44 and an occurrence of 33, and "decimals" in third position with a total link strength of 24 and an occurrence of 10, among several other keywords (For more details, see Table 3).

Table 3

Total Link Strength and Occurrence for Each Keyword

Cluster	Keyword	Occurrence	Total Link Strength
1	Development	5	8
	Intervention	8	15
	Learning disabilities	6	10
	mathematics	33	44
	Pedagogical content knowledge	5	8
	Teacher education	5	6
	Assessment	4	6
	Professional development	5	6
2	Arithmetic	7	21
	Conceptual knowledge	4	9
	Estimation	4	6
	Magnitude representation	5	13
	Mathematics achievement	10	22
	Numerical development	7	17
	Procedural knowledge	5	11
3	Mathematical cognition	6	13
	Mathematical development	5	8
	Numerical cognition	8	13
	Individual differences	4	9
	Number line	4	11
	Procedural and conceptual knowledge	4	11
4	Problem-solving	4	4
	Rational numbers	13	15
	Realistic mathematics education	5	3
	Decimals	10	24

Table 3 (Continued)

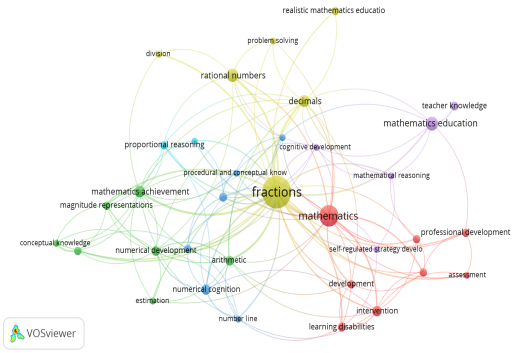
Total Link Strength and Occurrence for Each Keywor

Cluster	Keyword	Occurrence	Total Link Strength
	Fractions	76	117
	Divisions	4	6
5	Mathematical educations	14	11
	Self-regulated strategy development	4	7
	Teacher knowledge	6	2
	Cognitive development	4	10
	Mathematical reasoning	4	9
6	Proportional reasoning	5	10
	Working memory	4	9

The keyword network visualization (Figure 5) features five main clusters (red, green, yellow, blue, and purple). Cluster 1 comprises development, intervention, learning disabilities, mathematics, pedagogical content knowledge, and teacher education. Cluster 2 comprises arithmetic, magnitude representation, mathematics achievement, numerical growth, and procedural knowledge. Cluster 3 comprises decimals, fractions, proportional reasoning, rational numbers, and realistic mathematics education. Cluster 4 contains mathematical cognition, mathematical development, and numerical cognition; and finally. Cluster 5 includes mathematics education, professional development, and teacher knowledge. The frequency of a keyword's appearance determines the size of the circle, with a larger circle indicating a higher frequency for that keyword.

Figure 5

Network Visualization for Co-occurrence with Keywords

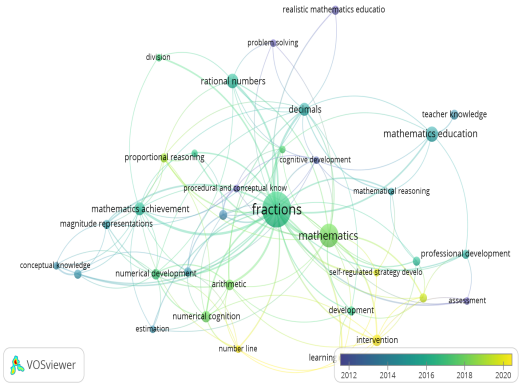


Then, Figure 6 shows the network connection classifications from 2012 to 2020. A keyword's color was determined by the color similarity to the corresponding color value (i.e., the year) in the overlay visualization. Keywords, such as realistic mathematics education, problem-solving,

cognitive development, assessment, procedural and conceptual knowledge, conceptual knowledge, and procedural knowledge, had a high frequency during the 2012–2016 period. Finally, from 2018 to 2020, the most prominent keywords were intervention, learning disabilities, number line, self-regulated strategy development, proportional reasoning, mathematics, numerical cognition, and arithmetic.

Figure 6

Overlay Visualization for Co-occurrence with keywords



Analysis of Authors

The present analysis noted that 589 authors (with 31 single-author publications and 16.16% international co-authorship) had contributed to the research on children's fraction comprehension. R.S. Siegler ranked first as the most prolific author in this field with 17 publications, followed by L.S. Fuchs and N.C. Jordan, who published seven articles (See Table 4). Siegler was also the author with the highest number of citations (285), followed by Geary (104), and Fuchs (87). Siegler emerged as the preeminent author, leading in the number of published works and citations.

Table 4

Most Prolific Writer

Author	Publications	Local Cited Sources	H-index	Articles Fractionalized
Siegler RS	17	285	15	4.92
Fuchs LS	7	87	6	1.68
Jordan NC	7	42	7	1.43
Geary DC	6	104	5	1.34
Bailey DH	5	51	5	1.29
Braithwaite DW	5	23	3	1.92
Ennis RP	5	22	3	1.83

Table 4 (Continued)

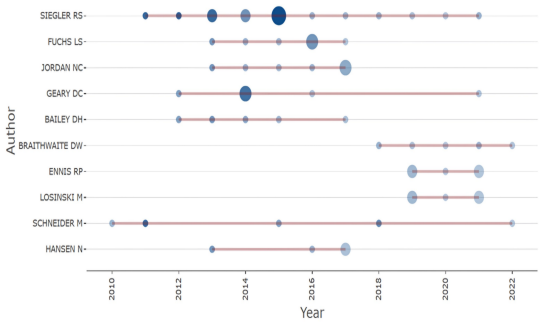
Most Prolific Writer

Author	Publications	Local Cited Sources	H-index	Articles Fractionalized
Losinski M	5	7	3	1.83
Schneider M	5	60	4	1.56
Hansen N	4	58	4	0.81

The results also indicate that Siegler has a significant impact or influence within the scope of the development of children's fraction comprehension, as noted in an H-index of 15. Jordan follows with an H-index of 7, and Fuchs with an H-index of 6. The H-index in this analysis illustrates the local impact of the author, referring to how much each author has contributed and the productivity of the researchers in the discourse of children's fractions understanding. See Figure 7

Figure 7

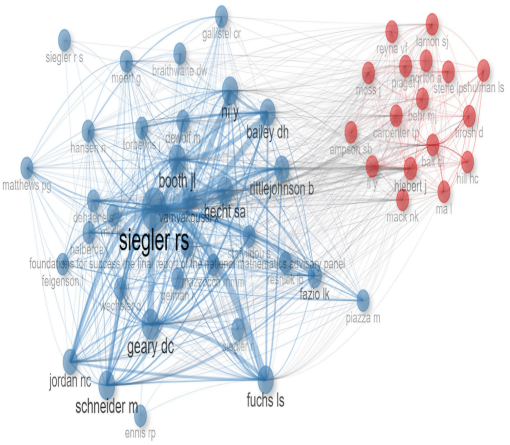
Author's Production Over Time



Siegler has been publishing from 2011 to 2021, with the most publications released in 2015, indicated by the most significant dot in Figure 7. In 2015, Siegler published five articles and received an average of 45.33 total citations per year (TC). The second-largest dot represents Geary in 2014, with three publications to its name and a cumulative citations of 31.9. The third-largest dot was seen in Siegler's graph in 2013, with two publications and 34.27 TC. Additionally, the co-citation network analysis based on authors often cited together in scholarly works is divided into two clusters. Each node in the network represents a mentioned author, and the connections between nodes indicate that these authors have been cited together (Figure 8).

Figure 8

Co-citation Network



Analysis of Countries/Regions and Institutions

The findings indicate that the literature on the development of children's fraction comprehension originates from 28 countries/regions, with the top three countries in terms of publication volume being the United States (325 publications), Indonesia (44 publications), and China (40 publications). The United States leads with 4,473 citations, Germany with 305 citations, and Canada with 171 citations. The United States dominates publications and citations from 1975 to 2023. Despite Indonesia and China having more publications, they have fewer citations. See Table 5

Table 5

Most Productive Countries/Regions

Country/Region	Publications	Citations	Average Citations per Item	Betweenness
United States	325	4473	58.90	122
Indonesia	44	80	8.90	0
China	40	7	1.80	35.3
Germany	34	305	25.40	22.5
United Kingdom	31	18	3.6	0
Italy	30	38	9.50	5.2
Türkiye	21	19	9.50	0
Canada	17	22	5.50	0.5
Belgium	14	171	34.20	0
	13	5	5.00	10.3

The present research also revealed a collaborative network involving countries in writing research articles. The visualization shows that a larger node with a betweenness value of 122.0 represents the United States. The prominent positioning of the United States in the network of nations underscores

its crucial role in collaborative scientific publishing, proven by robust partnerships with countries including South Korea, Austria, Brazil, Mexico, Chile, Switzerland, Hong Kong, and the United Kingdom.

Figure 9

Collaboration Network of Country

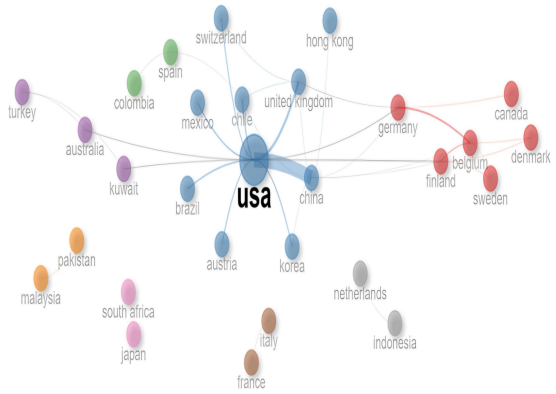


Table 6 identifies the three most productive institutions with the most publications: the University of Missouri (27 publications), the University of Delaware (18 publications), and Carnegie Mellon University (15 publications). These results also show that American universities dominate publications on children's understanding of fractions. Additionally, while the University of Missouri ranked first in the number of publications, the University of Chicago had a higher betweenness value (32.6). The pattern suggests that the University of Chicago had established a wide-ranging network of collaborations with several institutions for the authorship and publication of academic articles.

Table 6

Most Productive Institutions

Rank	Institution	Publications	Betweenness
1	University of Missouri	27	0
2	University of Delaware	18	5.11
3	Carnegie Mellon University	15	28.7
4	Universitas Pendidikan Indonesia	10	0
5	University Of Chicago	10	32.6

Table 6 (Continued)
Most Productive Institutions

Rank	Institution	Publications	Betweenness
6	Vanderbilt University	10	8.87
7	University Of British Columbia	9	0
8	Kansas State University	8	0
9	Qiannan Normal University For Nationalities	8	0
10	University Of California	8	0

Discussion

The findings of this research show that there is a growing interest in children's understanding of fractions among scholars. The increase in publications from 2008 to 2023 shows this trend. Current research issues focus on difficulties in mathematics learning, interventions, and cognitive processes in the context of fraction comprehension. This phenomenon may be linked to the growing awareness of the importance of fraction comprehension in mathematics development and education.

Fractions are fundamental for a deeper understanding of mathematical concepts in school and daily life (Baiduri, 2020; Sidney et al., 2019). However, learning difficulties in fraction comprehension are a common problem among children, mainly elementary school students. Fractions understanding involves visual, conceptual, and operational complexities, so some children struggle to grasp and apply these concepts (Bailey et al., 2014; Siegler & Lortie-Forgues, 2015; Tian & Siegler, 2017). Therefore, these difficulties necessitate effective interventions and learning strategies to help students overcome such obstacles. This increased awareness may also be attributed to its potential impact on students' mathematical understanding and performance. Despite the growing interest in this area, there is still a need for further exploration and a deeper understanding of the cognitive processes involved in children's comprehension of fractions.

Researchers have extensively studied children's understanding of fractions within psychology, focusing on developmental and educational contexts. The analysis outcomes demonstrate that journals primarily featuring research from developmental, cognitive, and educational psychology disciplines are the most prolific publishers, with the Journal of Educational Psychology contributing the most significant number of articles. However, among these ten journals, one falls outside the discipline of psychology, namely the Journal of Research in Mathematics Education, which includes research articles discussing fractions in mathematics classroom learning (Fitri & Prahmana, 2019; Kadar et al., 2020). The data suggest children's comprehension of fractions is an area enriched by a cooperative, multidisciplinary approach.

The most cited research on children's fraction understanding is the study by Halberda et al. (2008). In their research, Halberda & Feigenson described the 'sense of number' that develops across the lifespan, from childhood to adulthood, and how understanding numbers and calculations in

children affects mathematical understanding in adulthood. Therefore, their study forms a fundamental basis for research on fraction comprehension in children.

R.S. Siegler is identified as the most productive author in research on children's development of fraction comprehension and has a high citation frequency across several published research articles. Siegler et al. (2011) the study focused on children's challenges in comprehending fractions and decimals, as opposed to their comprehension of whole numbers. His studies include discussions on flexibility in learning about fraction concepts (Mcmullen et al., 2022; Schiller et al., 2022; Siegler et al., 2013) as well as individual differences that predict fraction comprehension (Bailey et al., 2014; Hansen et al., 2015; Sidney et al., 2019; Siegler et al., 2013; Watts et al., 2014). Siegler is also a central figure in children's fraction understanding due to the extensive collaborative publication efforts.

The keyword "fraction" is often used in conjunction with other keywords, such as "conceptual knowledge", which is related to "fraction". Several studies suggest conceptual knowledge is crucial when learning fraction procedures (Seethaler et al., 2011; Siegler et al., 2011). Moreover, the difficulty in fraction and decimal arithmetic reflects a lack of conceptual knowledge, without which students will be less likely to choose the correct arithmetic procedures or discern correct answers from the wrong ones. Indeed, the keyword "fraction" is often associated with and used alongside "rational number" and "decimal". Hansen et al. (2015) noted that arithmetic involving rational numbers (fractions and decimals) is complex and challenging. The "fraction" keyword is also frequently associated with "magnitude knowledge" and "decimals". Magnitude knowledge refers to the understanding that fractions and decimals represent magnitudes that one can compare, order, and place on a number line. Students can use this knowledge to identify arithmetic errors that result in inaccurate answers (Siegler et al., 2011).

This study could encourage further investigations into fraction understanding. First, this study demonstrates that the topic of fraction understanding is gaining traction in the academic community, leading to a rise in the number of related studies. It allows future studies to investigate several aspects of fraction understanding that are currently underexplored. It creates plenty of opportunity to conduct more in-depth research into this topic within the realms of education and mathematical cognition.

Second, this study found several journals that actively publish articles on fraction understanding, which can platform for academics looking to publish studies in this area. These journals provide an excellent forum for disseminating new results and possibilities to advance fraction understanding research.

Finally, this study identified the most commonly cited articles about fraction understanding, which can be referred to by academics looking further into the subject matter. These significant publications provide a solid foundation for future research and help researchers comprehend the numerous methods and theories used in the field.

Conclusion

This bibliometric study analyzed 228 research articles on children's understanding of fractions, focusing on research trends related to keywords, researchers, and institutions. The volume of publications in this area has increased notably over the last 15 years. Researchers predominantly study fraction understanding in psychology disciplines such as educational and cognitive discussion. Discussion topics have shifted from studying difficulties with fraction concepts to exploring alternative interventions. These findings suggest a need for further studies on strategies and interventions in children's fraction comprehension processes.

Recommendation

This study conducted an initial bibliometric analysis to investigate the trends and frontiers in children's fraction comprehension research. Nevertheless, it is important to recognize certain limitations. Initially, this investigation exclusively utilized publications indexed in Scopus. This might have led to a skewed literature representation, as other pertinent studies may have been indexed in alternative databases, e.g., Web of Science. Secondly, the analysis's reliance on English-language publications may result in omitting culturally diverse perspectives and educational practices, as it limits the insights gained from studies published in other languages. Future research should adopt a more comprehensive literature mapping approach to address these limitations, incorporating multiple databases and multilingual sources to ensure a more global, inclusive analysis.

Additionally, while bibliometric analysis offers an extensive view of research developments, a more nuanced understanding of fraction comprehension would benefit from empirical methods, such as longitudinal and experimental studies. These approaches can reveal how children's fraction learning evolves over time and across different instructional settings, leading to deeper insights into learning trajectories and interventions. The current analysis is predominantly based on research conducted in formal educational environments. Future research might broaden its scope by incorporating informal learning environments, e.g., digital platforms and home-based learning. Understanding how children interact with fractions in several settings can provide information for a comprehensive educational strategy that integrates real-world applications with school-based instructions.

Finally, future research should also prioritize culturally responsive teaching methods that integrate technological advancements and address the socioemotional aspects of learning. This approach will facilitate the development of inclusive and adaptive learning experiences, guaranteeing the practicality and accessibility of fraction comprehension education to many learners.

Declaration

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Authors' Contributions

NSZ: Conceptualization, Methodology, Investigation, Writing – Original Draft, Review & Editing; NAS, BYA, NNS: Investigation, Visualization, Writing – Original Draft; SW: Conceptualization, Methodology, Review & Editing, Supervision. All authors read and approved the final version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest to this article's research, authorship, and/or publication.

Declaration of Generative AI in Scientific Writing

The author declares that no artificial intelligence tools (such as ChatGPT, Gemini, or others) were used in the preparation of this paper.

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