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A bibliometric analysis of scientific articles on mathematics misconceptions

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ABSTRACT

The purpose of this study is to conduct a bibliometric analysis of the research published in the field of mathematics misconception from 1947 to 2023, to determine the general knowledge structure and participation in research publication. An analytical approach was used based on Scopus database data. This study used mixed methods; quantitative method to summarize the articles using bibliometric analysis, and qualitative method to analyze the content of the most cited papers on mathematics misconception. The results showed that research publications on mathematics misconceptions have increased over time. The majority of the researchers and educational institutions who published papers about mathematics misconceptions were from the USA, England, and Turkey. The most used keywords were teaching, students, and education. The qualitative analysis identified (23) common mathematics misconceptions, which were grouped into four categories: general mathematics misconception, algebraic mathematics misconception, trigonometric mathematics misconception, and calculus mathematics misconception.

Keywords: mathematics misconception, bibliometric analysis, scientific articles

INTRODUCTION

Concepts are essential to learning and thinking because they act as building blocks of knowledge and help learners to relate knowledge to one another (Baykul, 2003). Meaningful learning occurs when you fully comprehend concepts and establish connections between them (Julius et al., 2021).

As students experience mathematic concepts, they process information in ways that may be incorrect; some may memorize directly, while others may interpret incorrectly, all of which can cause misconceptions (Kadarisma et al., 2020).

A misconception is a mistake in understanding the concept or in interpreting its meaning (Ay, 2017). A student's understanding of mathematics in the future may be permanently affected by a misconception they encountered in mathematics class (Kula Ünver & Elçi, 2022). According to Kadarisma (2016), mathematical concepts are not isolated but are interconnected, so one mistake in a basic concept can lead to another mistake.

When conducting huge research studies, an approach called bibliometric analysis is frequently employed to review and analyze data (Donthu et al., 2021). Research development can be categorized according to publications, authors, and journals using bibliometric analysis (Merigó & Yang, 2016). Researchers use bibliometric analysis for a variety of research purposes, including describing the field of research, journal performance, research object collaboration, and exploring other developments in research (Sreylak et al., 2022).

Within the field of education, the growth of mathematics from a bibliometric perspective has been the primary topic of discussion. As a result, current findings from bibliometric analysis are required in mathematics education (Julius et al., 2021). In contrast to systematic review papers, bibliometric research involves analyzing published articles to identify global patterns within a specific academic field (Phan et al. 2022).

Research Questions

This study's goal is to use bibliometric analysis to examine research papers on mathematics misconceptions published between 1947 and 2022; to accomplish this, the study seeks to provide answers to questions that involve two major sub-purposes:

A. Performance analysis and benchmarking:

   1. What is the journal publications' trend in mathematical misconception over its lifetime?

2. What is the journal citations' trend in mathematical misconceptions and what are the most cited papers?

B. Who are the most productive and influential institutions, and countries in mathematical misconceptions publication? Content analysis and road map for future researcha:

1. What are the main thematic patterns in mathematical misconceptions?
2. What are the most frequent misconceptions used in the studies published in the mathematics misconceptions research area?

Theoretical Framework

A misconception is an aspect of a broader conceptual framework that people use to analyze and make sense of their everyday experiences. when students encounter new knowledge, they establish connections between new and previous knowledge. If the new input contradicts the current information, the current understanding must be reorganized. By giving solutions, solving problems, or providing evidence based on incorrect reasoning, students can accidentally generate misconceptions. Frequently, these misconceptions blend with others and errors, leading to a cycle of misperceptions (Kurtulus & Tatar, 2021).

Teachers need to be accurate in their grasp of mathematics ideas. Educators can prevent students from being misled by employing suitable approaches and strategies in learning environments (Tirosh, 2000). If educators are knowledgeable about misconceptions, they can actively work to prevent them. Through scientific approaches and models, students can be assisted in reorganizing and incorporating information by recognizing their misconceptions and creating a discussion that encourages them to address them (Kula Ünver & Elçi, 2022).

The concept of bibliometrics was introduced by Pritchard (1969) as a new way to conduct reviews. It has been used in a variety of research topics, including mathematics (Phan et al. 2022). A useful method for examining how a study domain has developed based on social, intellectual, and conceptual variables is bibliometric analysis, which may be applied to both topics and authors. This method has been applied to a variety of fields, including strategic management, corporate social responsibility, medicine, and corporate universities (Singh et al., 2020).

A bibliographic data collection contains several details about a source document, including the author, the nation, the keywords, the institution, the language, the publication source, the year of publication, the sources of references cited, and the subject categories (Öztürk et al., 2024). After the gathering of this data, a bibliometric analysis is performed to examine the relationships between citations in academic journals. As part of the citation analysis process, publications are typically evaluated based on how frequently they are cited elsewhere. Comparing papers can also be done using co-citation ratios (Drijvers et al., 2020).

Numerous bibliometric studies have been carried out in the field of education, such as the study by Djeki et al. (2022) that discussed e-learning collaborations, bibliometric analysis has rarely been used in mathematics education to map research trends worldwide. As an example, Muhammad et al. (2023) investigated discovery learning in mathematics while Behrens and Luksch (2011), Ramirez and Devesa (2019), Ozkaya (2018), Jimenez-Fanjul et al. (2013) and Julius et al. (2021) reviewed publications in mathematics education. Meanwhile, Sreylak et al. (2022) conducted literature review research on mathematics concepts. Ersozlu and Karakus (2018) examined publications on mathematics anxiety.

Ha et al. (2020) and Domenech et al. (2019) conducted bibliometric analyses of STEM education, whereas the purpose of this study is to examine mathematical misconceptions. Furthermore, this study focuses on misconceptions about math education. In a different field, Kurtulus and Tatar (2021) conducted a bibliometric analysis of articles concerning science misconceptions.

METHODOLOGY

This study follows the general bibliometric analysis workflow, consisting of the quantitative and qualitative methods. The quantitative approach consists of five stages: study design, data collection, data analysis, data visualization, and interpretation (Börner et al., 2003; Zupic & Cater, 2014). To identify worldwide research trends in mathematics misconceptions, bibliometric methods were applied. To investigate the common misconceptions found by bibliometric analysis in the top ten cited papers, systematic analysis (qualitative approach) of published publications was employed. Citations to related articles and other published works are used to evaluate the influence of an article. Tracking the trends on the most recent subject involved quantifying the distribution of publications over time, journals, countries, institutions, author performances, and the most popular subjects and how they changed over time.

Sampling Method

The data for the study is based on English-language publications published between 1947 and 2023 that contain the keyword "mathematics misconception, math concepts, errors in math," according to the Scopus database. The articles were published in various journals between 1947 and 2023. In the analysis of the database, books, book chapters, review articles, editorial materials, and letters are excluded. 1947 is regarded as the start date because, according to the scans, the first article on the topic was published in 1947. Since 2024 is still ongoing, it was determined that included articles published in 2024 thus far could have an impact on the study's findings; as a result, these articles were not included in the study's sample.

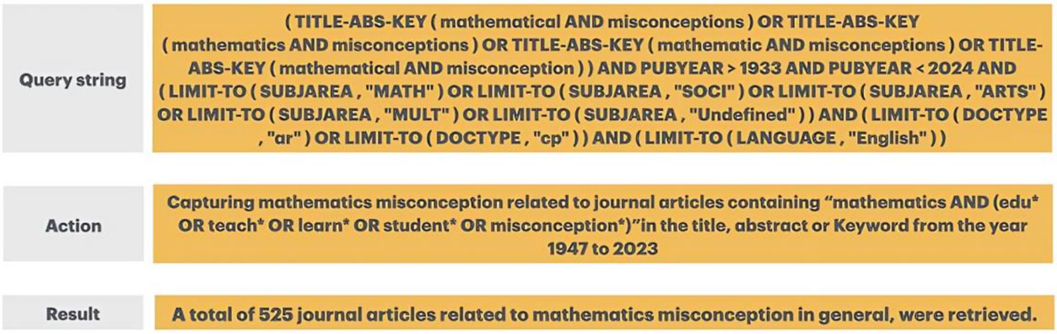

Figure 1. Flowchart of data collection and search strategy (Source: Authors' own elaboration)

Data Collection

750 papers were found in the database when the term "mathematics misconception, math concepts, math errors" was entered. In accordance with the goals of the study, a number of search limitations were placed, including those related to journal articles, subject areas, languages, and time periods. A total of 525 articles will be considered in the analysis. This sample of articles will be analyzed to find out how the articles are distributed, how average the citation scores are, which journals publish the most related articles, which authors publish the most related articles, how much each author's citation burst score is, how productive the authors' nation of origin are scientifically, which articles are cited the most frequently, collaboration networks, and patterns found through word cloud and word tree text mining techniques. The data collection and search approach is depicted in **Figure 1**.

Data Analysis

Within the scope of the study, the scanned papers were examined using the R-Studio and VOSviewer programs. It was possible to obtain the R program via https://cran.r-project.org/, the official website for the storage of several bibliometric analysis applications. These package programs for bibliometric analyses are quite beneficial in quantitative research (Aria & Cuccurullo, 2017). The R program will be used for the bibliometric analyses carried out in this study since it offers a wider variety of results with deeper details (Kurtulus & Tatar, 2021).

Based on the research criteria for article selection, the data file used for the study was created using Scopus. The first is to select "export", next "other file formats", then "records from (1-500)", and finally "record content (full record and cited references)". The data file for the study after completing the selection steps consisted of 525 articles in total. To analyze the articles, first, the "bibliometrix" package in the R program will be downloaded and activated for the analyses. Next, a web address was used to direct the R- Studio application to the bibliometric analysis page. The "plain text" file is saved here in a data segment that will be used for the study's analyses. Finally, a qualitative content analysis on the top ten papers–identified by the bibliometric analysis–was used to extract the most common mathematics misconceptions between 1947 and 2023.

Study Procedures

The study followed the following procedures (Öztürk et al., 2024).

- Review of educational literature and previous studies.
- Define the aims and scope of the bibliometric study.
  - What are the aims and scope of the study?
  - Is the scope of the study large enough to warrant the use of bibliometric analysis?
- Choose the data for bibliometric analysis.
  - What bibliometric analysis techniques should be chosen to meet the aims and the scope of the study?
- Collect the data for bibliometric analysis.
  - Do the search terms exemplify the scope of the study?
  - Is the coverage of the database adequate for the study?
  - Is the data free of errors such as duplicates and erroneous entries?
  - Does the final data set fulfil the requirements of the bibliometric analysis techniques chosen for the study?
- Run the bibliometric analysis and report the findings.
  - Can the bibliometric summary be easily understood by readers?
  - Does the writing align with the bibliometric summary presented?
  - Does the writing explain the peculiarities and implications of the bibliometric summary?
  - Does the writing align with the target outlet for publication?
- Discussing the results and writing recommendations.

Table 1. Overview of mathematical misconceptions

Description	Results
Documents	525
Sources (journals)	252
Keywords plus (ID)	823
Author's keywords (DE) 5	1303
Period	1947-2023
Average citations per document	18.23
Authors	1148
Author appearances	
Authors of single-authored documents	129
Single-authored documents	133
Documents per author	0.46
Authors per document	2.19
Co-authors per document	2.45
Document types	
Article	447
Conference paper	78

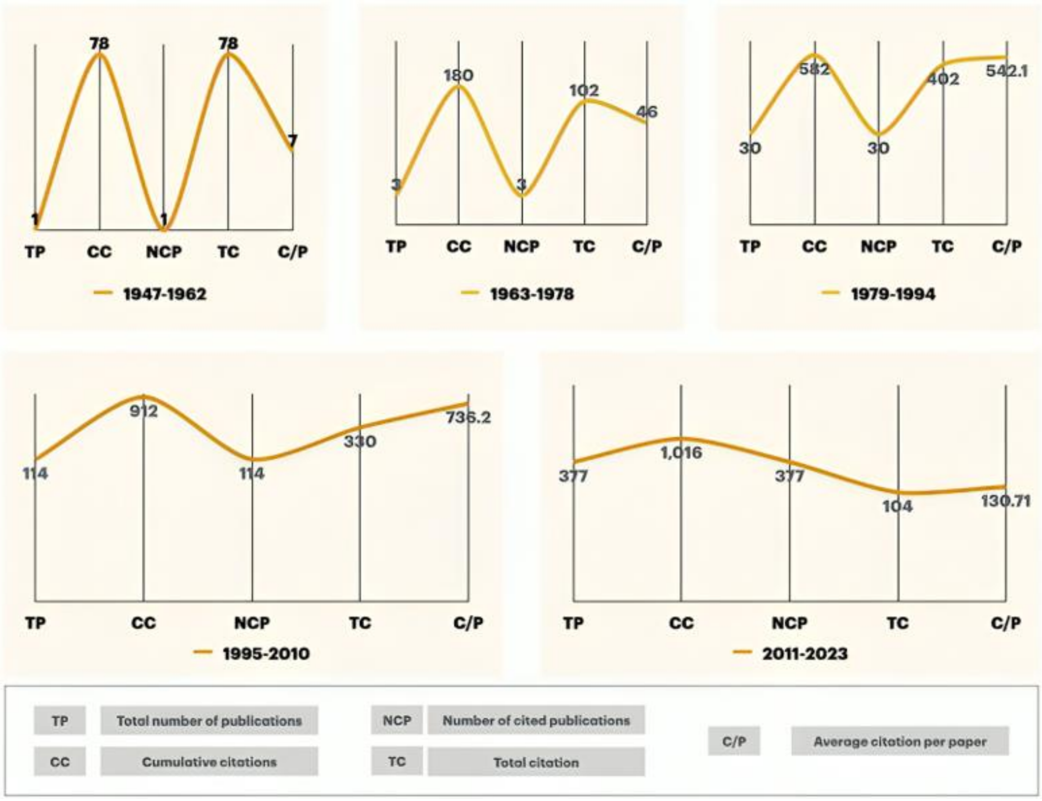

Figure 2. Publications on mathematical misconceptions and their growth trend (Source: Authors' own elaboration)

RESULTS

The Findings Related to Performance Analysis and Benchmarking of Misconceptions in Mathematics (Quantitative Analysis)

Overview of mathematical misconception

Between 1947 and 2023, 525 publications (447 articles and 78 conference papers) related to mathematical misconceptions were published. These publications were gathered from 252 sources, including books and journals, as shown in **Table 1** .

With an extensive examination of publications and citation data over various time periods, **Figure 2** explains the publication output and growth pattern and provides insights into how research impact has changed over time. The analysis is divided into 5 time periods, spanning from 1947 to 2023.

There was only one publication in the early period, which occurred from 1947 to 1962. It received 78 total citations, averaging 7 citations per paper. The next period, from 1963 to 1978, experienced an increase in publications to three and a total of 102 citations. The cumulative citations also grew to 180, with an average of 46 citations for every publication.

Table 2. Country production over time in the field of mathematical misconceptions

Year	Number of articles				
	USA	UK	South Africa	Indonesia	Turkey
1947-1962	1	0	0	0	0
1963-1978	5	1	0	0	0
1979-1994	84	30	0	0	0
1995-2010	989	276	37	5	26
2011-2023	34,591	512	394	263	952

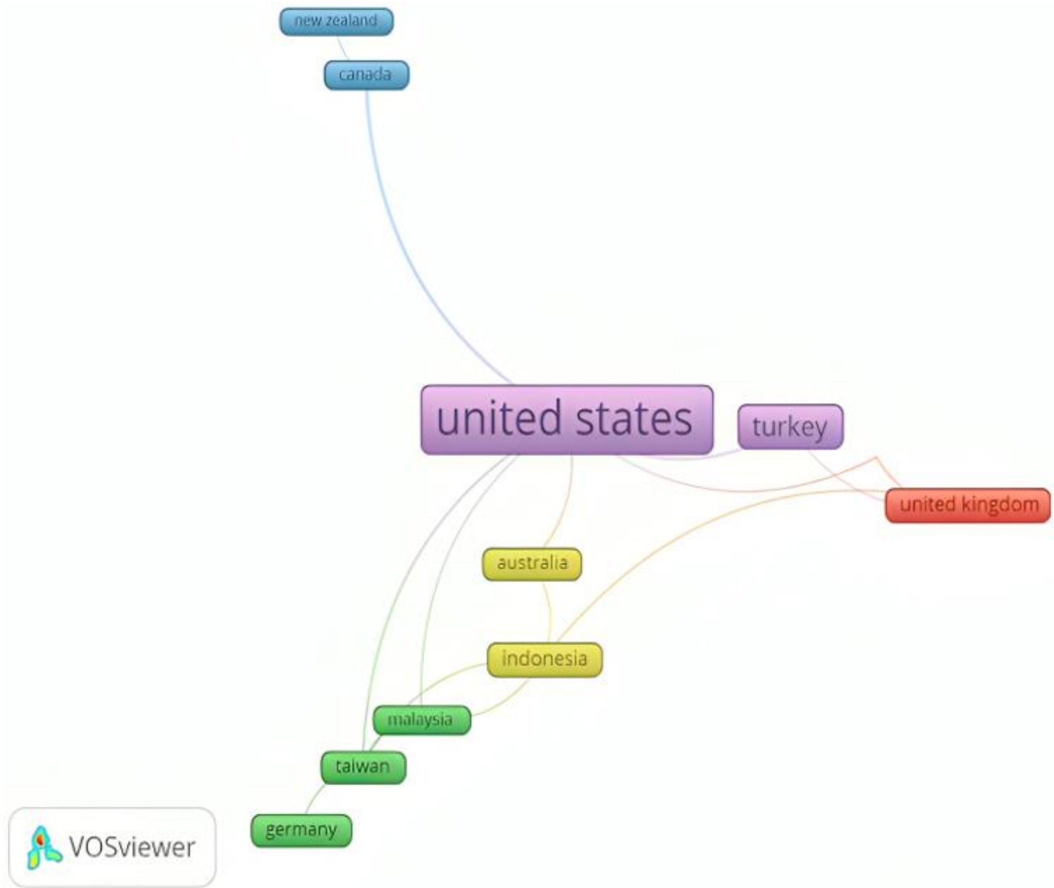

Figure 3. The academic cooperation on mathematical misconceptions research among countries in the world (Source: Authors' own elaboration, using VOSviewer)

Table 1 indicates that there was a significant increase in publications and citations from 1979 to 1994. Over this time, 30 publications and 402 citations totaled 582 citations, or 542.1 citations on average per paper. A total of 912 citations were obtained from 114 articles between 1995 and 2010; each piece received an average of 736.2 citations. Research output and citation rates have grown dramatically during this time, suggesting a more substantial and well-respected body of work.

Additionally, **Table 1** displays a noteworthy increase in research activity from 2011 to 2023, as evidenced by 377 publications with 104 citations and a total of 1,016 citations. During this time, the number of citations per paper decreased dramatically when compared to prior years.

Contribution by nations

The number of articles published across five different time periods in different regions is shown in **Table 2**. There was only one article recorded from the USA, between 1947 and 1962; with no contribution from the UK nor South Africa, Indonesia, or Turkey. In the subsequent period, the number of articles, especially in the USA. In all regions, the growth trend becomes increasingly noticeable in the following years. In contrast to the USA, there were still comparatively few articles from these nations.

The VOSviewer generated the diagram shown in **Figure 3**, in which the labels' sizes correspond to the total number of papers for each nation. The corresponding degree of association is indicated by the thickness of each line of connection. Five distinct clusters with varying degrees of connectedness are shown by colors. The graphic illustrates that the USA leads the world in publications and collaborates with numerous nations on research related to mathematical mistakes, including Australia, Turkey, Canada, Malaysia, South Africa, and Taiwan. Along with a few other nations, authors from the USA and Canada collaborate mostly.

Table 3. Top-10 most productive affiliations publishing in the field of mathematical misconceptions (contribution by institutions)

Order	Affiliation	Country	Articles
1	University of the Witwatersrand	South Africa	9
2	Arizona State University	USA	8
3	University of Manchester	UK	7
4	Indiana University	USA	7
5	Middle East Technical University	Turkey	7
6	Boston University	USA	6
7	Comenius University	Slovakia	5
8	Karadeniz Technical University	Turkey	5
9	University of Oklahoma	USA	4
10	Universiti Brunei Darussalam	Brunei	4

Table 4. The 10 most active journals in mathematical misconceptions based on the number of publications

Order	Journals	Country	n	CS 2022*	h-index*	Scopus quartile*	Publisher
1	Educational Studies in Mathematics	Netherland	444	4.7	13	First quartile	Springer Nature
2	International Journal of Mathematical Education in Science and Technology	UK	412	2.6	9	First quartile	Taylor & Francis
3	Journal of Mathematical Behavior	USA	180	2.7	8	First quartile	Elsevier
4	Primus	UK	153	1.2	4	Third quartile	Taylor & Francis
5	Lecture Notes in Computer Science	Germany	148	2.2	6	Third quartile	Springer Nature
6	Mathematics Education Research Journal	Netherland	128	3.7	3	First quartile	Springer Nature
7	School Science and Mathematics	USA	124	2.1	5	First quartile	Wiley-Blackwell
8	Proceeding–Frontiers in Education Conference	USA	118	1.1	3	Third quartile	Institute of Electrical and Electronics Engineers Inc.
9	International Journal of Science and Mathematics Education	Netherland	77	4.8	7	First quartile	Springer Nature
10	Mathematics Teaching-Research Journal	USA	68	2.7	3	Fourth quartile	Elsevier

Note. *According to Scopus (http://www.scopus.com); n: Number of articles; CS: Cite score

Contribution by institutions

The 10 most productive affiliations that publish in the area of mathematical misconceptions are listed in **Table 3**, arranged according to their affiliations. The variety of affiliations is one noteworthy feature; contributions have been made from South Africa, the USA, the UK, Turkey, and Brueni, demonstrating the field's international reach and collaboration.

Contribution by journal according to documents

The top-10 journals in the field of mathematics misconceptions are displayed in **Table 4** together with key metrics, such as article counts, citation scores, the h-index, Scopus quartiles, and publisher information.

The country origins of these papers range from the Netherlands and the UK to the USA and Germany, demonstrating the remarkable diversity in the global reach of research in mathematical education. **Table 4** also indicates the different impact and visibility levels of these journals, as seen by their citation scores, h-index, and Scopus quartile ranking.

Higher citation counts and h-indices for journals like "Educational Studies in Mathematics" and "Journal of Mathematical Behavior" demonstrate their importance in the area. Additionally, these publications' relative standing within the academic world is shown by Scopus' quartile rankings, several of which are among the prestigious first quartiles.

Contribution by journal according to citation

Table 5 provides a summary of 10 influential journals in the field of education, with an emphasis on learning sciences and mathematics education. Reputable publishers like Wiley-Blackwell, Taylor & Francis, Springer Nature, SAGE, and Elsevier publish a number of journals that highlight the quality and thoroughness of their editorial processes.

Moreover, the Scopus quartile classification provides an overview of each journal's ranking regarding its own field. Several of the prestigious journals are indicated by the fact that they are in the first quartile of publications for research on mathematics and education in **Table 5**.

Contribution by authors

As **Table 6** shows, ten authors in this field are affiliated with different universities and have published scholarly works. The authors are affiliated with multiple universities across multiple countries, including the USA, South Africa, Brunei Darussalam, Taiwan, Belgium, and Taiwan. Because academic research is globally represented, the knowledge and insights it produces cross national boundaries.

Beyond the quantity of papers, an author's impact and influence can be evaluated by an h-Index. Notably, authors with h-index scores of 6 and 5, respectively, are Bethany Rittle-Johnson and Kelley Durkin, both of Vanderbilt University. These results point to a significant academic impact, as evidenced by the widespread citation and recognition of their work in their field.

Table 5. The top-10 cited journals for articles on misconceptions in mathematics

Order	Journals	Country	n	CS 2022*	h-index*	Scopus quartile*	Publisher
1	Human Communication Research	USA	1,809	6.9	1	First quartile	Wiley-Blackwell
2	Journal of the Learning Sciences	USA	1,080	12	1	First quartile	Taylor & Francis
3	Educational Studies in Mathematics	Netherland	855	4.7	13	First quartile	Springer Nature
4	Review of Educational Research	USA	589	21.1	1	First quartile	SAGE
5	Journal for Research in Mathematics Education	USA	378	4.5	5	First quartile	NCTM
6	International Journal of Mathematical Education in Science and Technology	UK	327	2.6	9	First quartile	Taylor & Francis
7	Learning and Instruction	UK	316	11.2	4	First quartile	Elsevier
8	Computers and Education	UK	225	23.8	6	First quartile	Elsevier
9	Journal of Mathematical Behavior	USA	221	2.7	8	First quartile	Elsevier
10	American Educational Research Journal	USA	162	9.0	2	First quartile	SAGE

Note. *According to Scopus (http://www.scopus.com); n: Number of articles; CS: Cite score

Table 6. Top-10 most productive authors publishing in the field of mathematical misconceptions in terms of documents

Order	Authors	Institutions**	n	h-index**
1	Kelley Durkin	Vanderbilt University	6	6
2	Judah P. Makonye	University of the Witwatersrand	6	3
3	Bethany Rittle-Johnson	Vanderbilt University	5	5
4	Lieven Verschaffel	University of Leuven	5	5
5	Der-Ching Yang	National Chiayi University	5	4
6	Wim Van Dooren	University of Leuven	4	4
7	Osman Birgin	Usak University	4	3
8	Masitah Shahrill	University Brunei Darussalam	4	3
9	Iwan A.J. Sianturi	Indiana University	4	3
10	Dirk De Bock	University of Leuven	3	3

Note. **According to Scopus (http://www.scopus.com) & n: Number of douments

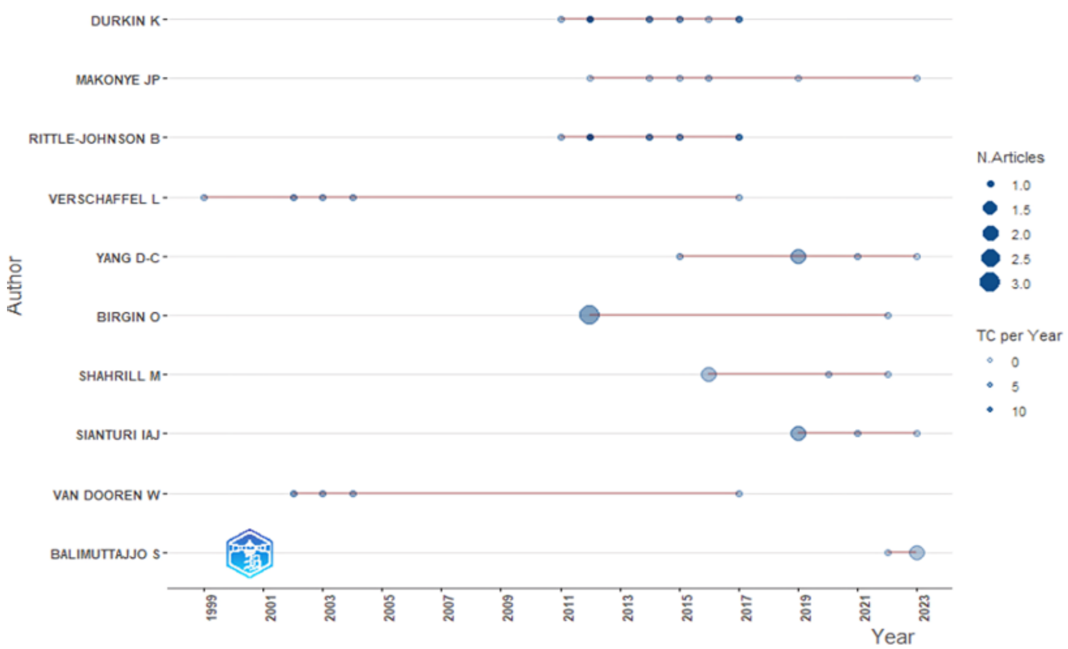

Figure 4. Top-10 most productive authors publishing in the field of mathematical misconceptions in terms of documents (Source: Authors' own elaboration, using R program)

The yearly publications of the top-ten writers in the field of mathematical misconceptions are displayed in **Figure 4**. There are differences in the publication histories of the ten writers, with some of them producing fewer papers than others. Some authors have produced a substantial body of work in the field; Kelley Durkin of Vanderbilt University and Judah P. Makonye of the University of the Witwatersrand, for example, have each written six publications. However, three records from authors like Dirk De Bock of the University of Leuven indicate a significantly lower level of publication activity.

Furthermore, **Figure 4** demonstrates how the top-10 authors have dedicated the last ten years to this issue. There haven't been any articles on this subject from Kelley Durkin, Bethany Rittle-Johnson, Lieven Verschaffel, and Wim Van Dooren since 2017.

Table 7 shows the scholarly effect of 10 authors in their respective domains, focusing on the overall number of citations created by their work. With an impressive total of 1,809 citations, Klaus Krippendorff is well recognized and influential in the

Table 7. Top-10 most productive authors publishing in the field of mathematical misconceptions in terms of citations

Order	Authors	Institutions**	Total citations**
1	Klaus Krippendorff	University of Pennsylvania	1,809
2	John P. Smith III	Michigan State University	1,084
3	Jeremy M.Roschelle	Institute for Research on Learning	1,080
4	Andrea A. Disessa	University of California	1,080
5	Gaea Leinhardt	University of Pittsburgh	699
6	Mary Kay Stein	University of Pittsburgh	589
7	Orit Zaslavsky	Technion- Palestine	589
8	Kelley Durkin	Vanderbilt University	452
9	Bethany Rittle-Johnson	Vanderbilt University	441
10	Lieven Verschaffel	University of Leuven	*263*

Note. **According to Scopus (http://www.scopus.com)

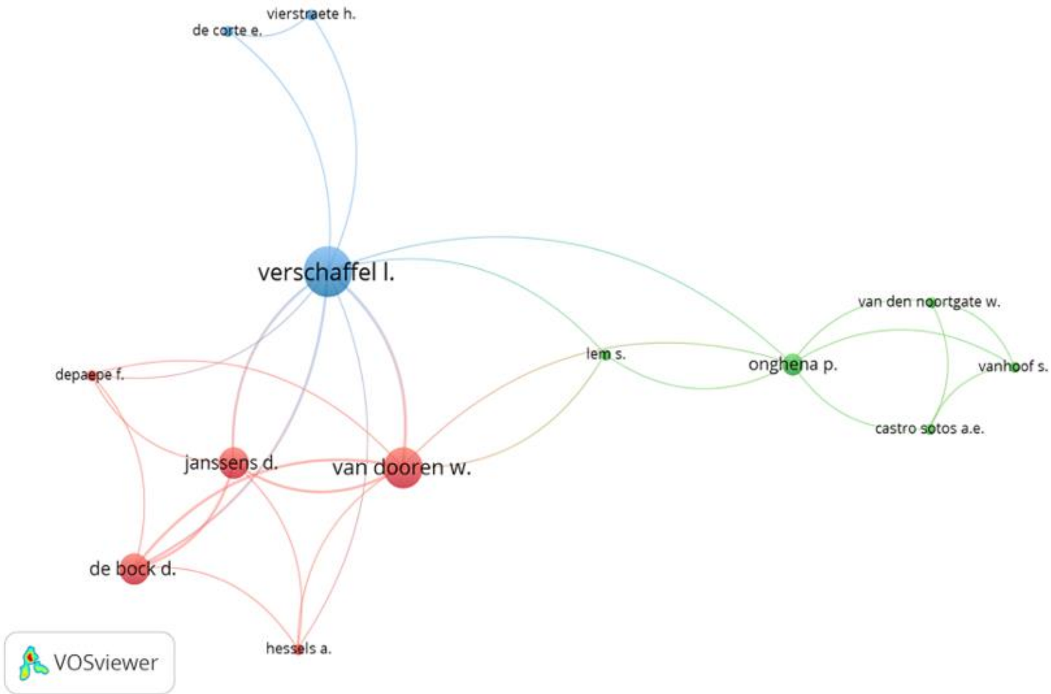

Figure 5. Collaborative network among authors in the field of mathematical misconceptions (Source: Authors' own elaboration, using VOSviewer)

academic community, positioning him at the forefront of scholarly influence. Among the writers on the list are John P. Smith III from Michigan State University, Andrea A. Disessa from the University of California, and Jeremy M. Roschelle from the Institute for Research on Learning. With more than a thousand citations between them, it is evident how much each of them has contributed to the field of study.

The fact that multiple authors are affiliated with the same academic institutions is a curious aspect of **Table 7**. Kelley Durkin and Bethany Rittle-Johnson attended Vanderbilt, while Gaea Leinhardt and Mary Kay Stein attended the University of Pittsburgh.

All 1,148 writers were included in the cooperation study of authors on mathematical misconceptions. Three groups were the only ones associated among the 318 different clusters found by the analysis (**Figure 5**), and this connection was made by a small number of researchers. The relevant cooperative author groups, which are the subject of study on mathematical misconceptions, are displayed in **Figure 4** in various colors. Even though there are adequate authors, **Figure 4**'s co-authorship network visualization map reveals that there is little collaboration between the academics addressing mathematical misconceptions.

Additionally, a few scholars are actively working in the majority of groups. A group of 13 authors, another of 11 authors, a group of 10 authors, and yet another of 9 authors, as well as 3 groups of 8 authors, 6 groups of 7 authors, 15 groups of 6 authors, 17 groups of 5 authors, 46 groups of 4 authors, 91 groups of 3 authors, 123 groups of 2 authors, and 1 group of single authors, are among the most significant groups out of the 318 groups.

The red cluster, which consists of five writers, is the largest group. Wim Van Dooren (4 publications), David Janssens, and Dirk De Bock (3 publications) are the authors with the most publications. With five authors, the second group is the green one. Patrick Onghena is the most well-known member of this group with two publications. The group shown in blue is the third-largest. Lieven Verschaffel stands out among the three authors in this category with five publications.

Table 8. Mathematical misconceptions document contribution

Order	Document title	Year	Citation	Journal	Publisher	Affiliation	Country
1	Reliability in content analysis: Some common misconceptions and recommendation	2004	1,809	Human Communication Research	Wiley-Blackwell	University of Pennsylvania	USA
2	Misconceptions reconceived: A constructivist analysis of knowledge in transition	1994	1,080	Journal of Learning Sciences	Taylor & Francis	Michigan State University	USA
3	Functions, graphs, and graphing: Tasks, learning, and teaching	1990	589	Review of Education Research	SAGE	University of Pittsburgh	USA
4	Enhancing prospective teachers' knowledge of children's conceptions: The case of division of fraction.	2000	205	Journal of Research in Mathematics Education	NCTM	Tel-Aviv University	USA
5	There is more to discourse than meets the ears: Looking at thinking as communicating to learn more about mathematical learning	2001	198	Educational Studies in Mathematics	Springer Nature	The University of Haifa	Palestine
6	The effectiveness of using incorrect examples to support learning about decimal magnitude	2012	187	Learning and Instructions	Vanderbilt University	Elsevier	USA
7	Developing an assessment-centered e-learning system to improving student learning effectiveness	2014	120	Computers and Education	National Tsing Hua University	Elsevier	Taiwan
8	An extensive analysis of preservice elementary teachers' knowledge of fractions	2008	112	American Educational Research Journal	Temple University	SAGE	USA
9	Seeing the complexity of standing to the side: Instructional dialogues	2005	110	Cognition and Instruction	University of Pittsburgh	Taylor & Francis	USA
10	The irregular cutting-stock problem- a new procedure for deriving the no-fit polygon	2001	109	Computers and Operations Research	University of Southampton	Elsevier	UK

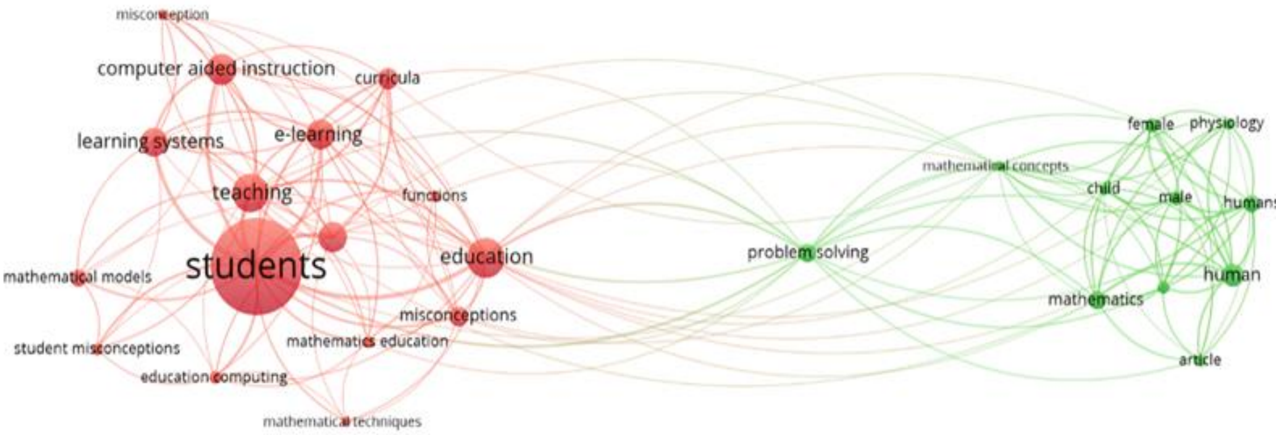

Figure 6. Co-occurrence network with index keywords in the field of mathematical misconceptions (Source: Authors' own elaboration, using VOSviewer)

Contribution by document

Table 8 combines a wide range of academic publications, each contributing its own special insights and knowledge to the topic of mathematical mistakes. The 2004 University of Pennsylvania article "Reliability in content analysis: some common misconceptions and recommendation" explores the field of content analysis and has received significant attention, receiving 1809 citations since it was published in Human Communication Research by Wiley-Blackwell. Similarly, Michigan State University in the USA's "Misconceptions reconceived: A constructivist analysis of knowledge in transition" (1994), which was published by Taylor & Francis in the Journal of Learning Sciences, has garnered significant attention with 1080 citations, indicating its significance in the discourse regarding education.

The Findings Related to Content Analysis and Road Map for Future Research of Mathematics Misconception. (Quantitative Analysis)

Terms analysis

A total of 525 papers addressing mathematical misconceptions contained 823 keywords. A co-occurrence analysis of the keywords shows that only 27 of them are present in more than five articles. As seen in **Figure 6**, the co-occurrence analysis indicated that the keywords are sorted into two clusters or groupings. Information about similar study topics in the area of interest is provided by the keywords in the clusters.

The red cluster, which has 16 keywords, is the largest cluster, as can be seen in **Figure 6**. Highlighted words include misconceptions, e-learning, students, education, teaching, and learning system. With eleven terms, the green cluster is the second one. These include humans, mathematics, and problem-solving.

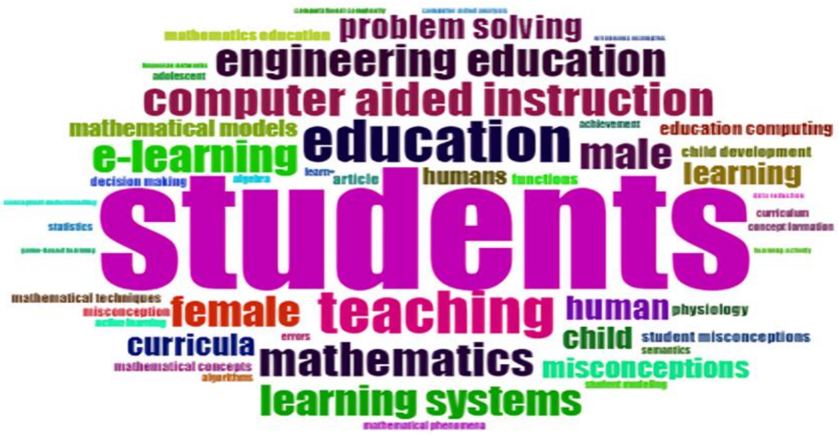

Figure 7. Words cloud (based on keywords) in the field of mathematical misconceptions (Source: Authors' own elaboration, using R program)

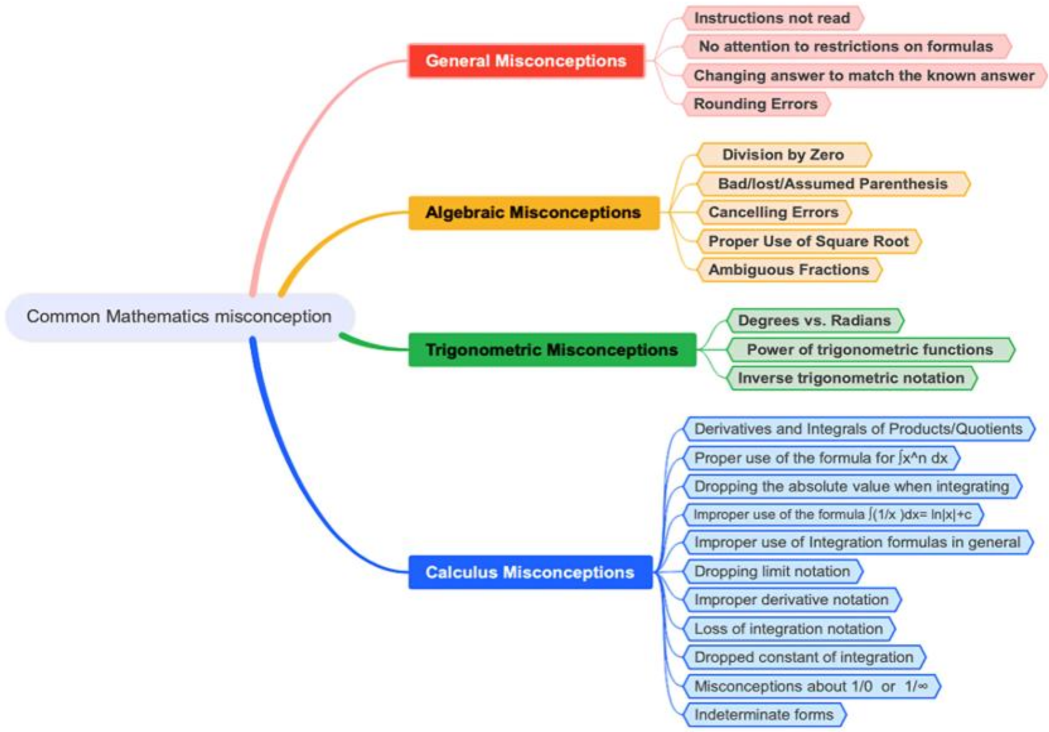

Figure 8. Common mathematical misconceptions according to error type (Source: Authors' own elaboration)

Biblioshiny software generated a words cloud in **Figure 7** based on keywords from published publications on mathematical misconceptions. It is evident that the two main fields where mathematical misconceptions research is present are students (64, or 14% of the total), and education and teaching (23, or 5%). Other than this, we can observe that there is a great diversity in the research themes and subjects.

The most common mathematics misconception (qualitative analysis)

Based on the number of citations monitored in **Table 8** through bibliometric analysis, **Figure 8** shows the common mathematical misconceptions identified through content analysis across the first ten scientific papers (Bennell et al., 2001; Durkin & Rittle-Johnson, 2012; Krippendorff, 2004; Leinhardt & Steele, 2005; Leinhardt et al., 1990; Newton, 2008; Sfard, 2001; Smith, 1993; Tirosh, 2000; Wang, 2014).

Four topics are covered by the most common misconceptions in mathematics, as shown in **Figure 8**. In the first field, there were four general errors. Five conceptual mistakes related to algebra. Calculus conceptual mistakes are 11 and trigonometric conceptual mistakes are 3.

DISCUSSION AND CONCLUSIONS

Discussion and Conclusions Related to Performance Analysis and Benchmarking of Mathematics Misconception

Overview of mathematical misconceptions

The large number of documents (525) highlights the range of research that was examined in the study. Interestingly, the split of document categories shows that articles account for the majority of the emphasis (447), indicating that in education, in-depth study and analysis are valued more highly than conference presentations.

A trend towards interdisciplinary collaboration and information exchange is suggested by the distribution of single-authored publications (133) and the prevalence of co-authors per document (2.45). These findings highlight the collaborative nature of scientific efforts.

Publication output and growth trend

Between 1979 and 2010, there was a notable increase in academic growth and influence. This pattern corresponds with more general advances in technology, communication, and multidisciplinary collaboration at this time, which probably made it easier for research to be disseminated and cited more frequently (Börner, 2003).

Between 2011 and 2023, there were 104 citations in all, which is a significant decrease from earlier times. Because scientific works frequently need time to become visible and receive citations from peers, this discrepancy can be explained by the relative recentness of publications within this span. Therefore, it is incorrect to interpret the lower citation count during this time frame as a sign of decreased scholarly impact or quality (Crea et al., 2023).

Contribution by nation

National Council of Teachers of Mathematics (NCTM, 2000) revised and updated its curriculum and evaluation standards which explains the significant increase in the article's output that was observed from 1995 to 2010, particularly from the USA, which contributed the most to scholarly literature during this time frame, from 2011 to 2023, article production increased dramatically across all countries, with the USA, Indonesia, and Turkey bringing the most notable contributions. This growth was probably caused by technological advancements, globalization, and research infrastructure, which made publishing platforms and international cooperation more accessible (Neidorf et al., 2020).

Contribution by institutions

The University of the Witwatersrand in South Africa is the top contributor with nine publications, demonstrating its importance in the academic community. The topic of mathematical misconceptions has generated a lot of interest because of the range of affiliations, which is due in part to the worldwide nature of academic collaboration and partly to the general curiosity in the field.

Contribution by journal according to documents

Mathematical misconceptions are frequently covered in journals such as Educational Studies in Mathematics, International Journal of Mathematical Education in Science and Technology, and Journal of Mathematical Behavior. Some of these journals were listed among the most prestigious journals, such as the Journal of Mathematical Behavior and Educational Studies in Mathematics (Nivens & Otten, 2017).

Contribution by journal according to citation

The top quartile of each Scopus ranking contains the ten journals that receive the most references when discussing mathematical misconceptions. There is a considerable correlation between journal quality and citation impact, as evidenced by the relationship between first-quartile position and high citation counts (Thelwall et al., 2023). According to this theory, journals in the top quartile receive more citations, which is indicative of their standing and influence within the field of education.

Contribution by authors

The h-index values and document counts of the writers differ significantly from each other. Despite contributing fewer documents, several authors like Bethany Rittle-Johnson from Vanderbilt University and Lieven Verschaffel from the University of Leuven had identical h-index values. More records were given by Kelley Durkin of Vanderbilt University and Judah P. Makonye of the University of Leuven. Ideally, an article's productivity and influence can be determined using the h-index and the quantity of documents (Julius et al., 2021).

Several factors could contribute to the lack of collaboration among authors of mathematical misconceptions. To maximize their academic achievement, researchers could prefer to work independently rather than in groups, which might not lead to an individual's acknowledgment right once. In addition, realistic challenges including accomplishing research goals, communicating effectively, and overcoming institutional barriers might have an impact on the coordination of collaborations (Lee & Bozeman, 2005).

Contribution by document

The two articles with the highest number of citations are "Misconceptions reconceived: An analysis of knowledge in transition" and "Reliability in content analysis: Some common misconceptions and recommendations". The citation counts of the two best publications differ significantly from those of the other research, indicating a worrying pattern in academic reference. This implies that scholars typically cite well-known works without acknowledging the important contributions of other writers (Kwon, 2022).

Discussion and Conclusions About the Content Analysis and Future Plans for Investigation Into Math Misconceptions

Terms analysis (topic trends)

From 1947 until 2023, the word "mathematics" was used without interruption, indicating the subject's continued significance in the classroom. This demonstrates how important mathematics is to schooling and developing problem-solving skills. It's also important to recognize that there are still misconceptions regarding mathematics (Ay, 2017).

It is consistent that the term "students" is used to refer to them most frequently because of their important role in the educational process. The core principle of education, which states that students' needs, aspirations, and development should come first, was endorsed by the study's researchers.

The increased usage of phrases like "computer-assisted instruction" and "e-learning" since 1995 suggests that technology is becoming more prevalent in the educational system. This pattern demonstrates how educational approaches are constantly evolving and the need for educators to adapt to new technologies to meet the demands of this evolution (Djeki et al., 2022).

The most common misconception in mathematics

According to McDonald (2010), misconceptions are common in many areas of mathematics, including computation, algebra, geometry, trigonometry, linear equations, quadratic equations, similar triangle relations, and functions. Four main categories of misconceptions were found based on our qualitative content analysis: general misconceptions, algebraic misconceptions, conceptual errors in trigonometry, and conceptual errors in calculus.

When solving mathematical problems, students frequently face common misconceptions, which affect their ability to solve problems. First, not reading instructions carefully; if instructions are not thoroughly read, it might result in misunderstandings and improper methods of problem-solving (Hübner et al., 2022). Important information on the actions to do or requirements to fulfill is frequently included in instructions, When students ignore this, they may fail to recognize crucial cues like constraints or variables to concentrate on, which could result in partial or inaccurate answers (Booth et al., 2013).

No attention to restrictions on formulas is another common misconception; Students may, for example, employ formulas without realizing their restrictions. This disregard for conditions, such as domain restrictions or certain presumptions that must be accurate before applying a formula, can lead to incorrect responses (Krippendorff, 2004).

Changing answers to match a known or expected answer is another significant misconception. Students who modify their answers to fit their own ideas of what is right show a lack of confidence in their ability to solve problems (Smith, 1993). Poor mathematical thinking is encouraged when people modify their answers without verifying their methods, rather than considering where they might have made a mistake. Lastly, rounding errors are also a major misconception, especially when pupils round too early or unevenly. In a multi-step problem, rounding at the wrong points can cause cumulative errors, which can change the solutions considerably in the result (Leinhardt et al., 1990).

$$\begin{gathered}\sqrt{ab} = \sqrt{a}\sqrt{b} \\ \sqrt{1} = \sqrt{1} \\ \sqrt{(1)(1)} = \sqrt{(-1)(-1)} \\ \sqrt{1}\sqrt{1} = \sqrt{-1}\sqrt{-1} \\ (1)(1) = (i)(i) \\ 1 = i^2 \\ 1 = -1\end{gathered} \tag{1}$$

Misconceptions about algebra may severely limit students' ability to solve problems; particularly concerning division by zero, the incorrect use of parentheses, the proper handling of square roots, and the interpretation of ambiguous fractions (Newton, 2008). Division by zero is often misunderstood; Many students can try dividing by zero without understanding that it is not a mathematical operation, which could cause them to make incorrect conclusions from their calculations (Durkin & Rittle-Johnson, 2012). Similarly, ambiguity around brackets can cause expressions to be misunderstood. Students' final responses may be affected when they miscalculate the order of operations due to losing track of assumed brackets (Sfard, 2001).

Additionally, using square roots correctly is essential; students frequently use the properties of square roots incorrectly, for example, assuming that $\sqrt{a} = a$ without considering that it can also equal to -a. Finally, ambiguous fractions can be confusing. If students don't understand the structure of a fraction, they might miscalculate or simplify it incorrectly (Tirosh, 2000).

$$\begin{gathered}(-3)^2 = (-3) \times (-3) = 9\ (correct) \\ (-3)^2 = -3 \times 3 = -9\ (incorrect)\end{gathered} \tag{2}$$

Trigonometric misconceptions: Misconceptions about trigonometry may hinder the students' understanding and problem-solving skills. A frequent problem is students misinterpreting angle measurements due to the mismatch between degrees and radians, which can lead to inaccurate trigonometric function computations (Wang, 2014). Furthermore, students frequently have difficulties determining the difference between expressions like $(\sin x)^2$ and $\sin(x^2)$ resulting in substantial computation error.

Table 9. Improper use of the formula $\int \frac{1}{x}dx = \ln(|x|) + c$

Integral	Incorrect answer	Correct answer
$\int \frac{1}{x^2+1}dx$	$\ln(x^2+1)+c$	$tan^{-1}(x)+c$
$\int \frac{1}{x^2}dx$	$\ln(x^2)+c$	$-x^{-1}+c=\frac{-1}{x}+c$
$\int \frac{1}{\cos x}dx$	$\ln\lvert\cos x\rvert+c$	$ln\lvert\sec x+\tan x\rvert+c$

Lastly, misconceptions about inverse trigonometric notations can lead to a lack of clarity about their domains and ranges, which makes using them to solve problems much more difficult (Ersoy, 2006).

Example: Find $\sin(30^2)$.

$$\sin(30^2) = (\sin 30)^2 = (\frac{1}{2})^2 = \frac{1}{4}\ (incorrect)$$

$$\sin\ (30^2) = \sin(30)(30) = \sin(900) = 0\ (correct)$$

Misconceptions about calculus can have a big impact on how well students grasp and use integrals and derivatives. One common problem is that students often handle products and quotients wrongly, applying the rules erroneously and making mistakes while attempting to calculate derivatives (McDonald, 2010). Furthermore, a lot of students make mistakes when integrating because they forget to include the absolute value sign, which can affect the function's domain determination (Leinhardt & Steele, 2005).

Calculus concepts can become more difficult for students to understand if they have misconceptions regarding limit notation, such as forgetting to add it during integration or differentiation. Additionally, students frequently have trouble understanding the concept of indeterminate forms, especially when assessing limits, which causes misunderstanding regarding the actual values of the forms (Bennell et al., 2001).

Example is shown in **Table 9**.

Conclusion and Recommendations

The continuous nature of misconceptions emphasises the necessity of educational strategies and instructional interventions that successfully address them. Teachers can create ways to address deeper conceptual understanding, identify and correct common errors, and enhance students' mathematical reasoning skills as they become aware of the persistent nature of these misconceptions (Kshetree et al., 2021).

In the light of the conclusions mentioned above, this study recommends the following:

- Based on the findings of this bibliometric analysis, which focused exclusively on English-language articles related to mathematics misconceptions, future researchers should consider conducting a similar bibliometric analysis on Arabic-language articles related to mathematics misconceptions.
- To facilitate joint research efforts on mathematics misconceptions, countries should allocate funding and promote international collaboration.
- Planning workshops for educators and teachers to address prevalent misconceptions about mathematics that have been discovered through research.
- Providing additional instruction or sessions to students to solve misconceptions around mathematics. During these sessions, students would have the opportunity to discuss and clear up any misunderstandings they might have had during regular class hours.

Study Limitations

A bibliometric analysis was conducted on scholarly papers on mathematics misconceptions that were indexed in the Scopus database between 1947 and 2023. The articles' sources were restricted to those that were presented at conferences or journals; novels and book chapters were not included.

The study only considers papers that are indexed by Scopus, which may leave out important studies conducted in languages other than English or in other databases. Additionally, research from a number of nations where papers are customarily published in regional tongues or in editions not listed in international databases is excluded from the analysis.

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