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A Bibliometric Analysis Study On Mathematics Education Research

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Abstract

The purpose of this study was to conduct a bibliometric analysis of publications in the field of mathematics education. The analysis focused on the journal "Educational Studies in Mathematics" (ESM). The bibliometric analysis revealed several key findings: (1) There has been a noticeable increase in the number of publications in mathematics education since the 2000s. (2) Collaborative research networks involving researchers from the USA, UK, Israel, Canada, and various European countries have provided significant contributions of scientific publications in the field. (3) The research topics within mathematics education have shifted from individual-focused to societal and social transformation. (4) International research collaborations often occur based on cultural similarities, with language and geographical proximity playing significant roles. (5) The research published in ESM covers a wide range of topics including mathematical reasoning, problem posing, equity, statistical reasoning, mathematical modeling, and teacher learning. This analysis provides an opportunity to reflect on the history and future of the ESM journal and the studies published within it.

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Introduction

The increasing number of academic publications has brought about the need for a general overview of the literature in each respective field. However, the growing number of publications poses challenges when it comes to analyzing these studies using traditional methods. For instance, determining which research topics authors prefer and how trends in these areas have changed can be a complex process (Olson & Delen, 2008). The remarkable surge in data prompts the exploration of alternative approaches to manage it. In this context, some researchers have begun to employ different methods such as systematic review or bibliometric analysis to identify trends and research topics within a field (Nie & Sun, 2017).

Systematic review typically provides a comprehensive overview of a subject's history, main research questions, pivotal studies, methods, and techniques (Chen, 2016). Nonetheless, systematic reviews come with certain challenges. Firstly,

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systematic review studies tend to focus on a specific subset of the chosen research area, thus falling short in providing a holistic and general perspective of the field. Aria and Cuccurullo (2017) emphasized that methods such as meta-analysis and literature reviews are conducted on a limited number of selected studies and are time-consuming in nature. They have pointed out that these limitations hinder the ability to draw suitable inferences aligned with the evolving dynamics of the research field, preventing comprehensive and multidimensional foresight. Upon recognizing similar shortcomings, many researchers have embraced quantitative techniques and started using bibliometric analysis to monitor developments within a research field (Keathley-Herring et al., 2016).

Bibliometric analysis involves the creation of a model using citations, references, authors, institutions, and keywords found within publications (Thelwall, 2008). Bibliometric analysis enables the quantitative data to be historically analyzed (Hung, 2012). Through citation analysis of publications, it is possible to examine in detail the institutions and countries to which contributing authors are affiliated (Keshaval & Gowda, 2008). Co-citation analysis, a widely employed method, reveals the relationships and structure of authors, publications, and journals within a scientific field. Studying reference co-citation is an important way to identify the structure and developmental trajectory of a specific field. Co-citation analysis is a method used to examine a citation network. Network analysis is applied to the selected literature of a scientific field to obtain its structure and characteristics, and clustering is performed as a result. This process reveals the map of the field.

In 1968, with the establishment of ESM, and in 1970 with the inauguration of the "Journal for Research in Mathematics Education" (JRME), specialized platforms for publishing research in mathematics education began to emerge (Ingles & Foster, 2018). Acknowledging 1968 as a starting point for the modern research field implies that mathematics educators have been publishing research in international journals for over half a century. As ESM and JRME celebrated their 50th anniversaries, Arthur Bakker (ESM editor) and Jinfa Cai (JRME editor) posed the question, "What themes should mathematics education research focus on in the next decade?" Bakker and Wagner (2020) emphasized the need for research that shapes the future of education in mathematics, reflecting the current trends and providing a specific perspective for the field.

Within the context of celebrating ERME (European Society for Research in Mathematics Education), ICME (International Commission on Mathematical Instruction), and PME (International Group for the Psychology of Mathematics Education), working groups, discussion groups, and panels on this subject have consistently been organized (Borba, 2021). Similarly, numerous studies have underscored the evolution of research areas within mathematics education and the importance of identifying themes to comprehend this evolution (Bakker, 2020; Choi & Kwak, 2019; Goos & Kaya, 2020; Gökçe & Güner, 2021; Hanna & Sidoli, 2002; Ingles & Foster, 2018).

Despite attracting considerable attention in literature, discussions regarding the evolution of mathematics education studies from a bibliometric perspective and the prominent themes continue to be discussed at important academic conferences. Therefore, it has been emphasized that there is a need for bibliometric studies that encompass current research on mathematics education (Hanna &Sidoli, 2002). There has been a growing interest in this research area in recent years. For example, Dede and Özdemir (2022) examined 416 mathematics education studies with a focus on Turkey, revealing the most influential and/or productive authors, institutions, and publications in Turkey. Similarly, Özkaya (2018) conducted a bibliometric analysis of scientific research published in the field of mathematics education between 1980 and 2018, determining the social and cognitive structure of the field. On the other hand, Julius et al. (2021) conducted a bibliometric analysis of 12,670 studies published in the field of mathematics education between 1980 and 2020. Additionally, bibliometric analysis has been used to examine changing trends and themes in specific academic journals (Chen, Cheng & Hao, 2019). Analyzing studies published in a long-standing journal such as ESM will reflect the characteristics and trends of research in mathematics education

(Bakker, 2019; Mesa & Wagner, 2019). Železnik, Vošner, and Kokol (2017) emphasized the importance of analyzing journals that have been shaping the field for many years. Comprehensive analyses of research journals from a bibliometric perspective are currently of interest. However, there have been relatively few studies conducted in the field of mathematics education (Inglis & Foster, 2018). Nevertheless, very few studies have been conducted from a bibliometric perspective on research on ESM journal, which has been proven to have the most influential and original publications in mathematics education. For example, Hanna and Sidoli (2002) conducted a statistical analysis of the keywords in ESM research specific to the fiftieth issue of ESM. Lerman and others analyzed the research published in ESM between 1990 and 2001. Despite the bibliometric studies mentioned above on mathematics education, none of them have focused on a bibliometric perspective with the aim of revealing the evolution, social structure, and themes of mathematics education research at the forefront in the field, such as ESM journal.

In this study, an attempt has been made to determine how the field of mathematics education has evolved based on the themes obtained through the bibliometric analysis of scientific research conducted in ESM from 1968 to 2022 using the VOSviewer (Visualization of Similarities viewer) tool. Within this scope, the study seeks to answer the following research questions based on bibliometric indicators related to the studies published in ESM:

- How are the numbers of articles and total citation counts distributed over the years, and which articles receive the most citations?
- Who are the most prolific authors and how is the distribution of citations to their works?
- Which institutions and countries have the highest number of publications?
- What is the collaboration network among authors, institutions, and countries?
- How are the keyword connections in the articles and their changes over the years?

Analyzing the current trends and evaluating the changes over time in research related to mathematics education is essential to identify societal needs that frequently shift, change, and adapt with the evolving era (Bakker et al., 2021; Borba, 2021; Engelbrecht et al., 2020; Kang & Kim, 2022). Similarly, in order to comprehend the evolution of research areas within mathematics education, it is crucial to define themes relevant to the field (Ingles & Foster, 2018; Choi & Kwak, 2019; Bakker, 2020; Goos & Kaya, 2020; Gökçe & Güner, 2021). Conducting a bibliometric analysis of influential journals like ESM holds critical importance in identifying such dynamics within the field of mathematics education (Bakker et al., 2021; Ingles & Foster, 2018). In this regard, this study on ESM will provide significant insights into the themes that mathematics education researchers have focused on for over 50 years. Furthermore, it is believed that this study will contribute to making predictions for future research endeavors.

Method

In this study, a bibliometric analysis of the articles published in the peer-reviewed journal ESM at an academic level in the field of mathematics education was conducted. The ESM journal was founded in 1968 by its first editor, Hans Freudenthal. The journal contains pioneering studies and innovations in the field of mathematics education at an international level. In this respect, it plays a significant role in the development and emergence of ideas in mathematics education. Due to the nature of bibliometric analysis, various sources such as national or international conferences, academic journals, books, and literature reviews constitute the basis of this analysis in mathematics education. Similarly, our study includes research on ESM, an academic journal that publishes international work in the field of mathematics education. This type of analytical approach helps to overcome criticisms such as limiting the scope of the review of the established credibility of ESM in the field of mathematics education and generalizing the results (Williams & Leatham, 2017). In parallel, Table 1 in the study by Williams and Leatham (2017) includes a citation-based ranking of academic journals published in the field of mathematics.

Dataset

This research encompasses a bibliometric analysis of studies conducted within the mathematics education

field, with a specific focus on ESM, a peer-reviewed academic journal. Founded by Hans Freudenthal in 1968, ESM is dedicated to presenting pivotal ideas and developments in mathematics education, featuring high-quality articles of global significance. While a comprehensive literature review in this field could utilize diverse sources such as research journals, books, and conference papers, our study's review is confined to articles published in ESM. Although critiqued for its limited scope, this approach enables the analysis of research studies within one of the most cited and respected journals in the field (Williams & Leatham, 2017). Williams and Leatham's (2017) study includes Table 1, which presents the results of a citation-based analysis for ten journals publishing articles in the field of mathematics education.

ESM's clear distinction from other journals is noteworthy. The impact factor of the journal is 3.23. The data source for this study is one of the most comprehensive bibliometric databases, Scopus (Yalçın & Koşar, 2021). Scopus was chosen as it encompasses all publications and data from the ESM journal. For the present study, metadata was analyzed and downloaded from Scopus in December 2022.

To prepare articles for bibliometric analysis, it is essential to document the articles in an appropriate format. Therefore, a search was conducted within the Scopus database by entering "Educational Studies in Mathematics" into the search bar. The results were then filtered by selecting the education-educational research category and the article document type in the left menu of the Scopus data search button. This search yielded 1924 studies. Additionally, these studies were individually verified for accuracy. As a result, the dataset for this study consists of 1924 research articles. All the necessary information for bibliometric analysis was extracted in CSV format from the export menu located in the top menu of Scopus. The obtained results, aimed at visualizing and analyzing bibliometric trends in the form of a network, were processed using VOSviewer. To achieve this, research articles published in the ESM journal within the field of mathematics education between 1968 and 2022 were downloaded in CSV format for analysis.

Bibliometric analysis is facilitated by various tools, some of which provide visual interfaces, such as CiteSpace, VOSviewer, and HistCite. There are also code-based tools like the Bibliometrix package in R, as well as more complex network analysis tools like Pajek and Gephi, all serving the purpose of creating insightful bibliometric analyses (Jia & Mustafa, 2022). Among the analysis tools provided, VOSviewer is a popular tool in bibliometric studies, based on network models of the analyzed data to create maps, provide insights from the data, and offer easy usage with superior visual capabilities

Table 1: Citation ranking of 10 journals that publish research in mathematics education (Williams & Leatham (2017))

Ranking	Journal	No. of citations (including self-citations)[a]	No. of citations (excluding self-citations)
1	Educational Studies in Mathematics (ESM)	2,729	1,872
2	Journal for Research in Mathematics Education (JRME)	2,188	1,854
3	Journal of Mathematical Behavior (JMB)	848	554
4	For the Learning of Mathematics (FLM)	625	507
5	Mathematical Thinking and Learning (MTL)	490	429
6	Journal of Mathematics Teacher Education (JMTE)	630	427
7	Zentralblatt für Didaktik der Mathematik (ZDM)	740	376
8	Mathematics Education Research Journal	263	175
9	International Journal of Math Education in Science and Technology (IJMEST)	526	166
10	School Science and Mathematics (SSM)	307	122

(Moral-Muñoz et al., 2020; Van Eck &Waltman, 2010). Additionally, the bibliometric analysis tool VOSviewer offers various advantages with its comprehensive literature review and the reproducible results of these analyses (Markoulli et al., 2017; Cobo et al., 2011). VOSviewer is widely used in different fields such as education, health, and natural sciences (Jia & Mustafa, 2022). The VOSviewer analysis program creates various nodes and connections between these nodes based on the analysis results obtained from the data used. These nodes and connections represent data clusters and the relationships between them. The sizes of the nodes change according to the sizes of the data clusters. Furthermore, the thickness of the connections between these nodes can vary based on the relationship between the data. Similarly, the distances between nodes change according to their relationships (Hernández-Torrano & Ibrayeva, 2020).

With the VOSviewer analysis program, researchers have conducted various analyses to observe and explore research collaborations among researchers, institutions, and countries. These analyses have resulted in the creation of VOSviewer visual maps. The size of the nodes in these VOSviewer visual maps varies based on the number of publications and citations generated by researchers, institutions, and countries. Additionally, the stronger the collaboration between researchers, institutions, and countries, the thicker and closer the lines between the respective nodes.

In order to explore the themes, present in the abstracts and titles of the articles used by researchers, bibliometric coupling and co-citation analyses are employed (Noor et al., 2020). In this study, the VOSviewer software (version 1.6.18) was used for visualizing and analyzing the data. To generate the visualization results, a total of 1962 articles published in the ESM academic research journal between 1968 and 2022 were transferred from the Scopus database to VOSviewer. The analysis process proceeded as follows:

1. A co-authorship network analysis was conducted to observe the scientific collaboration networks among authors' countries and institutions. Co-authorship analysis examines collaborations among authors through scientific articles (Acedo et al., 2006). In the field of social sciences, collaborative authorship, which has become increasingly common in recent years, is one of the most concrete and comprehensive documented forms of scientific collaboration within a discipline (Arslan, 2022). Since the analysis involves the affiliations of authors within a field, it allows for measurements and examinations at the institutional and national levels through various collaboration analyses (Zupic & Čater, 2015). The relationships between researchers' affiliations and institutions and countries vary depending on their coexistence (Van Eck & Waltman, 2014). Therefore, it is used to examine the temporal development and trends of the required data in scientific research within a specific field (Chen et al., 2009).
2. Citation analysis is based on the idea that the impact of a research study depends on how frequently it is cited as a source. It is believed that the more citations research receives, the more influential it becomes. As a result, citation analysis is used to reveal the true impact of a publication (Zan, 2012). In this study, the most cited works and authors in the ESM journal were compared and analyzed using data from the Scopus database.
3. Authorship attribution analysis is used to identify authors who have contributed with varying degrees of significance in a particular field. This method allows for the mapping of the field's structure. This analysis combines citations from publications based on how authors are cited together and used together. In this way, it reveals how authors are collectively cited in a document. The more frequently a publication is cited, the more dominant it becomes in shaping the focus of the field, reflecting the importance researchers place on the cited publication (Bellis, 2009).
4. In the examined studies, the frequent occurrence of specific keywords in the keywords section is revealed through the method of keyword analysis. In this method, a concept's cognitive space is represented through constructed maps. In keyword analysis, the unit of analysis is not documents, journals, or authors but rather concepts. In essence, this method examines the keywords of

publications with the aim of elucidating the conceptual structure of a field (Cobo et al., 2011). The co-occurrence of keywords in this method indicates conceptual relationships between these keywords (Koseoglu et al., 2016). The relationships between identified keywords are depicted through a network, and the conceptual space of the field is interpreted in this manner. This network also reveals the cognitive structure among the keywords (Koseoglu et al., 2016).

According to the data obtained from the Scopus database, ESM, which started publishing three issues each year in 1968, has received a total of 54,723 citations and published 2,002 academic studies from its inception until the present day. The distribution of these studies over the years is presented in Figure 1.

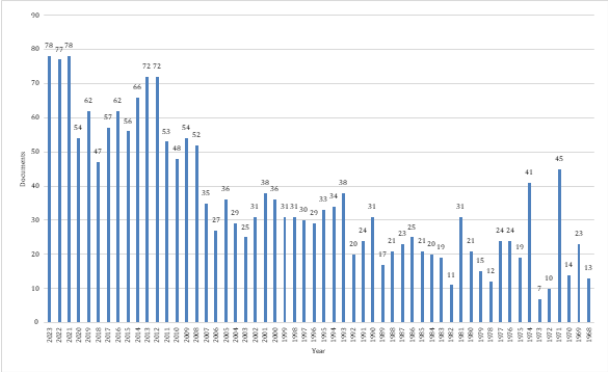

Fig. 1: Changes in the number of publications in ESM journal over the years

Figure 1 illustrates the dynamic growth in the number of publications in ESM from 1968 to 2023. For instance, while there were 38 articles published in the year 2001, the number of published articles increased to 78 in the year 2023.

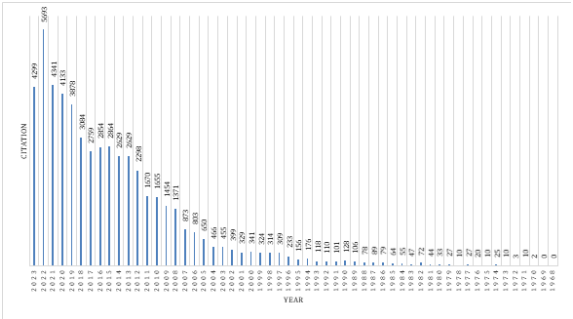

Fig. 2: Changes in the number of ESM journal citations over the years

Figure 2 depicts the growth in the number of citations received by the ESM academic research journal in the field of educational research from 1968 to 2023. The analysis indicates that there was not a significant increase in the number of citations to research published in ESM until the early 2000s. However, since 2001, there has been a noticeable increase in the citation counts. For example, the number of citations to articles published in 2001 was 329, while this number increased to 5693 in 2022. This demonstrates the popularity of the ESM academic research journal.

Leading Authors by Number of Publications and Citations

The dataset includes 2,002 articles published by 1694 authors from 70 countries worldwide. Figure 3 illustrates the pioneering authors of the ESM academic research journal and their respective publication counts.

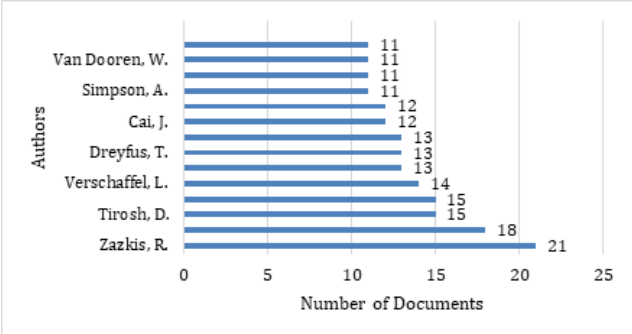

Fig. 3: Authors most published in ESM journal

In Figure 3, only authors with 12 or more publications are included. It has been determined that there are 10 authors with 12 or more publications in the ESM academic research journal. Rina Zazkis stands out as the author with the most publications, with 21articles. Following Rina Zazkis are Freudental (18), Tirosh (15), Weber (15) and Verschaffel (14). Figure 4 presents the authors who have received the most citations in the ESM academic research journal, along with their respective citation counts. In Figure 4, authors with 450 or more citations are listed, totaling 14 authors.

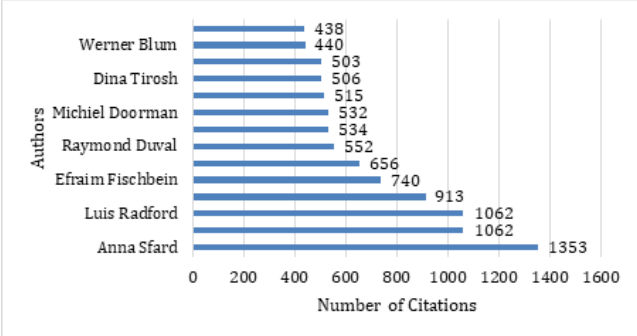

Fig. 4: ESM journal most cited authors

In Figure 4, it is evident that the author with the most citations is Anna Sfard, with 1353 citations. Anna Sfard is followed by David Tall (1062 citations), Luis Radford (1062 citations), and Shlomo Vinner (913 citations). Additionally, among researchers with 11 or more publications, Radford (with a total of 10 publications and 1062 citations, averaging 106,2), David Tall (with a total of 10 publications and 1062 citations, averaging 106,2), Fischbein (with a total of 12 publications and 740 citations, averaging 61,6), Tirosh (with a total of 15 publications and 506 citations, averaging 33,7), and Leiven Verschaffel (with a total of 14 publications and 503 citations, averaging 35,9) have the highest citation averages per article.

Leading Publications in Terms of Citation Frequency

The 15 most cited articles in the journal are given in Table 2. The most influential publications based on the number of citations have been provided from the ESM journal.

When examining Table 2, it can be observed that within the ESM academic research journal, Anna Sfard's (1991) study proposing a theoretical framework to investigate the role of algorithms in mathematical thinking has received 811 citations. David Tall's (1981) work exploring the concept image and how it differs from the formal definition of a concept, using the example of limits and continuity, has received 809 citations, while Raymond Duval's (2006) study on mathematics teachers' beliefs and practices has garnered 552 citations. Following these authors, Duval's (2006) work aims to understand the difficulties students face in comprehending mathematics, Arcavi (2003) delves into the definition

Table 2. The 15 most cited articles published in ESM journal

Ranking	Author	Citation year	Number of Citations
1	A.Sfard	1991	811
2	D.Tall & S.Vinner	1981	809
3	R.Duval	2006	552
4	A.Arcavi	2003	379
5	A.Thompson	1984	331
6	C.Kieran	1981	290
7	W.Blum & M.Niss	1991	281
8	FKS Leung	2001	237
9	M. Goos, P. Galbraith, P. Renshaw	2002	232
10	R. Moore	1994	231
11	M. van den Heuvel-Panhuizen	2003	229
12	E. B. Piriel & T.E. Kieren	1994	226
13	A. Sfard & L. Linchevski	1994	223
14	K. Gravemeijer & M. Doorman	1999	220
15	J Lithner	2008	219

of visualization and its various roles in learning and applying mathematics through analysis, sampling, and reflection, and Kieran's (1981) research investigates the usage of the equal sign and the underlying concepts of equivalence or non-equivalence among preschool (intuitive equality), elementary, middle school children, and university students.

The theory of figural concepts proposed by Efraim Fischbein in 1993 is a cognitive theory that focuses on individuals' ways of understanding mathematical concepts and processes. Fischbein's theory elucidates how individuals develop mathematical thinking and the mental representations they construct to make sense of mathematical ideas. Anna Sfard and Liora Linchevski's article titled "The Gains and the Pitfalls of Reification: The Case of Algebra," published in 1994, investigates the concept of reification in relation to learning and teaching algebra. Reification refers to the process of transforming abstract mathematical ideas into concrete objects or entities,

enabling students to better understand and work with these concepts. The article discusses the benefits and potential drawbacks of using reification in algebra education. The article titled "Growth in mathematical understanding: How can we characterize it and how can we represent it?" explores the nature of growth in mathematical understanding and discusses ways to characterize and represent this growth. The authors focus on the conceptual development and progression of students' understanding over time. The referenced studies heavily emphasize the role and importance of proof in mathematics education (Hanna, 2000; Moore, 1994; Weber, 2001), the effective development of students' understanding of the concept of functions in mathematics education (Breidenbach et al., 1992), how the Realistic Mathematics Education (RME) approach can be effectively used to reveal students' mathematical development (Van Den Heuvel-Panhuizen, 2003), and the design and evaluation of an educational program that supports the development of cognitive skills as well as emotional knowledge and skills to enhance students' problem-solving abilities (Blum & Niss, 1991).

Leading Organizations

The distribution of publication numbers based on the institutions where academics publishing in ESM are affiliated is provided in Figure 5.

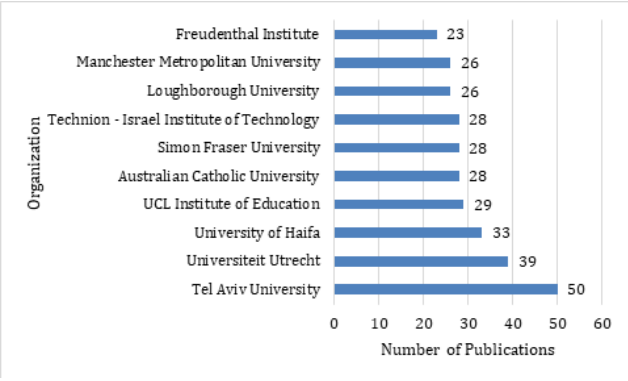

Fig. 5: The organizations with the most publications in ESM journal

When Figure 5 is examined, it can be observed that Tel Aviv University (50) and Utrecht University (39) are the institutions with the highest number of publications in the ESM academic research journal, followed by the University of Haifa (33). The majority of the leading institutions in terms of publications in the ranking are from Israel, and each of them is affiliated with a university in only five countries (USA, UK, Netherlands, Canada, and Australia) or regions. Additionally, it is noticeable in Figure 5 that institutions located in Africa and the Middle East are not represented.

The distribution of institutions where authors of the publications that receive citations in ESM work and their corresponding citation counts are presented in Table 3.

Table 3: The organizations publishing in ESM journal and the number of citations

Organizations	Number of Citations
The Hebrew University	2219
Michigan State University	1504
University of Warwick	1151
San Diego State University	879
School of Queensland	821
Utrecht University	796
Concordia University	765
Freudenthal Institute	702
University of Oxford	664
Simon Fraser University,	656
University of Cyprus	645
Weizmann Institute of Science	598
Université du Littoral	508
Manchester Metropolitan University	487
Kassel University	462
Roskilde University	446
Umeaa University	442
Università di Torino	439
University of Michigan	432
University of Pittsburgh	430
University of Haifa	425
University of Cambridge	414
University of Hong Kong	404

Upon examining Table 3, it can be observed that Hebrew University (2219) and the University of Michigan (1504) are the institutions with the highest citation counts. They are followed by the University of Warwick (1151) and San Diego State University (879). It is noteworthy that some institutions excel both in publication and citation generation. Similar to the publication ranking, the majority of institutions leading in citation generation are from Israel, the United States, the Netherlands, Canada, and the United Kingdom. Moreover, these institutions represent only seven countries or regions, including South Cyprus, Denmark, Italy, China, France, Sweden, and Australia.

Leading Countries

The distribution of countries where academics publishing in ESM have submitted their publications is shown in Figure 6.

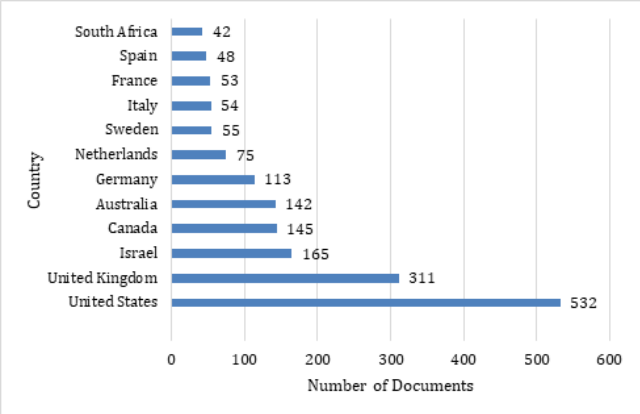

Fig. 6: Number of publications of countries in ESM journal

There are 18 countries worldwide (with 18 or more publications) that have contributed to the ESM mathematics education journal. It is evident that English-speaking countries dominate the research field, with the United States leading significantly with 532 publications. Following the United States, there is the United Kingdom with 311 publications, Israel with 165 publications, and Canada with 145 publications. While numerous European countries are present on the list, it is interesting to note the limited representation of Asian countries. Turkey, with 22 publications, is one of the newer members on the list. Turkey holds the 21st position among 57 countries.

The distribution of citation counts of publications by academics contributing to ESM mathematics education journal according to the countries they come from is provided in Figure 7.

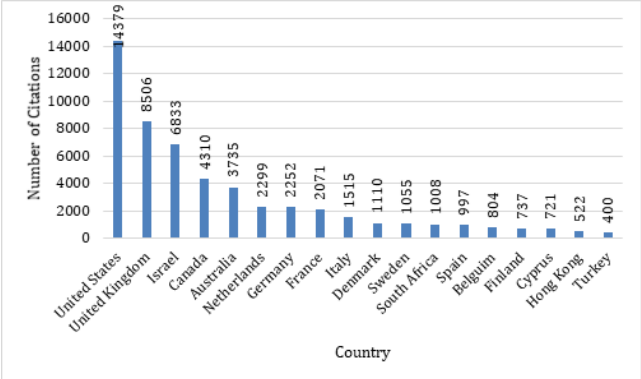

Fig. 7: Number of country citations in ESM journal

When examining Figure 7, which displays the citations received by the countries where ESM journal publications originated, it is noteworthy that the data is very similar to Figure 6. Furthermore, considering the number of publications and citations, the United States stands out with 576 publications and 14,379 citations. Following the United States in Figure 7, we have the United Kingdom (8,506 citations) and Israel (6,833 citations). These countries are followed by Canada with 4,310 citations, Australia with 3,735 citations, and the Netherlands with 2,299 citations. However, when examining the citations per publication, a different picture emerges. For instance, Finland ranks 17th in terms of the number of ESM journal publications and 15th in terms of citations received. However, when looking at citations per publication, Finland ranks first. Following Finland in terms of citations per publication are Cyprus, Israel, Denmark, and Hong Kong.

Collaborative Networks Between Authors

The authors conducted a co-authorship analysis to examine the collaboration networks formed by authors, institutions, and countries based on the data published in the ESM academic research journal. Figure 5 presents the collaboration networks among authors with at least five publications and at least one

citation in the dataset. Elements without connections to the created networks have not been included.

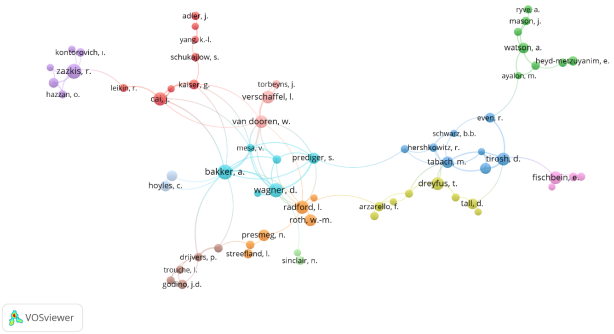

Fig. 8: Collaborative research networks between authors

In Figure 8, a research collaboration map among authors is provided, representing a total of 66 author nodes that form strong connections with each other. Authors who had no common connections with any other nodes were excluded from the analysis. When examining the author clusters represented in Figure 8 with different colors, the number of authors within each cluster ranges from 2 (e.g., the green cluster) to 8 (e.g., the red cluster). Authors within different colored author clusters who have strong connections within the cluster, and therefore strong collaboration indirectly, are represented at the center with larger nodes.

As seen in the figure, the connections and nodes are clustered around two central hubs. These two central hubs, the blue and navy nodes, have strong connection networks with the other nodes on the map in the visualization. This situation centralizes these two nodes as hubs of collaboration among authors in the ESM academic research journal. Additionally, researchers within these clusters seem to act as hub-like connections among all clusters. Notably, Arthur Bakker from Utrecht University in the Netherlands and Chaim Tirosh from Tel Aviv University in Israel are the prominent members within these two clusters. They exhibit strong scientific networks within their respective core clusters.

The red, green, blue, and yellow clusters stand out as the largest clusters, each comprising 8 researchers. The blue cluster's significance arises from the fact that all researchers within it are from three different universities in Israel. Specifically, four researchers (Tabach, Levenson, Tirosh, & Tsamir) are from Tel Aviv University, three (Arcavi, Hersckowitz, & Even) are from Weizman University, and one (Schward) is from Hebrew University. Consequently, researchers from different Israeli universities seem to have established a robust collaborative network within this cluster, with Tabach and Tirosh being its prominent figures. The navy cluster involves researchers from the Netherlands, the US, Norway, Germany, and Canada. Arthur Bakker from Utrecht University has connected this diverse set of universities and countries, forming the core of collaboration-based connections between them.

In the orange cluster, researchers from the US, Canada, Italy, and the Netherlands are present. Luis Radford from Laurentian University in Canada, within this cluster, holds a central position in collaboration networks among researchers from Europe and America. The purple cluster involves three Israeli researchers (Hazzan, Koichu, & Leron), along with researchers (Zazkis) from Canada, (Dubinsky) from the US, and (Kontorovich) from Australia. Rina Zazkis from Simon Fraser University in Canada, within this cluster, occupies the central position in collaboration-based connections among these different universities and countries.

Collaborative Networks Between Institutions

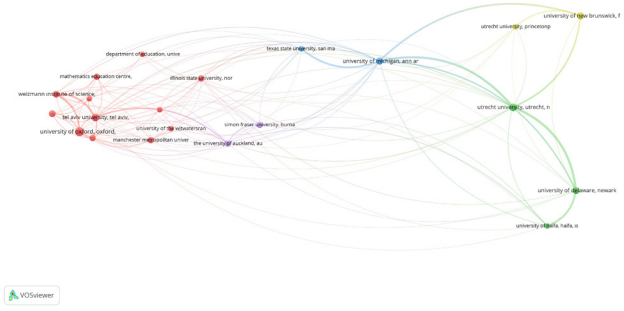

Fig.9: Collaborative research networks between institutions

In the data set of ESM, scientific networks among institutions with 5 or more publications and at least

1 citation are presented in Figure 9. The visual map shows that the data is split into five clusters, each represented by a different color. Utrecht University and Oxford University are the largest nodes among these clusters. This indicates that these institutions are quite active in collaborating with different universities. Figure 9 clearly demonstrates that there are multiple connections among institutions belonging to the same cluster, while there are very few connections between institutions belonging to different clusters.

In terms of research collaborations, prominent institutions include the University of Michigan from the United States, the University of Oxford from the United Kingdom, Tel Aviv University, and the Weizmann Institute of Science from Israel. When examining the clusters, it is evident that institutions in the United States collaborate both within the country and with Canada, which is geographically close. Additionally, institutions in the United States collaborate with countries on different continents such as the United Kingdom, Australia, and the Netherlands. Countries located in Europe typically collaborate with institutions that are geographically close within the same continent. An exception to this pattern is Utrecht University in the Netherlands, which collaborates with different countries for research partnerships. The most intense collaboration links and the highest number of countries involved in collaborations are found in the red cluster. In the red cluster, institutions from four different countries, namely the United States, the United Kingdom, Israel, and Canada, are represented, and the connections among these institutions in terms of collaborative research are noteworthy. It's worth noting that all institutions in the red cluster are located in the United States.

Collaborative Networks Between Countries

Figure 10 depicts a bibliometric map of international collaboration among countries using VOSviewer network visualization in overlay mode. The map focuses on countries that have at least two publications and two citations. In the visual map, the distances between nodes representing countries and the thickness of the connections between them can be examined to determine the collaborations between countries in terms of co-authorship.

The use of cold and warm colors on Figure 10's map provides information about the years when countries predominantly contributed to each other's publications. As relationships between countries strengthen or weaken, the connections between countries on the map's networks become thicker or thinner, respectively. This visualization provides insights into the evolving nature of collaboration between countries over time.

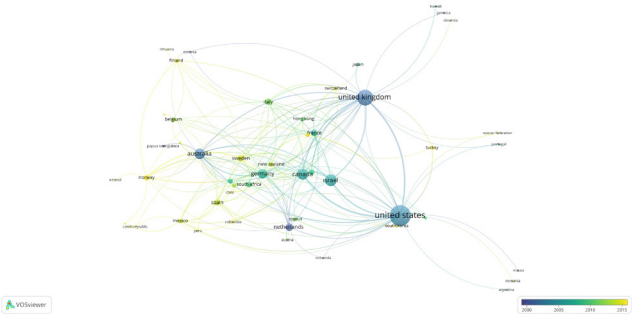

Fig. 10: Collaborative research networks between countries

The analysis results clearly indicate that the United States is at the center of research in the ESM journal. Countries like the United Kingdom, Israel, Canada, and Australia are shown to have established research networks with many other countries on the map. Additionally, using the overlay network visualization method, it is evident that in recent years, countries such as Turkey, China, South Korea, Sweden, and Norway have established significant connections with the ESM journal in terms of research. When examining research collaborations between countries, it becomes evident that beyond the major leading countries like the US and the UK, emerging countries like Turkey represent the expanding landscape of the field. The increased involvement of countries such as Turkey indicates a growing diversity and global spread of research efforts in the field of mathematics education, beyond the traditionally dominant countries. This highlights a shift towards more international collaboration and contributions in the domain.

Topical Foci in the ESM Journal

The analysis of keywords in the publications of the ESM journal has been used to determine the research

themes and how these themes have evolved over the years. The analysis included key words with at least 8 occurrences (n=95). In Figure 11, themes that are not connected to each other have not been provided. The size of the nodes representing themes varies based on numerical data. The proximity of nodes to each other and the thickness of the links represent the strength of the themes. Figure 8 explains the development of research focuses in the ESM journal from 1969 to 2023. The themes presented in Figure 8 are represented with different colors because they have different trends. Cool colors are used to describe older themes compared to warm colors. Warm colors are examined to identify current trends. This analysis provides insights into the shifting landscape of research themes over time in the ESM journal, reflecting the evolving interests and trends within the field of mathematics education.

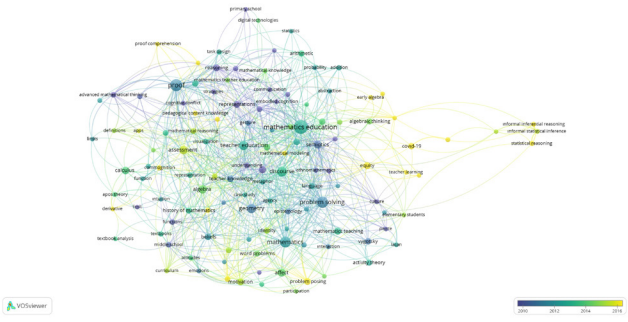

Fig. 11: Evolution of research themes in ESM journal research

As seen in Figure 11, keywords like “mathematics education,” “proof,” “problem solving,” “teacher education,” and “discourse” form the largest nodes in the network. On the other hand, keywords such as “geometry,” “technology,” “assessment,” “problem posing,” “semiotics,” “affect,” and “algebra” are notable nodes based on their size and citation counts. However, when looking at Figure 11, it is noticeable that statistical reasoning and informal statistical inference stand out distinctly differently from the rest of the set. As mentioned in the previous section, the overlay visualization allows tracking trends over the years. These prominent keywords provide insights into the central themes and areas of interest within the field of mathematics education as covered by the ESM journal. The trends and shifts in the prominence of these keywords over time can help researchers and educators understand the evolving focus of research and practice in mathematics education. Furthermore, when considering the average publication years of these keywords, it is possible to make some observations about the trends. As an example, keywords related to recent events that have affected society, such as COVID-19, stand out. Additionally, concepts like mathematical reasoning, problem posing, equity, statistical reasoning, mathematical modeling, and teacher learning have also started to emerge as research themes in recent years.

Discussion and Conclusions

This study encompasses the bibliometric analysis of articles published in the ESM journal between 1968 and 2022. Scopus database was used for bibliometric analysis. This analysis examines the current status and changes in the themes present in the ESM journal over the years. The findings reveal a remarkable increase in the number of publications and citations in the ESM journal from 1968 to 2022. This significant growth in the ESM journal, as mentioned by Inglis and Foster (2018), serves as evidence of development and progress. The recent steady increase in publications in the field of education (Huang et al., 2019) parallels the growing interest in the ESM academic research journal over time.

When examining the findings regarding the countries where publications in the ESM journal originate, it becomes evident that the United States, United Kingdom, Australia, Canada, Israel, and in recent years, Turkey, China, and South Korea have been prominently leading in the production and dissemination of scientific research in the journal. Among these countries, the United States, Israel, and the United Kingdom have had influential roles through national-level and international collaborations, contributing significantly to this development. On the other hand, it is noticeable that researchers from Africa and the Middle East are limitedly represented in ESM publications. One reason for this is that the countries contributing to the ESM journal offer researchers better opportunities in terms of scientific infrastructure, research resources, and funding

compared to others (Hangul, Ozmantar, & Agac, 2022; Hernández-Torrano & Ibrayeva, 2020). These characteristics have a positive impact on the quality and quantity of scientific production. However, the fact that this scientific production is predominantly concentrated in certain countries may lead to the development of research content in the ESM journal within specific cultural contexts and educational traditions. This limitation becomes even more pronounced when we observe that research in the ESM journal tends to focus on culturally sensitive topics, as evidenced by its emphasis on themes related to mathematics education as a social turn (Inglis & Foster, 2018). The inclusion, or at least participation in collaborative efforts, of third-world countries with limited contributions to ESM publications can enrich the scope, content, and depth of ESM publications through cultural diversity.

The analysis of research collaborations in the publications of ESM academic journal allows for the emergence of different perspectives and methods in terms of the development of the analyzed publications (Freshwater, Sherwood, & Drury, 2006). Additionally, research collaboration opens the door to the development of new research skills and the acquisition of new research methods and techniques. Grathwol (2005) has argued that research collaboration allows individuals to view research from a different perspective through the networks it facilitates, expanding one's horizons. When examining research collaboration findings in the ESM journal, it becomes evident that these networks are shaped and expanded based on cultural similarities and geographic proximity. Recent bibliographic studies (e.g., Huang et al., 2020; Hangul et al., 2022) also indicate parallel trends with ESM collaboration findings. These trends suggest that ESM journal publications are expected to make significant contributions to the enrichment of content, research skills, methods, and techniques indirectly through the establishment of geographical and cultural diversity in research collaborations.

When examining the most cited studies in the ESM journal, it is observed that research in the field is primarily centered around themes such as mathematical concepts and concept imagery, teachers' beliefs (teaching practices), mathematical understanding (cognitive processes), problem-solving, proof, and RME (realistic mathematics education). The fact that these themes continue to be actively researched suggests that they remain popular and relevant. The analysis results highlight that these themes are not only frequently studied but also of strategic importance in the development of the field. The findings from the analysis of keywords suggest a social transformation in themes in mathematics education research (Inglis & Foster, 2018). However, when considering the publication years of these keywords, some trends become apparent. Between 2000 and 2014, the most cited keywords somehow emphasize a social transformation (Inglis & Foster, 2018). During these years, there appears to be a shift from cognitive keywords focused on individual thought processes such as reasoning, meaning, and thinking towards social transformation-related keywords. This transition suggests that social justice and equality issues have received more attention in ESM journal publications (as indicated by the increased frequency of these keywords), marking a sign of the journal's themes undergoing a social transformation. Furthermore, Hanna and Sidoli (2002) examined the themes and content that contributed to the chronological growth of the ESM journal and its transformation into a leading research journal in mathematics education. Their study noted an increase in the number of studies supporting social transformation. Similarly, Gutiérrez (2013) argued for a "sociopolitical turn" in mathematics education, advocating for a greater focus on social justice and equality issues. When examining the findings of the ESM journal, Figure 8 illustrates that this social transformation is clearly reflected in the keywords of articles published in the journal. It is believed that this social transformation indirectly influences the thematic evolution of ESM publications over time.

Since the 1980s, themes such as mathematics education, equality, and gender studies have been prominent in the ESM journal. However, Schoenfeld (2016) argues that despite their long history, these themes have yet to reach a resolution. In his study identifying international research themes in mathematics education, Shin (2020) asserted that the themes of identity and equity came to the forefront between 2000 and 2019. Similarly, Bakker et al.

(2021) noted that equity was a significant theme in mathematics education research during the period of 2020-2021. The findings of this study suggest that in ESM journal publications, themes of identity and equity retain their strategic importance, indicating that they are still unresolved issues. Particularly in 2020-2021, due to the COVID-19 pandemic, some regions experienced interruptions in teaching processes, leading to the implementation of remote online learning practices. Studies conducted in the ESM journal related to COVID-19 highlighted that these measures may have led to the exclusion of certain disadvantaged groups from the education process. Researchers emphasized the need for a renewed and stronger focus on equity in mathematics education (Xie, Xiao, Hou, Liu, & Liu, 2021).

When examining the research themes in the ESM journal, it is noticeable that themes such as problem-solving, modeling, and problem posing prominently stand out, as shown in Figure 8. The development of the problem-solving theme, when examined chronologically, was initially emphasized in the 1980s, as noted by Hanna and Sidoli (2002). The upward trend of the problem-solving theme continued until 2007 (Hannula, 2009). However, Inglis and Foster (2018) stated in their research examining studies conducted in mathematics education over the past fifty years that interest in problem-solving had decreased in recent years. When examining the findings illustrating the changes in research themes in the ESM journal over time, it was observed that the problem-solving theme showed a similar chronological trend to the studies mentioned (Hanna & Sidoli, 2002; Hannula, 2009; Inglis & Foster, 2018). Additionally, interest in the problem-solving theme has increased in recent times. In the ESM journal, problem posing has been identified as a prominent theme. Cai et al. (2015) suggested that problem posing is an important mathematical skill and that generating problems supports the cognitive and affective development of various mathematical skills. When examined chronologically, it is notable that problem posing has emerged as a new trend and gained significance in recent years (Cai & Leikin, 2020). Another prominent theme in mathematical skills in ESM research findings is modeling. Bakker et al. (2021) argued that particularly during the pandemic, more emphasis should be placed on mathematical modeling research. Arseven (2015) emphasized that mathematical modeling is a highly important theme in mathematics education. Through mathematical modeling, students develop skills to understand real-life problem situations (Lesh & Doerr, 2003). In their research where they chronologically examined mathematical modeling studies, Bora and Ahmed (2019) asserted that modeling is becoming an increasingly popular and important theme in mathematics education for understanding real-life problem situations and enhancing different thinking skills. In ESM, Geiger et al. (2022) and Krawitz et al. (2022), among many similar studies, have highlighted in their publications that a system focused solely on mathematical measurement methods for exam results will not produce results without also understanding and thinking about real-life problem situations, in parallel with previous studies. From this perspective, it can be considered that the themes of problem-solving, modeling, and problem posing in the ESM journal trend as popular themes where researchers focus on developing students' skills in understanding, thinking, and solving real-life problem situations, as opposed to traditional methods in mathematics education.

The analysis of keywords in the ESM journal reveals that statistical topics in mathematics education research are notably distinct and currently a focal point of interest. In recent years, statistical reasoning and informal statistical inference have emerged as prominent statistical topics in the ESM journal. Bakker et al. (2018) have discussed trends and trends in statistics education. In their study, they noted that a significant portion of articles in statistics education focuses on student learning. Bakker et al. (2018) argued that teachers often approach teaching statistics in the same way as other mathematical topics, emphasizing results, procedures, graphs, etc., rather than focusing on statistical thinking and reasoning processes. They emphasized the need for educational researchers to pay more attention to this area. Our findings indicate that the ESM journal aligns with these conclusions by actively contributing to statistics education and attracting interest in topics like statistical reasoning, consistent with contemporary trends in the field.

Overall, this study shows that there is research collaboration in the area of mathematics education between different countries, institutions, and individuals. This study only includes a bibliometric analysis of articles published in the ESM journal between 1968 and 2022. Other types of publications have not been included in this analysis. To gain a more comprehensive understanding of the development of research in the field of mathematics education, similar analyses can be conducted for leading journals in the field. This approach would enable the creation of a more detailed map of mathematics education research, contributing to a deeper understanding of its evolution and trends. The proliferation of such studies will lead to the emergence of various themes and research areas within the field. Examining the trends in mathematics education themes will allow for more in-depth exploration of some underrepresented topics in terms of content. Additionally, delving deeper into mathematics education themes will contribute to researchers, educators, students, and policymakers and shed light on future studies.

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