IX. ПРОБЛЕМЫ ЭКОНОМИКО-МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ. БИЗНЕС-ИНФОРМАТИКА

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MAPPING OF SCIENTIFIC RESEARCH ON "MATHEMATICAL MODELLING" IN MATHEMATICS EDUCATION: A SCOPUS CASE STUDY

Mathematical modelling, as a universal language of modern science, is an indispensable mathematical skill that transforms complex real-world problems into quantitative and systematic frameworks, enhances prediction accuracy, optimizes decision-making processes, and guides the development of interdisciplinary solutions. This study conducts a bibliometric analysis to map scientific publications on mathematical modelling in mathematics education. Bibliometric analysis is a statistical method used to identify, evaluate, and track published literature through bibliometric data, including citation information related to authors, publications, institutions, journals, and countries. A total of 536 publications in the categories of Mathematics and Social Sciences from the Scopus database were analyzed. Findings reveal that the most prolific countries are the United States, Germany, and Spain, while the most influential journals are ZDM-Mathematics Education, ZDM-International Journal on Mathematics Education, and Journal of Engineering Education. Additionally, the conceptual structure of mathematical modelling is visualized and presented.

Keywords: mathematical modeling, mapping, mathematics education, bibliometric.

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ОТОБРАЖЕНИЕ НАУЧНЫХ ИССЛЕДОВАНИЙ ПО ТЕМЕ "МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ" В МАТЕМАТИЧЕСКОМ ОБРАЗОВАНИИ: ТЕМАТИЧЕСКОЕ ИССЛЕДОВАНИЕ SCOPUS

Математическое моделирование, как универсальный язык современной науки, является незаменимым математическим навыком, который преобразует сложные проблемы реального мира в количественные и систематические рамки, повышает точность прогнозирования, оптимизирует процессы принятия решений и направляет разработку междисциплинарных решений. В этом исследовании проводится библиометрический анализ для составления карты научных публикаций по математическому моделированию в математическом образовании. Библиометрический анализ – это статистический метод, используемый для выявления, оценки и отслеживания опубликованной литературы с помощью библиометрических данных, включая информацию о цитировании, относящуюся к авторам, публикациям, учреждениям, журналам и странам. Всего было проанализировано 536 публикаций в категориях математики и социальных наук из базы данных Scopus. Результаты показывают, что наиболее плодовитыми странами являются Соединенные Штаты, Германия и Испания, а наиболее влиятельными журналами являются ZDM-Mathematics Education, ZDM-International Journal по математическому образованию и Journal of Engineering Education. Кроме того, визуализирована и представлена концептуальная структура математического моделирования.

Ключевые слова: математическое моделирование, картографирование, математическое образование, библиометрический анализ.

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INTRODUCTION

The role of mathematics in cultivating individuals who solve problems through innovative thinking and apply their knowledge to daily life is paramount. Mathematical modelling stands as one of the most effective ways to bridge mathematics with real-world applications. Today, mathematical modelling is utilized not only in mathematics but also in technology, architecture, economics, engineering, medicine, and many other fields. Rapidly changing societal conditions necessitate individuals who are technologically literate, capable of creative thinking, and skilled in mathematical modelling. Mathematical modelling is defined as the process of representing and analyzing real-world problems using mathematical expressions (Bluman & Cole, 2013). This approach is increasingly employed to understand complex systems, make predictions, and improve decision-making processes in fields such as engineering, physics, economics, biology, and sociology (Lesh & Doerr, 2003).

Mathematical modelling abstracts real-world problems by expressing relationships between variables mathematically, enabling the analysis of complex systems and informed decision-making. The modelling process involves understanding real-world problems, developing mathematical expressions, solving models, and interpreting results. In recent years, mathematical modelling has been approached from an interdisciplinary perspective, as real-world problems often exceed the scope of a single discipline. By integrating knowledge and methodologies across disciplines, mathematical modelling offers holistic solutions, making individuals skilled in this area highly sought after in today's workforce.

BIBLIOMETRIC ANALYSIS

Scientific research and publishing are essential elements of the academic world. By sharing the results of their work with the scientific world, researchers contribute to the advancement of knowledge and new discoveries. However, in this process, especially during the literature review phase, it is critical to systematically evaluate the quality and effects of research and interdisciplinary interactions. This is where bibliometric analysis provides researchers with a powerful tool for analyzing complex networks of information.

Bibliometric analysis is a set of techniques and methods that enable the quantitative evaluation of scientific publications. It allows researchers to quickly identify significant publications, leading researchers, and emerging trends in a particular field. By using this method, researchers can make the resource search process more efficient. For example, citation analyses make it easier to access the foundational sources of a field, while co-authorship networks make interdisciplinary collaborations visible. The term "bibliometric" is derived from the Greek words "biblio" (book) and "metric" (measurement) (Sengupta, 1992), and it serves as a compass in mapping scientific production. This analysis method examines parameters such as citation counts, journal impact factors, keyword relationships, and geographical distribution to reveal the structure, dynamics, and future trends of research fields. Thus, researchers can use this data for more effective management and planning of scientific activities.

This study aims to map the research on "mathematical modeling" in mathematics education using bibliometric analysis. The study focuses on scientific publications related to mathematical modeling in the mathematics and social sciences categories from the Scopus database, analyzed using bibliometric methods. The findings aim to reveal research trends, impact factors, and interdisciplinary relationships in this field through various bibliometric techniques such as author analysis, author citation analysis, source citation analysis, keyword analysis, country citation analysis, and author co-citation analysis. The research questions guiding this study are as follows:

1. What is the distribution of studies on "mathematical modeling" in mathematics education over the years?
2. Which countries are the most productive and have the highest impact in terms of citation counts in research on "mathematical modeling" in mathematics education?
3. Which scientific journals have published the most and have the highest impact in terms of citation counts in research on "mathematical modeling" in mathematics education?
4. Which publications are the most cited and have the highest impact in research on "mathematical modeling" in mathematics education?
5. Which institutions/universities are the most productive and have the highest impact in research on "mathematical modeling" in mathematics education?
6. Which keywords are the most prominent in terms of publication and citation counts in research on "mathematical modeling" in mathematics education?
7. What are the most frequently co-cited author groups/networks in research on "mathematical modeling" in mathematics education?

8. Which countries have the highest impact in terms of co-authorship in research on "mathematical modeling" in mathematics education?

METHODOLOGY

This study examines research in the field of mathematical modeling using bibliometric analysis. As a quantitative research method, bibliometric analysis allows for the objective examination of large datasets obtained from scientific databases (Donthu et al., 2021; Ellegaard & Wallin, 2015; Zupic & Cater, 2015). Bibliometric analysis not only reveals trends, themes, and research gaps in a particular field but also uncovers the structure of researcher collaborations, the intellectual framework guiding the research, and the cognitive structure of the studies in the field (Börner et al., 2003; Donthu et al., 2021; Van Eck & Waltman, 2014; Zupic & Cater, 2015). Additionally, bibliometric measures help identify the most influential publications, authors, keywords, institutions, journals, and countries in a given field.

In this study, research on mathematical modeling is evaluated using bibliometric techniques such as author, publication, country, journal, and institution (university) analysis, keyword analysis, co-cited journal analysis, co-cited author analysis, and annual publication analysis. The bibliometric analysis techniques aim to identify the most influential and productive authors, countries, and sources in mathematical modeling research. They also reveal which keywords are most effective in this field.

DATA COLLECTION

In this study, bibliometric data were obtained from the Scopus scientific database on **February 12, 2025**. The widespread use and acceptance of the Scopus database worldwide, along with its inclusion of high-quality publications, are significant. This study aims to access all publications on mathematical modeling in mathematics education, and bibliometric data were collected using the keywords "mathematical modelling," "mathematical modeling," "math*," and "education." After determining the search terms, 1861 scientific records were retrieved from the Scopus database. The data were filtered to include only publications in the Mathematics and Social Sciences categories. Thus, this study focuses solely on sources in the mathematics and social sciences literature. Additionally, by filtering publication types, book reviews, book chapters, editorials, and conference papers were excluded, and 536 English-language articles were included in the study.

DATA ANALYSIS

In this study, the bibliometric data of 536 articles were analyzed using the VOSviewer software (version 1.6.20) and R-Studio through the "biblioshiny" interface. VOSviewer is a distance-based visualization tool that frequently displays related items in the same color clusters and shows the strength of their relationships through connections (Van Eck & Waltman, 2010; Van Eck & Waltman, 2011; Van Eck & Waltman, 2014; Van Eck & Waltman, 2021). In this visualization, related items are positioned close to each other, and the strength of the relationship between items is indicated by the thickness of the connections. Each item is represented as a node, and the size of the node represents the weight of the item. Additionally, the R-Studio program, which operates through the web interface "biblioshiny" of Bibliometrix, allows for the analysis of datasets, sources, authors, documents, clustering, conceptual structure, intellectual structure, and social structure. It is a powerful tool for data analysis, visualization, and reporting and is widely preferred in this field. Particularly, R packages like Bibliometrix are specifically designed for bibliometric analyses (Aria & Cuccurullo, 2017). These analyses enable the examination of relationships. The reason for choosing VOSviewer and R-Studio in this study is that they are free and can easily transform large datasets into bibliometric visualization maps (e.g., co-word networks, co-author networks). Bibliometric analysis methods can be grouped under two headings: performance analysis and science mapping (Donthu et al., 2021; Gutiérrez-Salcedo et al., 2018; Noyons et al., 1999; Zupic & Cater, 2015). Performance analysis examines the contribution of research elements in the literature in terms of productivity and impact. Science mapping visualizes the connections between research units, the strength of their connections, the clusters they belong to, and their changes over time. In this study, trends or research gaps in mathematical modeling research in mathematics education were identified through author, publication, country, journal, and institution (university) analysis, keyword analysis, co-cited country analysis, and co-authorship analysis by country. Additionally, before analysis in VOSviewer, the data were examined, incorrect characters were corrected, and a "thesaurus file" was created to standardize synonymous terms.

RESULTS

1-) Annual Publication Count

The publications on mathematical modeling in mathematics education and their changes over the years are presented in Figure 1. Upon examining Figure 1, it is observed that studies conducted on mathematical modeling between 2014 and 2024 constitute approximately 78.5% of the research included in the study. Based on these findings, it can be inferred that prior to 2014, research on mathematical modeling was relatively scarce. However, despite some fluctuations, there has been a general upward trend in the number of studies published since 2014.

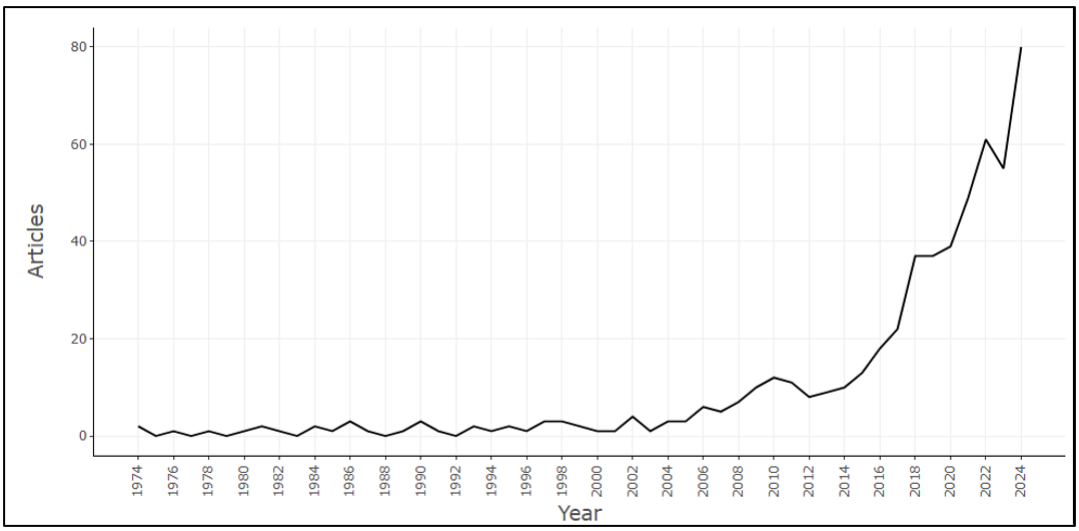

Figure1 – Annual Scientific Production

Years	Articles
1974-1983	**8**
1984-1993	**14**
1994-2003	**19**
2004-2013	**74**
2014-2024	**421**

Table 1 – Scientific Production by Decade

The data indicate that academic interest in the field was limited until 2004; however, a significant increase has been observed since then. Notably, after 2014, the number of publications gained considerable momentum, leading to a substantial rise in research output.

2-) Mapping the Most Influential (Popular) Countries Based on Citations

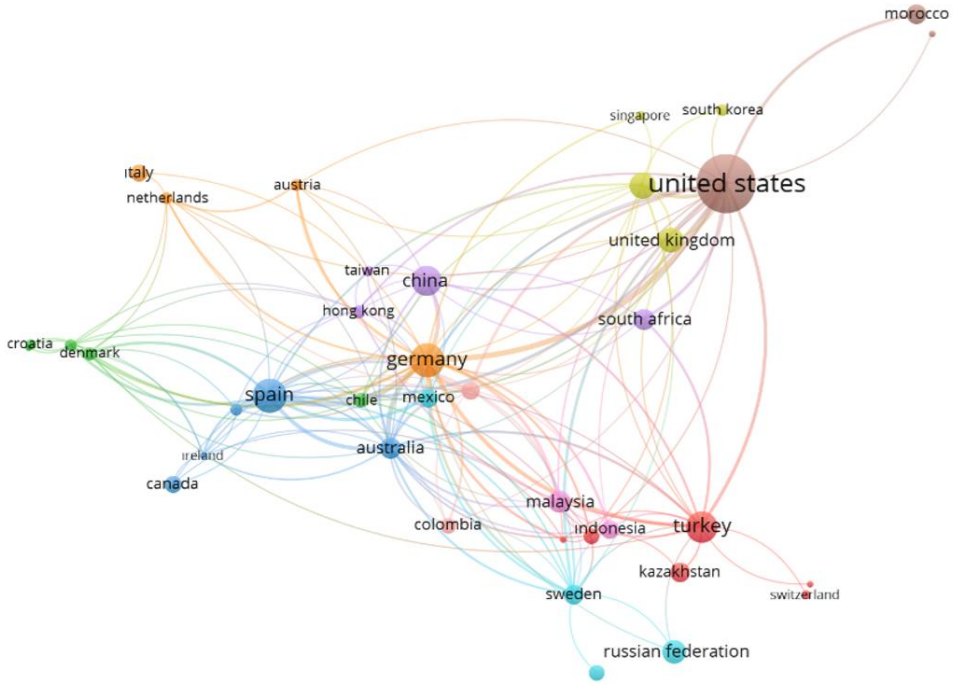

Figure 2. Bibliometric Network Map of the Most Influential (Popular) Countries Based on Citations (Vosviewer)

Country	Documents (f)
USA	**123**
Germany	**42**
Spain	**41**
Türkiye	**36**
China	**33**

Table 2 – Number of Publications by Country

An analysis of Table 2 reveals that the countries with the highest number of publications are, in order, the United States (F=123), Germany (F=42), Spain (F=41), Turkey (F=36), and China (F=33).

At this stage, a citation analysis was conducted to identify the most influential and productive countries in mathematical modeling research. The network map illustrating the relationships between countries in mathematical modeling studies is presented in Figure 2. For the citation analysis, the criteria were set using the RStudio program, requiring a country to have at least one publication and a minimum of 10 citations. Among 75 countries, 61 met these criteria. The map in Figure 3 displays the interconnectedness of 39 countries, highlighting their influence and relationships in the field of mathematical modeling. The analysis reveals that mathematical modeling research is grouped into 10 clusters based on country distribution.

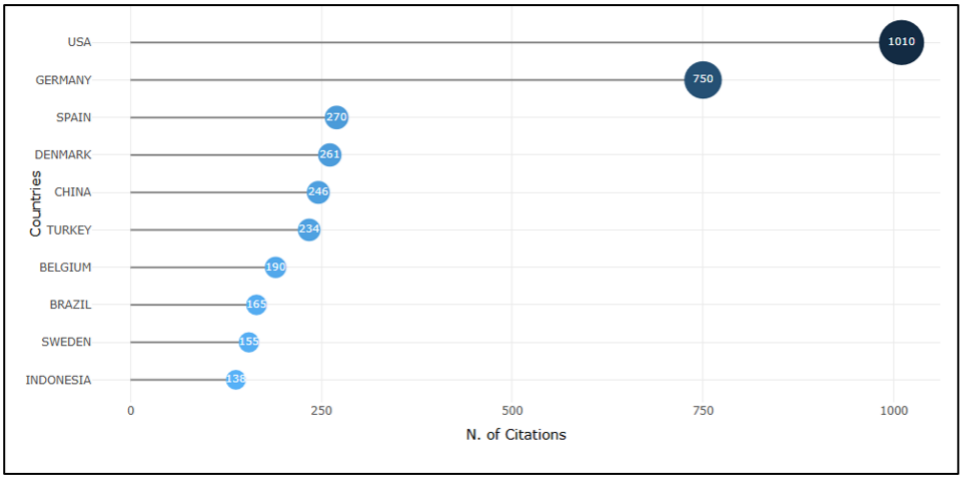

Figure 2 – Number of Citations by Country (R-Studio)

According to Figure 2, the United States is evidently the most influential country in this field. Further details on the top 10 countries that have received at least 100 citations in this field are provided in Figure 2. The United States is the most influential country, with a citation count of 1,010. Following the U.S., Germany stands out as the second most influential country. After U.S.A. and Germany, Spain, Denmark, China, and Turkey are among the most highly cited countries. This indicates that these countries have made significant contributions to the field and hold a strong citation impact.

3-) Mapping the Most Influential (Popular) Journals Based on Citations in Mathematical Modeling

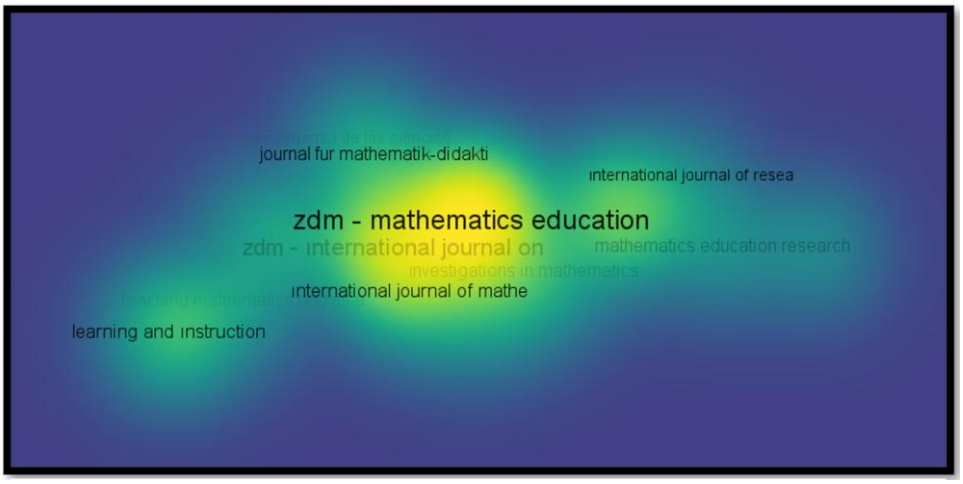

Figure 4. Bibliometric Density Visualization of the Most Influential Journals Based on Citations (Vosviewer)

To identify the most prestigious and influential scientific journals in the literature, citation analysis was conducted. Figure 3 shows the density map of the most influential (popular) journals based on citations in mathematical modeling. The density map visually presents the citation density of journals. In the map, the journal "ZDM-Mathematics Education" stands out as the most cited journal, located at the most prominent point.

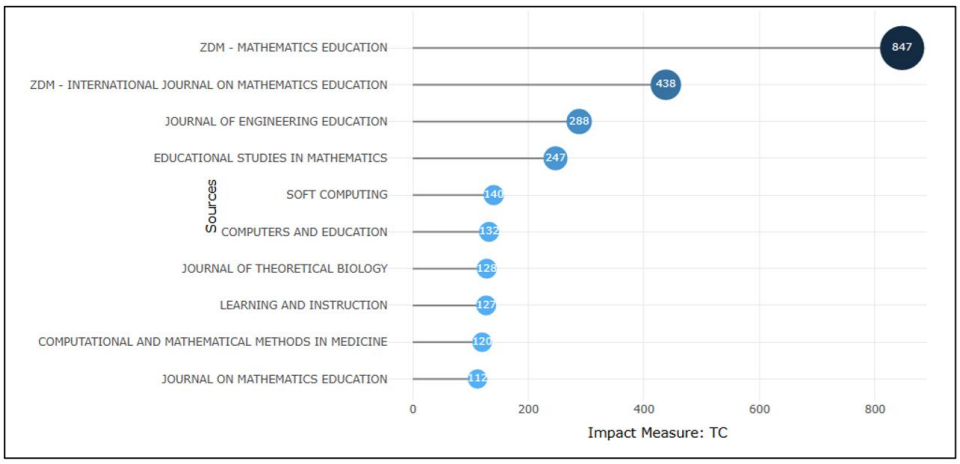

Figure 5. The most effective (popular) first 10 journals based on citations (R-Studio)

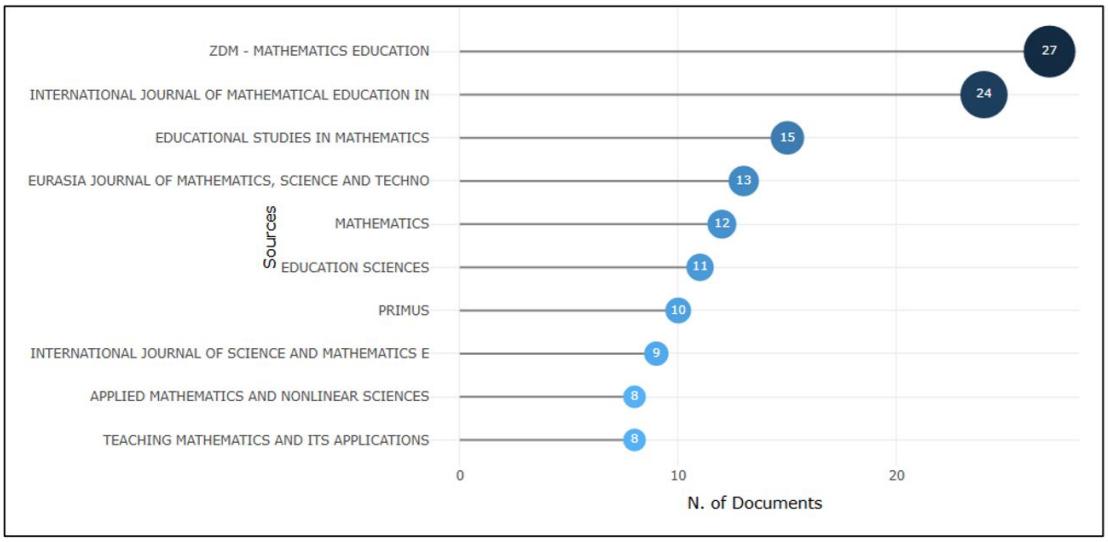

Figure 6. The first 10 Journals Producing the most publications on the related topic (R-Studio)

The top three most influential scientific journals in the field are "ZDM-Mathematics Education," "ZDM-International Journal on Mathematics Education," and "Journal of Engineering Education." Additionally, the journal with the most publications in the literature is "ZDM-Mathematics Education" with 27 documents, followed by the "International Journal Of Mathematical Education In Science And Technology" with 24 documents. Citation analysis was conducted to identify the cornerstone, popular, most notable, and most influential journals in mathematical modeling research. The most cited article, "Word Problems in Mathematics Education: A Survey," was published in "ZDM-Mathematics Education," one of the top five most influential journals. The studies in these influential journals are primarily theoretical articles that form the framework for mathematical modeling. It also appears that the number of publications produced by journals does not affect their citation counts.

4-) Mapping the Most Influential (Popular) Publications Based on Citations in Mathematical Modeling

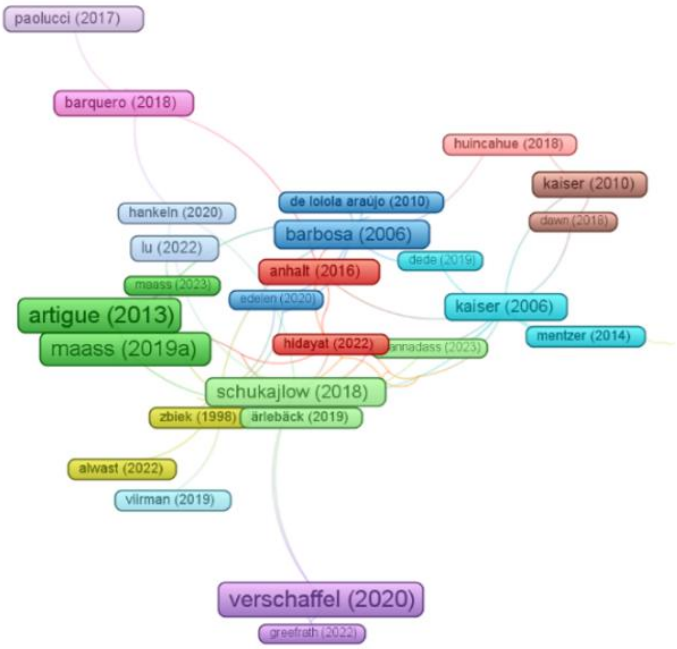

Figure 7. Bibliometric Network Map of the Most Influential (Popular) Publications Based on Citations (Vosviewer)

When creating the network map, the criteria of at least 5 citations per publication were used in VOSviewer. Based on this criterion, 248 out of 536 articles met the criteria. This bibliometric map visualizes the authors and citation relationships of the most influential publications in mathematical modeling. Nodes represent individual publications or authors, colors represent different clusters, and connections represent citation relationships between studies. The thickness of the lines indicates the strength of the citation link. Figure 3 shows a total of 68 articles grouped into 15 clusters. When examining the most cited publications in the field, the top 10 publications received between 72 and 190 citations. However, their connection strengths are not significantly higher compared to other publications. The author and article information for these top 10 publications is presented in Figure 7.

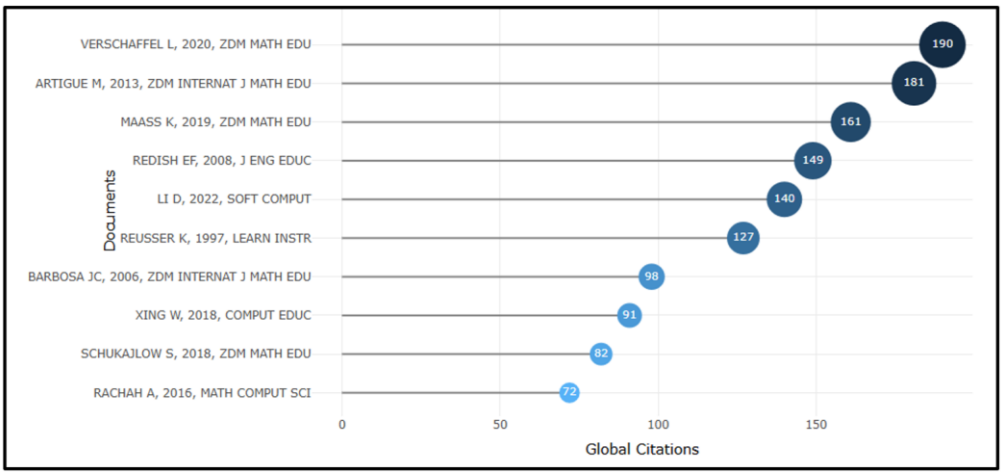

Figure 8. Most Cited Publications

Historiograph

It is possible to identify the most distinguished studies on a particular subject and to create a chronological direct quote network associated with bibliographic data by following the historical development of these studies by years (Garfield, 2004). This method reveals the intellectual connections in historical order by establishing a historiography on direct quotes. Each knot in this flow represents core documents with the number of high quotes in the collection, which is referred to by other documents and is analyzed. The connections of different colors show direct quotations and

the horizontal axis shows the years of broadcasting. In this way, the trace of a concept and its historical development can be traced (Aria & Cuccurullo, 2017, 2022b).

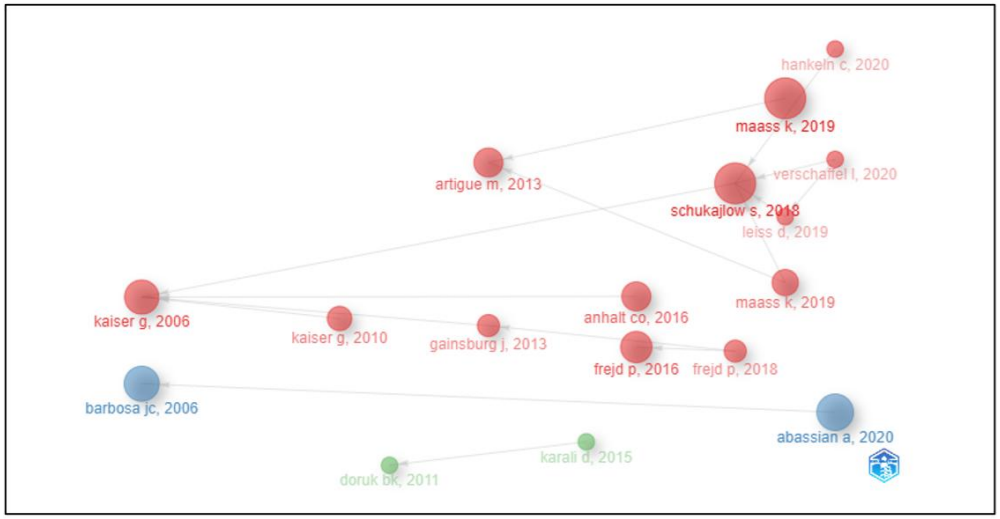

Figure 9

Figure 8 illustrates historical development by mapping studies on mathematical modeling through bibliographic data analysis. From a histographic perspective, each node reflects the impact of a study in the field and its connections to other documents. For example, publications such as "Maass K. (2019)" represent important centers of intellectual debate in this field. In addition, his early works "Barbosa JC, 2006" and "Kaiser G, 2006" influenced the later literature.

Three-Field Plot

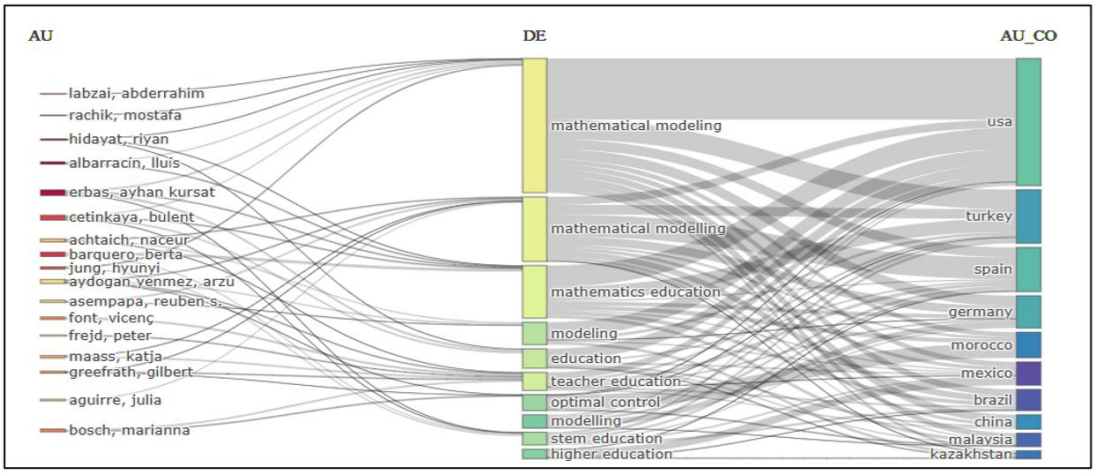

Figure 10

The three field plots are created by the selection of three main meta -data fields and the Sankey diagram is used to visualize the relationships between these areas (Aria & Cuccurullo, 2022a). These three fields can be identified as authors, connections, countries, keywords, keywords of authors, headings, summary, resources, references and quote sources. The size of the selected areas is limited to 50 (Aria & Cuccurullo, 2022A).

Looking at Figure 10, the left field is selected as authors, the middle field is keywords, and the right field is selected as countries. In this way, the relationship between the best authors, the most used keywords and the most influential countries can be seen. The size of the rectangles in each area shows the contribution it has made to the field: The first area in the figure includes the authors who have produced the most publications in the literature. When we look at these authors, the author with the largest rectangular size "Erbaş, Ayhan Kürşat" drew attention. Considering the keywords in the Middle Area, it seems that the most common keywords are "mathematical modelling", "mathematical modeling", "mathematics education" and "modeling" with the largest rectangular size. In the right field, there are countries that have published articles on the relevant subject and contributed to the literature. Looking at these countries, the United States, Turkey, Spain and Germany are located with the largest rectangular size, respectively.

5-) Analysis of the Most Productive Institutions-Universities in Mathematical Modeling

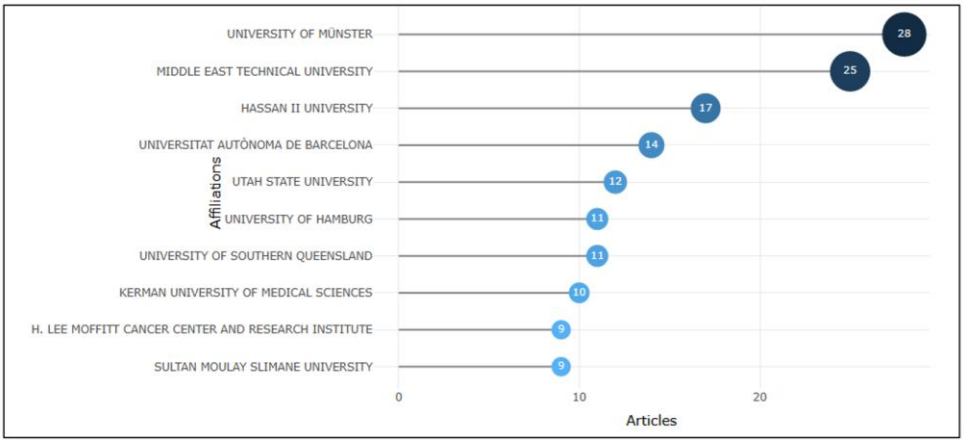

Figure 11. Most Relevant Affiliations (R-Studio)

According to the data in Figure 10, the University of Münster (Germany) is the most productive university with 28 articles. It is followed by Middle East Technical University (Turkey) with 25 articles. Other notable universities include Hassan II University (Morocco) with 17 articles and Universitat Autónoma de Barcelona (Spain) with 14 articles. These data show that these universities have high productivity in certain fields and that their scientific contributions are internationally significant.

6-) Analysis of the Most Prominent Keywords Based on Citations in Mathematical Modeling

At this stage, keyword analysis has been applied to identify the most frequently emphasized topics, concepts, and keywords in studies related to mathematical modeling. This analysis aims to determine how keywords in mathematical modeling interact and which terms hold a more central position. By doing so, it provides an in-depth examination of the citation network structure and relationships among scientific publications.

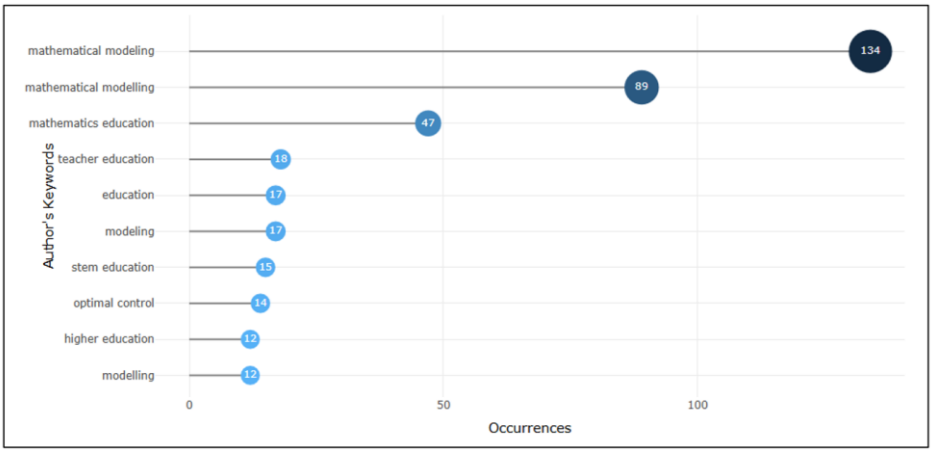

Figure 12. Most Frequent Words (R-Studio)

The word cloud of keyword relationships in mathematical modeling research is presented in Figure 13, highlighting the most frequently occurring terms. According to Figure 12, the most commonly used keyword is "mathematical modeling." The top five most frequently used keywords, in order, are "mathematical modeling," "mathematical modelling," "mathematics education," "teacher education," and "education."

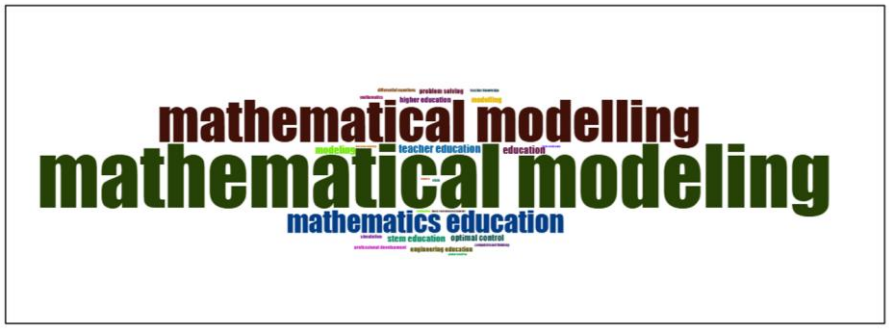

Figure 13 WordCloud (R-Studio)

7-) Mapping Co-Cited Authors in Mathematical Modeling

The increasing expectations regarding the quantity and quality of academic publications have led to a rise in multi-authored studies (Hudson, 1996). In this context, collaborations in multi-authored publications are also attracting more attention. Co-cited author analysis is considered a measure of collaboration in scientific publications and indicates strong social ties. Additionally, bibliographic data, including authors' institutions and geographical regions, can reveal collaborations between institutions and countries through co-cited author analysis (Zupic & Cater, 2015).

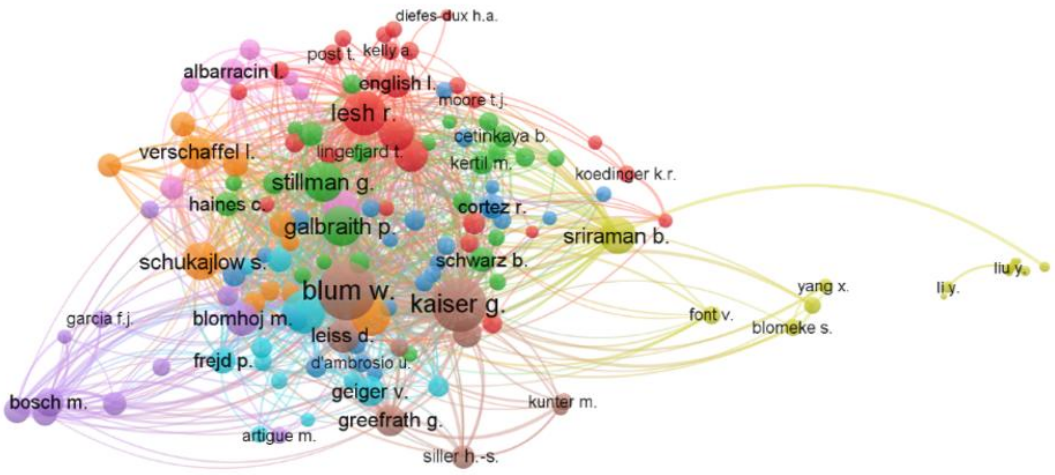

Figure 14. Co-citation citied author (Vosviewer)

When examining the co-citation analysis conducted using the 536 included publications, 25,849 cited authors were identified. When the criterion of at least 20 citations was set as the cutoff point, the number of authors was reduced to 143. The map shows a total of 143 authors and 9 different clusters, with a total of 123,568 connections. In the map, authors represented by large nodes are the most cited and influential authors in mathematical modeling. Among these authors, Blum W., Kaiser G., and Lesh R. stand out. The different colored clusters represent groups of authors or research communities that frequently cite each other. These communities are centered around specific subtopics or research areas. The size of the nodes represents the total number of citations received by the authors, while the number and density of connections between authors indicate the frequency of collaboration and citation relationships.

As supported by Table 4, authors such as "Blum W.," "Kaiser G.," "Stillman G.," and "Galbraith P." stand out with their extensive citation networks and central positions, while authors like Sriraman B. and Lesh have large nodes. The fact that these authors are frequently co-cited in many publications suggests similarities between them. The strength and density of their relationships are high. The map visualizes the structure of the academic network in mathematical modeling and the relationships between authors, providing valuable insights into the dynamics and future research directions in the field.

Table 4 – List of Authors with the Highest TLS Values in Co-Citation Analysis on Mathematical Modeling

Sıra	Yazar	Atıf Sayısı	Total Link Strength (TLS)
1	Blum, W	503	17109
2	Kaiser, G	377	14065
3	Lesh, R	257	8712
4	Niss, M	231	8041
5	Stillman, G.	169	6976
6	Galbraith, P.	179	6741
7	Maass, K	156	6006
8	Schukajlow, S.	132	5751
9	Borromeo, Ferri	157	5745
10	Sriraman, B.	142	5089

8-) Mapping Co-Authorship by Country in Mathematical Modeling

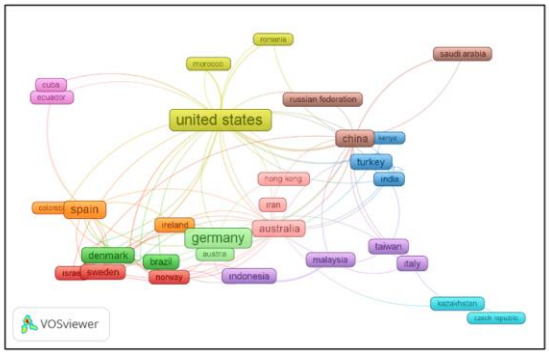

Figure 15. Network Map of countries in the context of co-authorship in scientific research on mathematical modeling

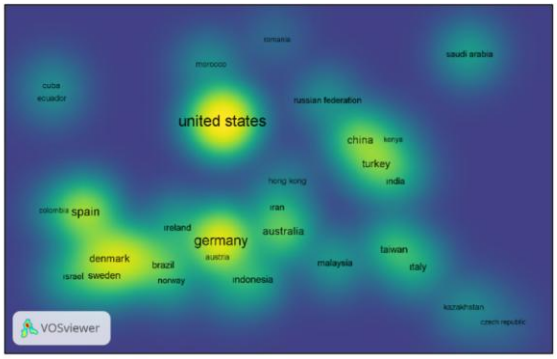

Figure 16. Density map of countries in the context of co-authorship in scientific research on mathematical modeling

When analyzing co-authorship by country, the criteria of at least one publication and at least 10 citations per country were used in VOSviewer. Out of 75 countries, 61 met these criteria. In the network map in Figure 14, 52 countries are grouped into 11 clusters. In the context of mathematical modeling research, the top three countries with co-authorship collaborations are the United States, Germany, and Spain, followed by China, Australia, Denmark, and France. To show the collaboration between countries in this field, the social network map obtained from the co-country analysis is presented in Figure 8. Table 6 provides data on the number of publications and citation counts for these collaborating countries.

Conclusion

In the field of mathematics education, mathematical modelling stands out as a critical tool in solving real-world problems and in interdisciplinary research. This study aims to systematically map the scientific studies on mathematical modelling through bibliometric analysis. The analysis of 536 articles from the Scopus database provides important findings on research trends, leading actors and global collaborations in the field.

Mathematical modelling has become a research area that has gained momentum in recent years, especially after 2014. The findings of the study show that articles published in the period 2014-2024 account for 78.5% of the total production. This increase can be explained by the integration of mathematical modelling into educational curricula as well as the growing interest in applications in disciplines such as technology, engineering and social sciences. Bibliometric analysis supported these dynamics with quantitative data, allowing researchers to visualise the structure and development of the field. In particular, the use of tools such as VOSviewer and R-Studio has been effective in transforming complex data sets into understandable maps.

The results of the analysis revealed that the most productive countries in the field of mathematical modelling are the USA (123 articles), Germany (42 articles) and Spain (41 articles). The USA is also the most influential country with 1010 citations. In terms of universities, University of Münster (28 articles) and Middle East Technical University (25 articles) stand out. These findings indicate that Germany and Turkey have a significant research capacity in the field of mathematics education. Among the journals, ZDM-Mathematics Education", "International Journal of Mathematical Education" and "Journal of Engineering Education led the field by reaching the highest number of publications and citations.

Keyword analysis showed that terms such as "mathematical modelling", "mathematics education" and "teacher education" are frequently used and play a central role. The word cloud and network maps reveal that mathematical modelling is intertwined with pedagogical practices and teacher education. Furthermore, the high number of citations of authors such as Blum W., Kaiser G. and Lesh R. proves that they have played a leading role in shaping the theoretical frameworks in the field.

Co-authorship analyses have shown that the US has established strong academic links with countries such as Germany, Spain and China. However, despite the productivity of countries such as Turkey and Morocco, it is noteworthy that international co-operation is limited, indicates that interdisciplinary and multinational projects should be encouraged in future studies.

This research has made a significant contribution to the literature by systematically identifying research gaps, trends and global trends in the field of mathematical modelling, In particular, it provides a data-based guide for shaping educational policies and curriculum development processes. However, limiting the study to the Scopus database and excluding non-English publications may have affected the scope of the findings. It is recommended that other databases (Web of Science, ERIC) be included in future studies and qualitative analyses be supported.

Mathematical modelling is an indispensable tool in the acquisition of 21st century skills and interdisciplinary problem solving. This study aims to map the current situation in the field It has provided a strategic perspective for researchers, policy makers and educators. Supporting research, especially in underrepresented regions, and increasing international collaborations will strengthen the role of mathematical modelling in achieving global educational goals.

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