LUMAT
International Journal on Math, Science and Technology Education

Research article

Exploring the implementation of STEM education through mathematical modelling activities in schools: A bibliometric analysis

Aslipah Tasarib [1], Roslinda Rosli [*,1] and Azmin Sham Rambely [2]

[1] Faculty of Education, The National University of Malaysia, Malaysia
[2] Faculty of Science & Technology, The National University of Malaysia, Malaysia

Abstract: For the last few decades, mathematical modelling has been an important topic in school education. Practical approaches to applying mathematical concepts to real-world scenarios are beneficial to students. The process of seeking solutions to real-world problems could foster students' inquiry skills and have more impactful advantages. However, the implementation of mathematical modelling in schools presents numerous challenges in terms of finding its practical application. Integrating modelling activities with STEM education benefits students by providing practical applications. This research sought to investigate the growth and development of research activities in the area of the integration of STEM education into mathematical modelling by using a bibliometric approach. We followed the PRISMA guidelines and conducted a thorough search in the Scopus database to find important articles published between 2005 and 2025, looking at the article titles, abstracts, and keywords. We conducted an analysis of 139 relevant articles to investigate the implementation of mathematical modelling in the context of integrated STEM education. We analyzed the data using VOSviewer, which performs co-occurrence analyses of authors and keywords. We used Harzing's Publish or Perish software for citation metrics and analysis and Microsoft Excel for frequency analysis. The results indicate that the United States happened to be the most productive country in this field, with 53.24% of the publications. The most productive authors and institutions also show that more than half of the top ten publications in this area were from the United States. The findings of this study will enhance the understanding of integrating STEM education and mathematical modelling in school. It also demonstrates that the scope of this research is relevant, potentially improving the quality of teaching and learning and supporting future studies in the mathematics education field.

Keywords: mathematical modelling, STEM education, school, real-world problems, bibliometric analysis

Correspondence: roslinda@ukm.edu.my

1 Introduction

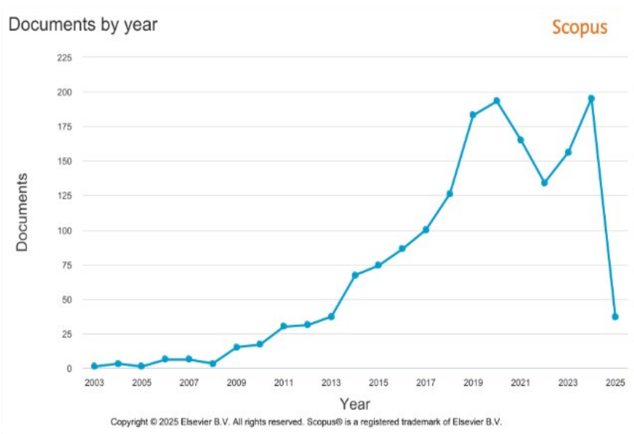
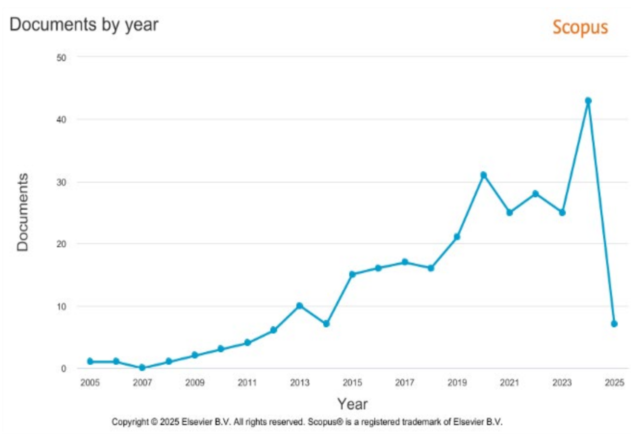
In the current educational environment, mathematics education in school strives to equip students for the challenges of the twenty-first century by fostering skills in critical thinking, problem-solving, and inventive ability (AlAli, 2024; Beswick & Fraser, 2019; Uyen et al., 2021). The challenges in teaching mathematics arise from the lack of interest in this

Received 1 September 2024 / Accepted 22 June 2025 / Published 19 July 2025
Published by the University of Helsinki, Finland and LUMA Centre Finland.

subject among school students in many countries (AlAli, 2024; Meles & Ali, 2024; Rehman et al., 2023). Schools have integrated mathematics education into other disciplines like science, technology, and engineering to address this issue (English, 2023). STEM, an acronym for science, technology, engineering and mathematics, is a frequent topic in discussions on education policy and economic competitiveness. It has also become associated with classroom teaching that aims to foster abilities such as creativity and problem-solving (Hallström et al., 2023; Hallström & Schönborn, 2019). According to Goos et al. (2023) and Tuong et al. (2023), mathematics offers an important connection to other STEM disciplines, thereby addressing significant educational concerns, including an absence of STEM-inclined students and a deficiency of STEM graduates. Therefore, integrated STEM education is an effort to combine science, technology, engineering, and mathematics into one class that is based on connections between the subjects' real-world problems (Jamali et al., 2023).

Since the early twenty-first century, researchers have made various contributions to mathematics and STEM education (AlAli, 2024; Pathoumma & Trinh, 2024; Rehman et al., 2023). Although STEM education has gained popularity among educators and stakeholders, recent trends in the studies do not show any increase. A survey of 139 studies as of March 27, 2025, shows that the scope of mathematics and STEM education has had a sustained trend for the last six years, as illustrated in Table 1(a).

Table 1. The difference in trends between two fields of study

(a)Mathematics and STEM education	(b)Mathematics, STEM education and mathematical modelling
	

However, Kertil and Gurel (2016) and Hallström et al. (2023) suggest that a practical approach to teaching STEM education is to integrate it with modelling activities. Consequently, numerous studies have emphasized modelling as a component of the mathematics teaching method (Ngu et al., 2025). This approach is a valuable instrument for integrating STEM education with mathematics as well (Lu & Kaiser, 2022). These statements align with the early stages of this study's survey, which included 279 studies reported since 2005. Based on Table 1(b), the graph suggests that the trend in mathematics and STEM education that incorporates mathematical modelling has the potential to expand the scope of mathematics education research.

Conversely, mathematical modelling activities are challenging to carry out and teach (Zbiek et al., 2022). According to Bas-Ader et al. (2023) and De Bock and Zwaneveld (2020), teachers' prior knowledge and experiences with mathematical modelling in high school, college, teacher preparation and professional development programmes were important in the early phases of mathematical modelling's implementation in classrooms. To accomplish the curriculum objectives, it is essential for teachers to be equipped with the fundamentals of mathematical knowledge to ensure they are able to guide students with current and future practices (Ebbelind & Helliwell, 2024). Indirectly, teachers will afford students in mathematical modelling activities more effectively (Copur-Gencturk et al., 2023; Copur-Gencturk & Li, 2023; Göhner et al., 2022).

By modelling activities, the related mathematics and STEM concepts can be taught concurrently within a well-chosen learning situation. To do this, the teacher should have the necessary knowledge in supporting the emergent ideas of STEM disciplines (Lu & Kaiser, 2022; Spooner, 2022). Therefore, there is a need to investigate the significance of integrating STEM education in mathematical modelling. However, limited research has been done until now to visualize quantified research trends in the adoption of this technique to understand the strategies that have developed. Hence, it is imperative to conduct a more thorough investigation of these trends to guide future researchers in determining the most effective method of teaching and learning STEM education through mathematical modelling activities.

To accomplish the goal of the present study, the study seeks to explore the relevance and trends of integrating STEM education with mathematical modelling from 2005 to 2025 (March 27). Filling this knowledge gap might offer a comprehensive understanding of the field of study and provide insights for researchers and practitioners. This study seeks to close the gap and answer the research questions (RQs) by collecting data from the Scopus database and using bibliometric analysis based on the following RQs:

RQ1: What is the current trend and the impact of publishing on the implementation of STEM education through mathematical modelling activities in schools?

RQ2: Which countries, authors and institutions are most productive and influential in implementing STEM education through mathematical modelling activities in schools?

RQ3: How do authors and countries collaborate in publications on the implementation of STEM education through mathematical modelling activities in schools?

RQ4: What are the dominant themes among scholars regarding the implementation of STEM education through mathematical modelling activities in schools?

2 Literature review

Mathematics education now recognizes modelling as a key component and one of the most important skills in mathematics (Lu & Kaiser, 2022). Many mathematics education curricula acknowledge mathematical modelling and related competencies with the goal of promoting responsible citizenship. Doing modelling activities fosters critical thinking, problem-solving and analytical skills, which are essential for students to succeed in science, technology, engineering and mathematics fields (Ledezma et al., 2023; Meles & Ali, 2024; Peng, 2023). Furthermore, students have the chance to participate actively in the learning process and could cultivate their communication skills through group tasks. Working in a group and addressing a real-world problem requires flexibility in communication and develops responsibility (Spooner, 2022). Within this paradigm, mathematical modelling represents an effective tool that not only enhances students' understanding of mathematical concepts but also equips them with the ability to apply the concepts to real-world problems (Ikeda & Stephens, 2020). Therefore, the process in modelling that uses mathematics to represent, analyse and make predictions about real-world scenarios is also an essential element in STEM education.

The potential of mathematical modelling to enhance students' understanding of complex situations and problem-solving abilities has been the subject of numerous studies (Blum & Niss, 1991; Greefrath & Vorhölter, 2016; Spooner, 2022). The studies have conducted extensive research on a variety of topics related to mathematics education, including student engagement, pedagogical strategies and curriculum development. According to English (2017), STEM education research emphasizes the importance of interdisciplinary approaches for the integration of STEM with modelling activities, with the potential to improve students' mathematical skills.

Meanwhile, Lantau et al. (2020) stated that the teacher preparation programmes should be designed to enable educators to oversee challenging multidisciplinary STEM modelling initiatives that remained unclear. STEM-based problem-solving incorporates critical mathematical modelling and other competencies (Hallström et al., 2023; Lantau et al., 2020). The development of STEM education strategies would benefit students through deeper understanding of classroom learning, where STEM activities foster an appreciation of mathematics' complexity, consistent with mathematical modelling activities (Goos et al., 2023; Hallström et al., 2023; Hallström & Schönborn, 2019; Kertil & Gurel, 2016). However, there is still a need for further research to understand better the benefits of the implementation of STEM education and mathematical modelling and to develop more effective strategies for integrating these approaches in the classroom (Goos et al., 2023; Roehrig et al., 2021; Tuong et al., 2023).

This study employed bibliometric analysis techniques as its research methodology to systematically explore the research landscape of mathematics education in schools, STEM education and mathematical modelling. A Belgian librarian, Paul Otlet, developed the concept of bibliometric analysis, which measures all aspects related to the publication and reading of books and documents (Rousseau, 2014). Bibliometric analysis provides a quantitative method to assess the scholarly impact, research trends and collaboration patterns within a particular field. The examination of publication data, citation metrics and authorship networks through bibliometrics reveals insights into the development of research, key influential works and emerging themes (Nyirahabimana et al., 2022).

Thus, the approach to quantify and analyze the publications indexed for the investigated repository was used. An overview of bibliometric analysis and the procedures required to perform it to help scholars learn about the technique and use that knowledge to analyze specific topics in the body of current literature with vast bibliometric data (Öztürk et al., 2024). Researchers use bibliometric analysis for several purposes, including identifying developing trends in article and journal performance, cooperation patterns, and research elements, as well as examining the intellectual structure of a specific discipline within the existing literature (Donthu et al., 2021).

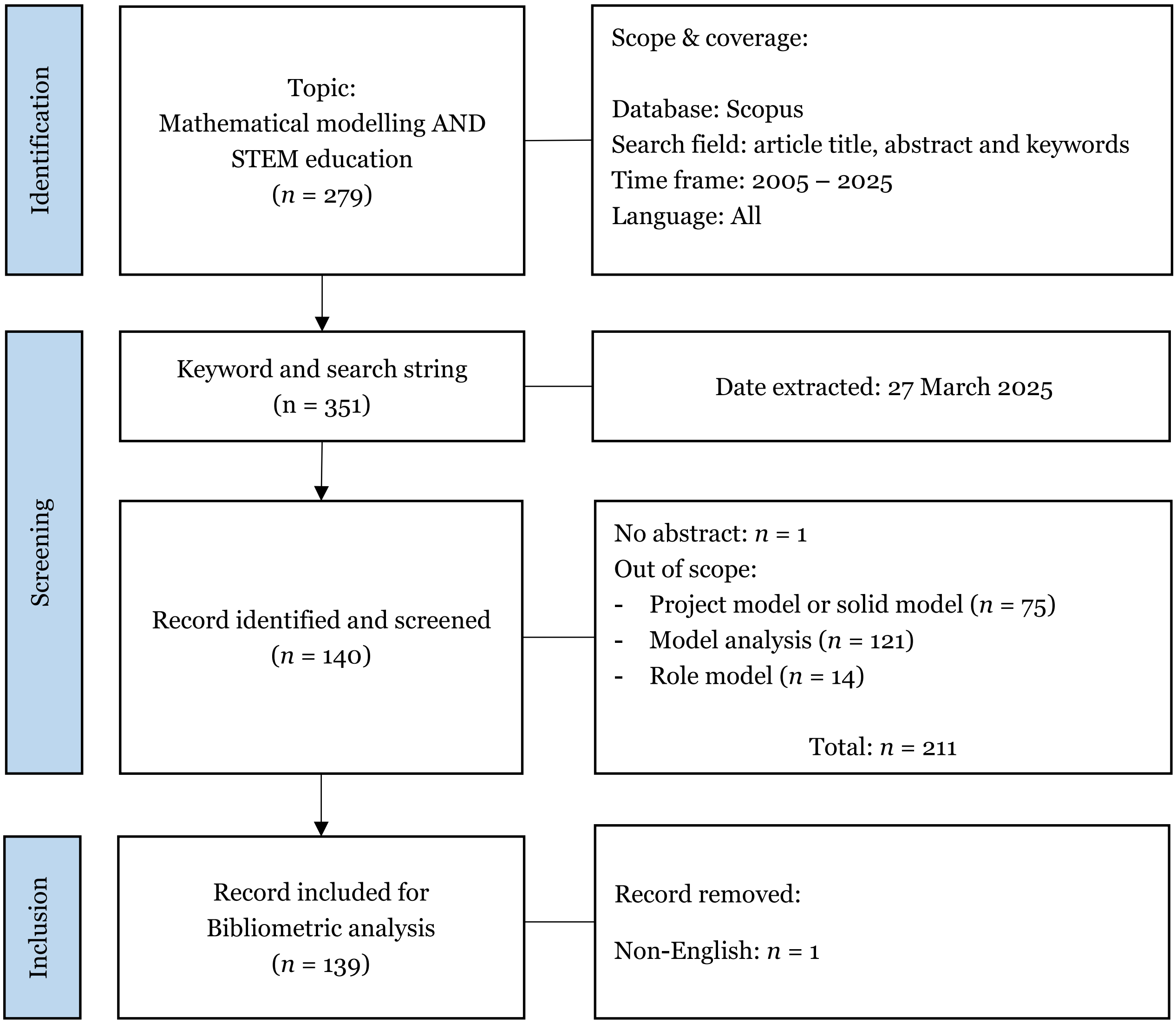
This study utilized multiple tools such as VOSviewer, Harzing's Publish and Perish software and Microsoft Excel to obtain detailed results that address all the research questions (Cevikbas et al., 2022). VOSviewer pays particular attention to the graphical depiction of bibliometric maps a feature that is very helpful for providing large bibliometric maps in an easily comprehensible way (Jan van Eck & Waltman, 2010). Overall, the literature suggests that modelling activities can play a significant role in enhancing STEM education by fostering interdisciplinary thinking, promoting authentic learning experiences, and bridging the gap between theoretical conceptualization and practical applications.

3 Methodology

The focus of this study is the implementation of STEM education in mathematics education through mathematical modelling activities in primary and secondary schools. In this study, the new design of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 proposed by Boers (2018), Mayo-Wilson et al. (2018) and Stovold et al. (2014) was used to organize and improve the review's transparency, accuracy and quality (Page et al., 2021). The selection process comprises three main stages: i) identification; ii) screening; and iii) inclusion, as illustrated in Figure 1.

Therefore, in order to investigate the relationship, the study incorporated all articles from the Scopus database, using VOSviewer (version 1.6.20) to generate bibliometric connections, and calculating citation metrics with Harzing's Publish and Perish software. This study utilized only the Scopus database because bibliometrics analyses are mainly performed by retrieving publications from the Web of Science (WoS) or Scopus database (Echchakoui, 2020). Cobo et al. (2011) state that Scopus is one of the most important bibliometric databases. Besides, the Scopus database has the highest coverage of total publications, at 72 per cent compared to WoS at 69 per cent (Aksnes & Sivertsen, 2019). Taking these arguments into consideration, Scopus was chosen as the preferred database for this study (Nuar & Seah, 2024). Additionally, the study utilized Microsoft Excel 2019 to compute each publication's citation frequency and percentage as well as to create appropriate graphical representations.

Figure 1. Flow diagram of the PRISMA 2020 proposed by Boers (2018), Mayo-Wilson et al. (2018) and Stovold et al. (2014).



3.1 Identification

In this bibliometric analysis, we aim to examine the implementation of STEM education through mathematical modelling activities in primary and secondary schools, considering different educational systems and curricula that incorporate mathematical modelling activities in mathematics classroom teaching and learning practices. We compile studies from various regions worldwide to ensure a diverse perspective on the implementation of mathematical modelling in STEM education.

For the identification phase, to begin the process of selecting suitable papers, we created a search string as shown in Table 2 after identifying all relevant terms. The analysis includes literature published in the years 2005 to 2025. The research articles, conference papers, reviews, book chapters, conference reviews, books, editorials, notes and letters encompassed a broad spectrum of academic discourse and practical applications. At this stage, we obtained 279 papers.

Table 2. The search string for the identification phase

Searching phase	Search string
Identification	**TITLE-ABS-KEY** (mathematics AND school AND ("STEM education" OR "Science, technology, engineering and mathematics" OR "Science, technology, engineering, mathematics") AND ("mathematical modelling" OR "mathematical modelling" OR modelling))

3.2 Screening

The study employed a screening sequence to determine the search terms for article retrieval. Afterwards, we revised the search string for the initial step in the screening phase as shown in Table 3. During the second phase, we included all types of publication; we obtained 351 articles as of 27 March 2025. For the second step, we excluded some studies extracted based on the abstract in the table of metadata exported from the Scopus database.

We subsequently omitted 211 studies due to the study being without an abstract or outside the research scope. These included one study without an abstract, 75 studies on the use of term ‘model’ for the project model or solid model, 121 studies on the use of term ‘model analysis’—for example, hierarchical linear modelling, structural equation modelling or multilinear modelling—and 14 studies on the use of term ‘role model’.

Table 3. The search string for the initial step in screening phase

Searching phase	Search string
Initial step	**TITLE-ABS-KEY** (mathematics AND (school OR classroom OR "school student*" OR "school teacher*" OR "primary school" OR "secondary student*" OR "high school" OR "junior high school" OR k-8 OR k-9 OR k-10 OR k-11 OR k-12) AND ("STEM education" OR "Science, technology, engineering and mathematics" OR "Science, technology, engineering, mathematics") AND ("mathematical modelling" OR "mathematical modelling" OR modelling OR modelling))

After all records had been identified and screened, we obtained 140 studies which were eligible for the next stage.

3.3 Inclusion

In the third stage, known as inclusion, the primary criteria for inclusion were language, time line, and literature type, as shown in Table 4. The review focused on all papers published from 2005 to 2025 without excluding any specific years to understand the current landscape, identify trends that provide a comprehensive view of recent developments and historical trends, and highlight the impact of mathematical modelling within STEM education. By selecting specific years, results can be very flawed and miss studies that would have been relevant; it is also possible to come to the wrong conclusion or, perhaps more serious, provide false evidence of a specific effect (Snyder, 2019).

Table 4. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2005–2025	Not applicable
Literature type	Research articles, conference paper, review, book chapter, conference review, book, editorial, note and letter	Erratum paper

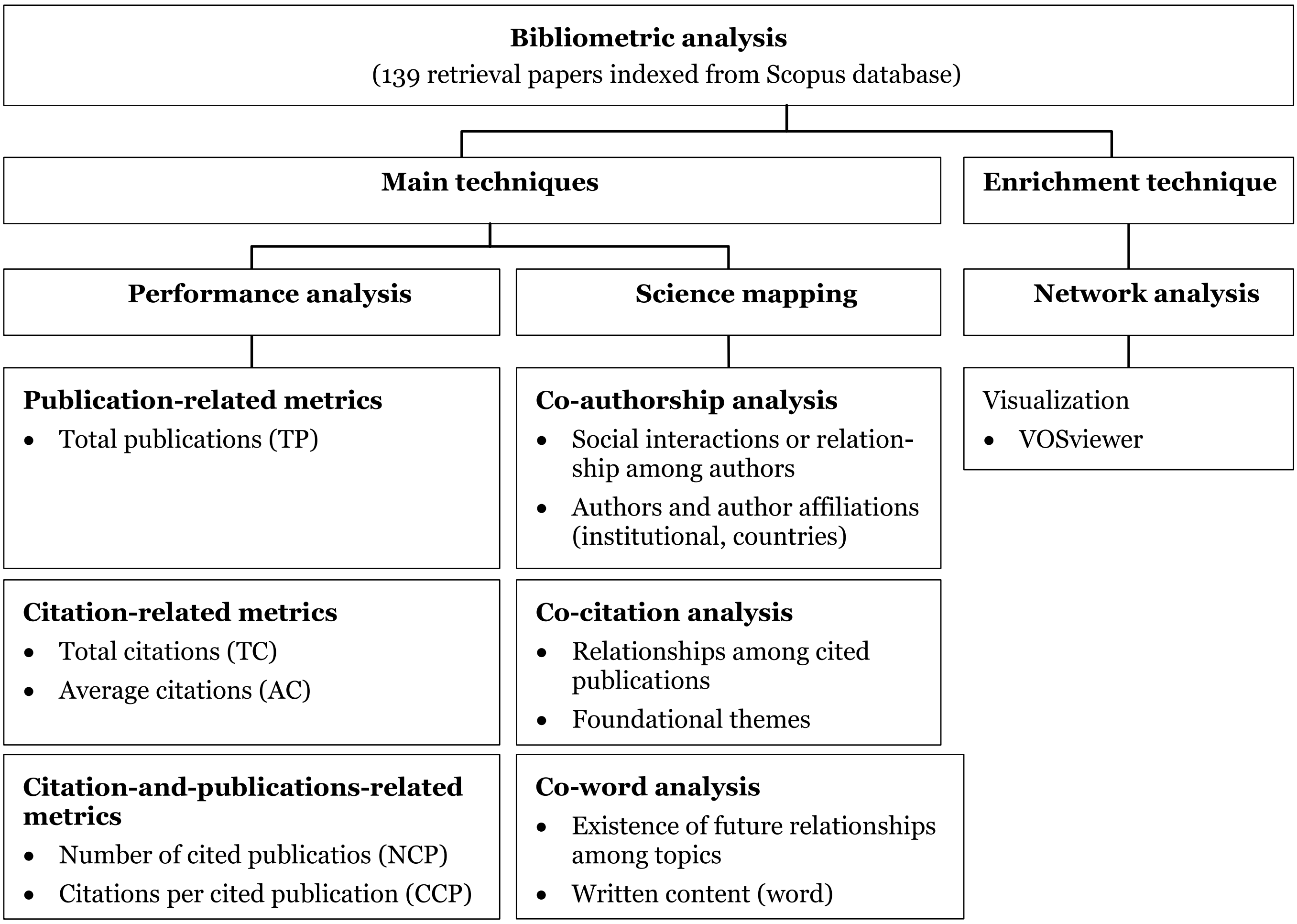
For the language selection, we scrutinized 140 results from the second phase and excluded just one article that was not in English. The selection process of papers written only in English instead of taking into accounts any artificial intelligent (AI) is one of the limitations of this study. We excluded non-English papers to prevent misinterpretation during translation, which could lead to inaccurate information. Finally, a total of 139 articles were identified for the bibliometric analysis.

4 Results and discussion

The purpose of the bibliometric analysis was to address the concerns brought up in the study. The study's goal was to determine the direction of current publication trends and the significance of research on the implementation of STEM education through mathematical modelling in schools. This section answers the research questions and discusses the results.

Based on the data collected from the last step, we carried out the analysis using the bibliometric analysis toolbox suggested by Donthu et al. (2021), as shown in Figure 2. According to Donthu et al. (2021), the techniques for bibliometric analysis manifest across two categories: i) performance analysis and ii) science mapping. In essence, performance analysis accounts for the contributions of research constituents, whereas science mapping focuses on the relationships between research constituents. The next subsections shed light on the techniques available for performance analysis and science mapping.

Figure 2. The bibliometric analysis toolbox for this research



4.1 The trend of publication on the implementation of STEM education in schools through mathematical modelling activities over the years

In this section, we represent the current trend in this topic by means of two aspects based on the growth in publications and the type of documents and sources.

4.1.1 Annual growth of publications

Table 5 shows that the number of publications has grown significantly over time. The first ten years (2005–2015) show relatively low total publications (TP), most years having fewer than ten publications. A notable increase begins in 2016. The peak year is 2021 with 14 publications, and mostly more than ten since. This indicates a growing interest and research focus on STEM education through mathematical modelling all over the world.

The total number of citations indicates the impact and reach of the research. We observed the top three highest total citations (TC) values in 2016 (1,255 citations), 2020 (204 citations) and 2021 (244 citations), indicating significant contributions during these years. The average citations per publication (AC) metric reveals the average frequency of citation for each publication. The years 2016 (125.50), 2017 (17.80) and 2020 (15.69) exhibit remarkably high AC values. This value indicates that while these years had fewer publications, those published had significant influence. The average citations per cited publication (CCP) refines this parameter by considering only cited publications. Here, 2016 (139.44), 2009 (27.00) and 2017 (25.43) stand out, reinforcing the high impact of research in these years.

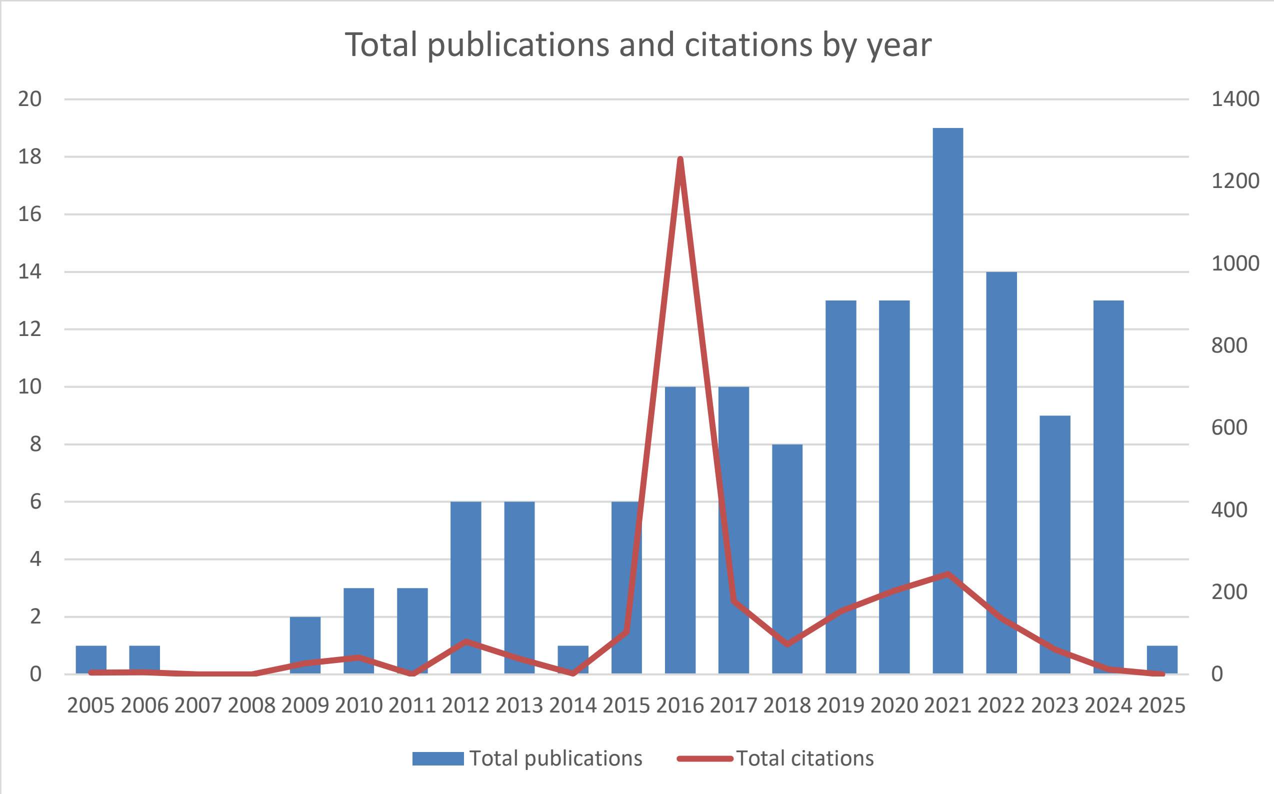
Table 5. Growth of publication by year

Year	TP	Percentage (%)	NCP	TC	AC	CCP
2025	1	0.72	0	0	0.00	0
2024	13	9.35	5	12	0.92	2.40
2023	9	6.47	8	60	6.67	7.50
2022	14	10.07	8	136	9.71	17.00
2021	19	13.67	11	244	12.84	22.18
2020	13	9.35	11	204	15.69	18.55
2019	13	9.35	11	154	11.85	14.00
2018	8	5.76	7	73	9.13	10.43
2017	10	7.19	7	178	17.80	25.43
2016	10	7.19	9	1255	125.50	139.44
2015	6	4.32	5	103	17.17	20.60
2014	1	0.72	1	2	2.00	2.00
2013	6	4.32	5	38	6.33	7.60
2012	6	4.32	5	80	13.33	16.00
2011	3	2.16	0	0	0.00	0.00
2010	3	2.16	1	41	13.67	41.00
2009	2	1.44	1	27	13.50	27.00
2008	0	0.00	0	0	0.00	0.00
2007	0	0.00	0	0	0.00	0.00
2006	1	0.72	1	5	5.00	5.00
2005	1	0.72	1	4	4.00	4.00

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; AC = average citations per publication; CCP = average citations per cited publication.

The total number of publications and citations is also presented graphically in Figure 3. The increase in publications over the past few years highlights the growing recognition of the subject's importance in the mathematics educational field. The citation metrics show that certain years had particularly influential publications, contributing significantly to the field's development.

Figure 3. Total publications and citations by year



Overall, the analysis reveals a dynamic and growing field, with increasing interest in STEM education through mathematical modelling. The data underscore the evolving nature of research in this area, with sustained interest and impactful contributions continuing to shape its trajectory.

4.1.2 Document and source type

Table 6 shows that the implementation of STEM education through mathematical modelling activities in schools has garnered significant scholarly interest, as evidenced by the diverse range of published document types on the topic.

Table 6. Types of document

Type of Document	Total Publications	Percentage
Article	65	46.76%
Conference paper	54	38.85%
Review	3	2.16%
Book chapter	13	9.35%
Conference review	2	1.44%
Book	1	0.72%
Editorial	1	0.72%

It can be seen that articles are the most prevalent form of publication, accounting for 46.76 per cent of the total publications. This high percentage highlights the importance and widespread acceptance of peer-reviewed articles in disseminating research findings and theoretical advancements in this field. Conference papers follow with 38.85 per cent, underscoring the role of academic conferences as vital forums for sharing innovative practices, emerging trends and collaborative research efforts. Book chapters make up 9.35 per cent, reviews account for 2.16 per cent, and conference reviews add 1.44 per cent to the total publications, showing that the academic community is still actively analysing, summarizing existing research and discussing research results. The remaining types of document, such as books and editorials, make up a smaller proportion of the publications, accounting for combined totals of 1.48 per cent and 0.72 per cent respectively. The books section indicates a deficiency in the publication of books that propose a more comprehensive exploration of the topic. To help teachers and teacher educators learn how to teach mathematical modeling in school and teacher education, it is necessary to provide more books and teaching materials that can be used by them in preparing high-quality teaching of mathematical modeling (Asempapa & Sturgill, 2019). This could involve providing in-depth theoretical frameworks or extensive practical guides that reflect the dynamic and evolving nature of STEM education through mathematical modeling.

Moreover, as shown in Table 7, the significant proportion of the source type highlights the importance and recognition of review articles in disseminating scholarly work on this topic. Journals account for 48.20 per cent of the total research publications and conference proceedings represent 36.69 per cent, indicating that conferences are also a key venue for presenting and discussing new research findings. Book series and books account for 9.35 per cent and 5.76 per cent of the total publications, respectively, suggesting that while these formats are less common, they still play a role in the academic discourse on STEM education and mathematical modelling.

Table 7. Source type

Source Type	**Total Publications**	**Percentage**
Journal	67	48.20%
Conference proceeding	51	36.69%
Book series	13	9.35%
Book	8	5.76%

Overall, these distributions of document and source types demonstrate the multifaceted approach researchers and educators take to explore, document and disseminate knowledge, highlighting the robust academic engagement and the variety of platforms utilized to advance understanding and practice in this area. The distribution highlights the diverse avenues through which researchers share their findings and contribute to the field.

4.2 The most productive and influential countries, authors and institutions in implementing STEM education through mathematical modelling activities in schools

The second research question (RQ2) emphasizes the importance of analysing publications and citations to identify the most productive and influential works within the research scope. Therefore, in this section, we identify and discuss the top ten publications based on country, authorship and institutions.

4.2.1 Publications by countries

Table 8 indicates that the United States leads by a substantial margin, with 74 total publications, constituting 53.24 per cent of the top ten countries' output. The country's average citations per publication (AC) stand at 26.58, while its average citations per cited publication (CCP) are 34.15. Hong Kong is the second most prolific contributor with six publications (4.32%) for this scope of research with AC 23.83 and CCP 28.41, underscoring their significant contribution to the field. Turkey also exhibits notable academic influence, its five publications comprising 3.60 per cent and with CP and CCP values of 3.20 and 4.00, respectively. Despite placing fourth with four publications (2.88%), South Korea's AC and CCP both have high scores (26.50 and 35.33, respectively). Taiwan is another country with high AC and CCP values, scoring 41.67 for both, despite having only three publications. These parameters demonstrate higher citation quality relative to the country's output.

Table 8. Top ten of total publications by country

Country	TP	Percentage (%)	NCP	TC	AC	CCP
United States	74	53.24	57	1967	26.58	34.51
Hong Kong	6	4.32	5	71	11.83	14.20
Turkey	5	3.60	4	16	3.20	4.00
South Korea	4	2.88	3	106	26.50	35.33
Italy	4	2.88	3	9	2.25	3.00
Canada	4	2.88	4	19	4.75	4.75
Taiwan	3	2.16	3	125	41.67	41.67
Sweden	3	2.16	2	30	10.00	15.00
Spain	3	2.16	3	11	3.67	3.67
Brazil	3	2.16	3	17	5.67	5.67

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; AC = average citations per publication; CCP = average citations per cited publication.

Other countries such as Italy, Canada, Sweden, Spain and Brazil also make meaningful contributions, Italy and Canada contributing four publications each (2.88%) and Spain three publications but having a lower impact in terms of citations with AC and CCP values below 10, at 2.25, 4.75, and 3.67 for AC value, and 3.00, 4.75, and 5.67, respectively. In contrast, Sweden, despite having fewer publications (only three), exhibits higher AC and CCP values of 10 and 15, respectively, indicating impactful research.

This bibliometric snapshot highlights the diverse global landscape of research in STEM education through mathematical modelling, with varying degrees of output and impact across different countries.

4.2.2 Authorship analysis

Table 9 observes a significant contribution from several prominent authors. Among them, Biswas, from Vanderbilt University, stands out with nine publications, contributing 6.47 per cent to the total publications analyzed.

Table 9. Authorship analysis

Author	TP	Percentage	Affiliation	Country	NCP	TC	AC	CCP
Biswas, G.	9	6.47 %	Vanderbilt University, Nashville	United States	7	190	21.11	27.14
Basu, S.	7	5.04 %	Vanderbilt University, Nashville	United States	6	168	24.00	28.00
Hutchins, N.	5	3.60 %	Vanderbilt University, Nashville	United States	3	37	7.40	12.33
Wilensky, U.	4	2.88 %	Northwestern University, Evanston	United States	4	1046	261.50	261.50
Kinnebrew J, S.	4	2.88 %	Vanderbilt University, Nashville	United States	4	146	36.50	36.50
Shekhar, S.	3	2.16 %	Vanderbilt University, Nashville	United States	3	35	11.67	11.67
Snyder, C.	3	2.16 %	Vanderbilt University, Nashville	United States	2	29	9.67	14.50
Caglar, F.	3	2.16 %	Vanderbilt University, Nashville	United States	3	35	11.67	11.67
Gokhale, A.	3	2.16 %	Vanderbilt University, Nashville	United States	3	35	11.67	11.67
Lin K.-Y.	2	1.44 %	Taiwan Normal University, Taipei	Taiwan	2	121	60.50	60.50

Notes: TP = total number of publications; (%) = percentage; NCP = number of cited publications; TC = total citations; AC = average citations per publication; CCP = average citations per cited publication.

Biswas's work has garnered considerable attention, with an average of 21.11 citations per publication, indicating sustained scholarly impact. He is followed by Basu, also from Vanderbilt University, who has made a notable contribution with seven publications, being 5.04 per cent of the total publications, and an average of 24.00 citations per publication, reflecting deep engagement and influence within the field of STEM education and mathematical modelling in school.

Further analysis reveals that eight of the ten top authors are affiliated with Vanderbilt University, Nashville. Authors affiliated with Northwestern University and Taiwan Normal University, Wilensky and Lin, demonstrate strong publication records with high average citations per publication (261.50 and 60.50, respectively), underscoring their influence on the discourse around STEM education and mathematical modelling.

These findings suggest a robust scholarly network driving innovation and development in educational practices that integrated STEM education with mathematical modelling activities in school.

4.2.3 Most active institutions

Data in Table 10 reveals that Vanderbilt University emerges as the most active institution with 12 publications, contributing significantly to the field. With an average of 22.08 citations per publication (AC) and average citations per cited publication (CCP) of 29.44, Northwestern University follows, with only three publications but an impressive average of 331.33 citations per publication, indicating a strong influence in integrating mathematical modelling into STEM education practices and sustained productivity within the academic community.

Table 10. Top ten most active institutions

Institution	TP	Percentage	Country	NCP	TC	AC	CCP
Vanderbilt University	12	8.63	United States	9	265	22.08	29.44
Northwestern University	3	2.16	United States	3	994	331.33	331.33
Texas A&M University	3	2.16	United States	3	91	30.33	30.33
Purdue University	3	2.16	United States	3	50	16.67	16.67
North Carolina State University	3	2.16	United States	1	26	8.67	26.00
University of Texas	3	2.16	United States	1	2	0.67	2.00
National Taiwan Normal University	2	1.44	Taiwan	2	121	60.50	60.50
Sungkyunkwan University	2	1.44	South Korea	2	72	36.00	36.00
The Education University of Hong Kong	2	1.44	Hong Kong	2	9	4.50	4.50
University of Brescia	2	1.44	Italy	2	6	3.00	3.00

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; AC = average citations per publication; CCP = average citations per cited publication.

Institutions like Texas A&M University, National Taiwan Normal University and Sungkyunkwan University also exhibit notable contributions: though they have only three, two, and two publications, respectively, they have high AC values of 30.33, 60.50, and

36.00. Purdue University, North Carolina State University, University of Texas, The Education University of Hong Kong, and University of Brescia, among the other five institutions, have either three or two publications, each with an average of fewer than 20 citations.

This analysis underscores Vanderbilt University's leadership in advancing mathematical modelling within STEM education, shaping future research and pedagogical practices in this research area.

4.3 Collaboration among authors and countries

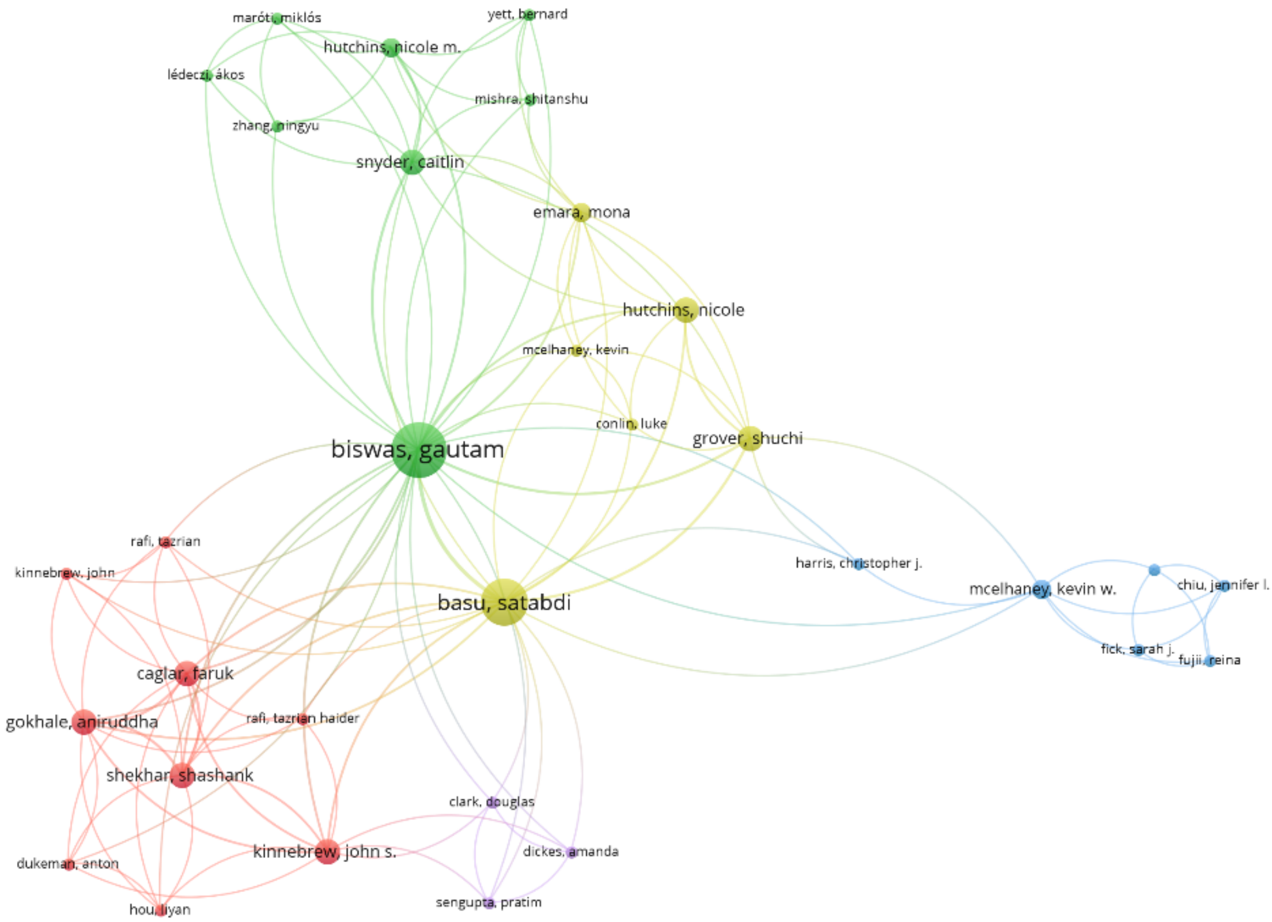
To get a greater understanding of the international collaboration among researchers, visualization of the network mapping represents by the themes that emerged from the focus on STEM education through modelling activities. Co-authorship analysis examines the interactions among scholars in a research field (Donthu et al., 2021). This visualization maps the co-authorship network, showing relationships among i) authors and ii) countries.

4.3.1 Co-authorship among authors

Using co-authorship analysis, the network mapping visualized the collaboration among authors who have written articles about STEM education and mathematical modelling activities in schools. The number of publications per author is shown by the size of the nodes in the network map, while the line thickness shows collaboration strength. Nodes within the same colour cluster indicate similar topics, and the distance between any two keywords reflects their relative strength and topic similarity. The size of a node indicates the frequency of a selected keyword (Cevikbas et al., 2022). The thicker the line, the more papers the authors have written collaboratively (Lim et al., 2023).

With the full counting method requiring one minimum document and zero citations, there are five clusters with a total of 32 connected authors out of 425 authors, as shown in Figure 4. These clusters are represented by different theme colours. The first cluster with a red colour is the biggest, containing nine authors: Shashank Shekhar, Tazrian Haider Rafi, Tazrian Rafi, John Kinnebrew, Liyan Hou, Aniruddha Gokhale, Anton Dukeman, and Faruk Caglar. The second biggest cluster represents eight authors connected by the green theme colour: Gautam Biswas, Nicole Hutchins, Akos Ledeczi, Miklos Maroti, Shitanshu Mishra, Caitlin Snyder, Bernard Yett, and Ningyu Zhang. The third cluster is displayed with the blue theme colour, connecting six authors: Kevin McElhaney, Christopher Harris, Reina Fujii, Sarah Fick, Jennifer Chiu, and Nonye Alozie. The yellow theme colour cluster is the fourth cluster, which includes six authors: Satabdi Basu, Luke Conlin, Mona Emara, Shuchi Grover, Nicole Hutchins, and Kevin McElhaney. Pratim Sengupta, Amanda Dickes, and Douglas Clark make up the smallest cluster in the purple theme colour.

Figure 4. Network visualization map of the co-authorship based on author



The largest node size belongs to Gautam Biswas, indicating that she has co-authored a relatively high number of articles on this topic, while the line linking Satabdi Basu and Gautam Biswas appears thicker, indicating their joint authorship of more articles.

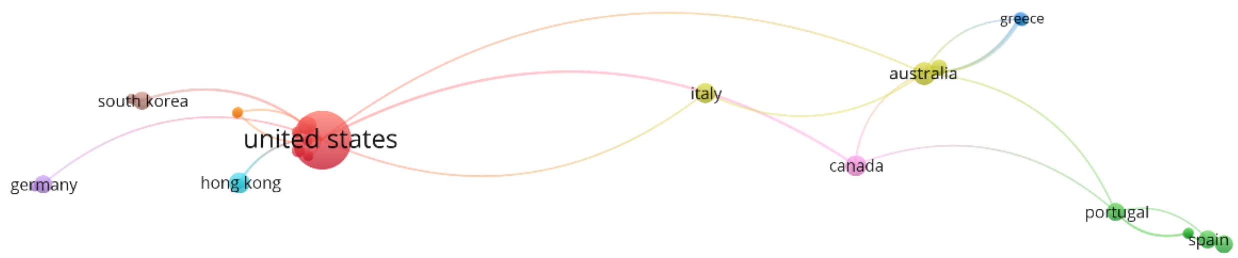
This network visualization map can be a useful tool for researchers studying the field of STEM education through mathematical modelling activities in schools. By examining the map, researchers can identify the leading scholars in the field, as well as potential collaborators for future research projects.

4.3.2 Co-authorship among countries

Using co-authorship analysis by country with the setting of a minimum of zero citations and one document, the network visualization map reveals nine clusters with 27 connected countries out of 43 countries. These clusters correspond to the co-authorship country networks that have published articles on the implementation of STEM education through mathematical modelling activities in schools. The lines that connect the circles reveal the patterns of collaboration among these countries. Each node in the co-authorship network represents a different country, while each node's size indicates the total number of papers written by researchers from a particular country. The larger the node size, the more publications there are in that country (Lim et al., 2023).

Based on the network map of co-authorship by country as shown in Figure 5, the United States leads as the biggest node with the most lines of collaboration originating from it. There are six connections with other countries, including Hungary, Egypt, China and Brazil, which form the first cluster with the red theme colour. Portugal is represented by the second biggest node, connected to four countries: Spain, France, Sweden and Vietnam. This group forms the second cluster in the green theme colour.

Figure 5. Network visualization map of co-authorship based on country



The visualization shows that some countries are more prolific in this field of research than others, while the remaining clusters show that the connections are fragile. These seven clusters, which serve as cluster centres, include Greece, Australia, Germany, Hong Kong, Puerto Rico, South Korea, and Canada.

4.4 The dominant themes among scholars regarding the implementation of STEM education through mathematical modelling activities in schools

The primary aim of the fourth question was to explore the dominant themes related to the implementation of STEM education through mathematical modelling activities in schools. To obtain the themes, we use keyword analysis. The unit of analysis for co-word analysis is words. The words in a co-word analysis are often derived from author keywords; in their absence, notable words can also be extracted from article titles, abstracts and full texts. The co-word analysis assumes that words that frequently appear together are thematically related (Donthu et al., 2021). In this section, we use VOSviewer software for co-occurrence analysis of keywords, specifically i) those provided by authors and ii) those derived from titles and abstracts.

4.4.1 Keywords analysis by author

We conducted distinct author keyword co-occurrence analyses aiming to discern temporal trends in keywords. The analysis yielded 534 keywords used by authors. Selecting relevant keywords is vital in terms of implications and future research directions. This analysis technique determined the relationship between concepts in article titles, abstracts, or keywords. It assumes that words that frequently appear together have a thematic relationship with one another (Donthu et al., 2021).

The findings therefore showed up-to-date information on the topic and pointed out the many aspects of STEM education research, especially the importance of focusing on students, combining different subjects, using modelling to improve learning results, and proposed areas for future study. Table 11 illustrates the top 20 keyword categories used by authors in all studies.

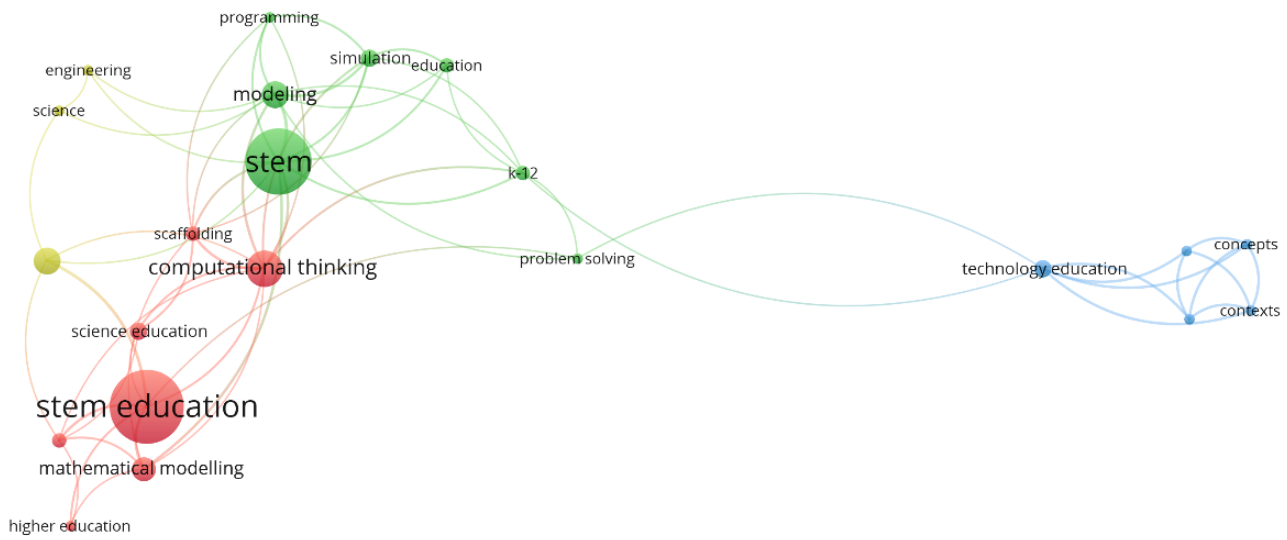
Table 11. Top 20 author keywords

Author Keyword	Frequency	Percentage
STEM	73	13.67
Education	69	12.92
Learning	44	8.24
Modelling	39	7.30
STEM Education	29	5.43
Science	19	3.56
Engineering	18	3.37
Mathematics	16	3.00
Technology	13	2.43
Computational Thinking	11	2.06
Simulation	11	2.06
Teaching	9	1.69
Mathematical Modelling	8	1.50
Programming	8	1.50
Science Education	7	1.31
Mathematical Modelling	7	1.31
Integration	7	1.31
K-12	7	1.31
Engineering Design	6	1.12
Concepts	6	1.12

Apart from the themes used in the search string—STEM (or STEM education or science or technology or engineering or mathematics), mathematical modelling (or modeling), and school (or K-12)—the most frequently occurring keyword is "learning," which appears in 8.24 per cent of the analysed publications, indicating a strong emphasis on the need for student engagement and outcomes in STEM education research. "Computational thinking" and "simulation" follow, each with 2.06 per cent frequency, underscoring the significance of skills development and integrating modelling activities into STEM education. The keywords "programming" (1.5%) and "engineering design" (1.12%) highlight the crucial role of technology and interdisciplinary approaches in modern educational practices. Other notable keywords such as "teaching" (1.69%), "science education" (1.31%) and concept" (1.12%) reflect core components of educational strategies, while terms like "e-learning" (4.56%) and "learning systems" (5.71%) indicate a growing interest in digital and adaptive learning environments.

Additionally, regarding authors' keywords, we conducted a bibliometric analysis utilizing VOSviewer network visualization mapping as shown in Figure 6. According to Donthu et al. (2021), connecting documents through a combination of bibliometric and second-order textual similarities can improve the accuracy of document clustering.

Figure 6. Network visualization map of the author keywords



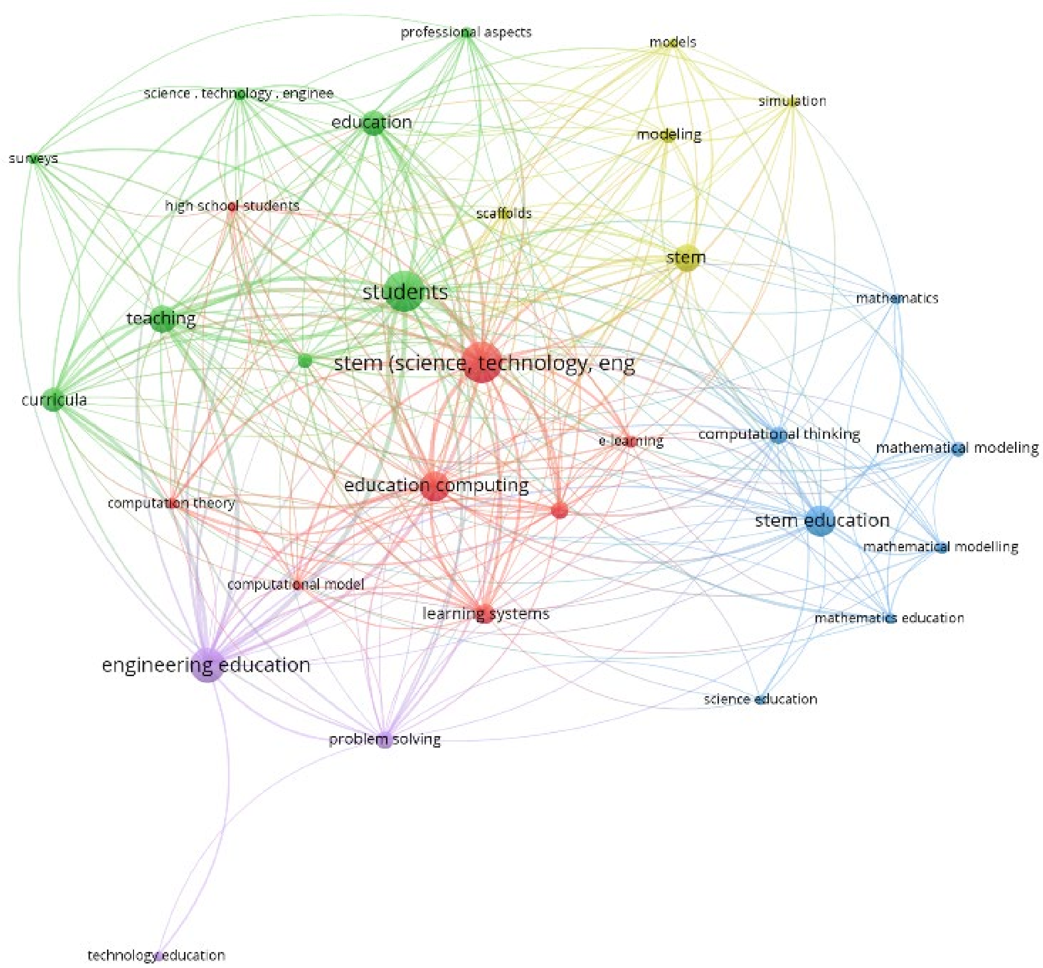
Using co-occurrence analysis with the full counting method and requiring that a keyword appear at least three times, we found four clusters containing 22 out of 25 connected items comprising different keywords used by authors. Different colours distinguish each of the clusters. According to the network visualization, the first cluster consists of seven items, highlighted with the red theme colour, featuring prominent terms such as STEM education, connecting with six other keywords: computational thinking, higher education, mathematical modelling, scaffolding, and science education and mathematics education. The green theme colour emerges as the second prominent cluster, connecting seven keywords: STEM, simulation, programming, problem-solving, modelling, K-12 and education. The third cluster, presented with a blue theme colour, comprises five items: technology education, engineering education, contexts, conceptual learning, and concepts. Only three items—mathematical modelling, science and engineering—make up the fourth cluster.

Overall, the visualization shows a strong focus on the integration of STEM education and mathematical modelling, with a particular emphasis on implementation in schools and evaluation of its effectiveness. Based on the visualization map, the researcher can identify any gaps between two nodes for future research purposes. For example, there is no connection, or a lack of research, between mathematical modelling (or modeling) and technology education, between STEM (or STEM education) and technology education, or between technology education and programming.

4.4.2 Keywords analysis based on title and abstract

We utilized VOSviewer software to analyse the number of co-occurrences based on titles (index keywords) and abstracts (all keywords) of all the retrieved papers. With full counting and five minimum occurrences of all keywords, the network map is visualized as illustrated in Figure 7.

Figure 7. VOSviewer visualization of co-occurrence based on all keywords

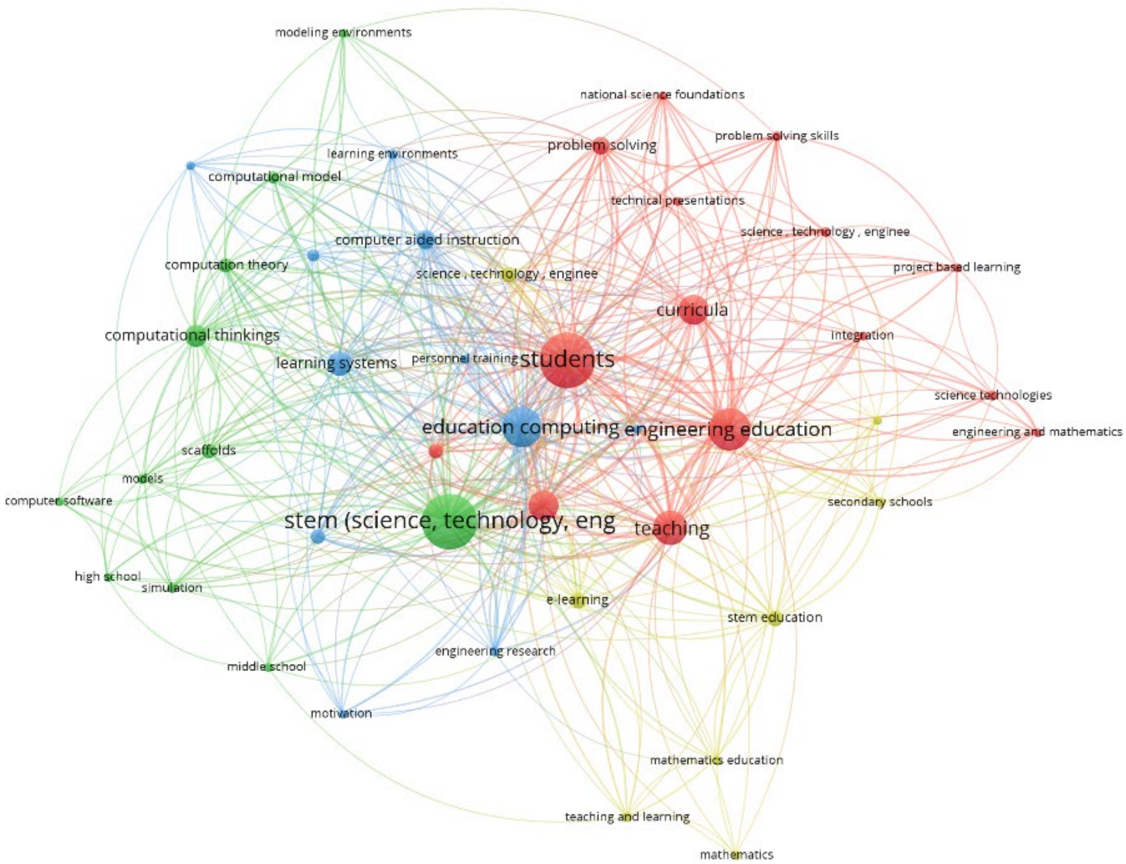


The results indicate five clusters with 31 linked items. The first cluster, located in the red group, comprises eight linked items with "STEM (science, technology, engineering, and mathematics)" serving as the central term and connected to other terms like learning system, high school students, education computing, e-learning, computational thinking, computational model, and computational theory. The second cluster with the green theme colour emerged with the term "student" serving as its focal point. This cluster encompasses seven more items: teaching, surveys, science-technology-engineering-mathematics, professional aspects, education, curricula, and computer-aided instruction.

The implementation of STEM education through mathematical modelling activities demonstrates its application to real-world scenarios and realistic experiences. There are three further clusters, coloured blue, yellow and purple. The third cluster consists of seven items: STEM education, mathematical modelling, science education, mathematics, computational thinking, mathematics education, and mathematical modeling. The fourth cluster encompasses five items, including STEM, models, modelling, simulation, and scaffolds. Only three items—engineering education, problem-solving and technology education—comprise the final cluster.

Figure 8 demonstrates that the network mapping relies on the index, utilizing full counting and a minimum of three occurrences of keywords. The visualization shows that there are four clusters involving 45 connected items.

Figure 8. VOSviewer visualization of co-occurrence based on index keywords



The major cluster, coloured red, includes 15 items, being students, engineering education, teaching, curricula, education, engineering, mathematics, integration, the National Science Foundation, problem-solving, problem-solving skills, professional aspects, project-based learning, science-technology-engineering, and science technologies. It represents the core research area, focusing on the relationship between mathematical modelling and STEM education generally.

The second major cluster, in green, connects 11 items, including STEM (science, technology, engineering, and mathematics), computational thinking, computational theory, computational models, computer software, high school, middle school, modelling environments, models, scaffolds and simulation. The focus appears to be on the practical aspects of implementing mathematical modelling activities in STEM education that are suitable for applying real-world situations to the students' learning. The third cluster, in blue, involves education computing, learning systems, computer-aided instruction, STEM (science, technology, engineering, and mathematics), elementary schools, engineering research, high school students, learning environments, models and simulations, motivation, and surveys. The final cluster, coloured yellow, links e-learning, STEM education, mathematics education, teaching and learning, secondary schools, and the fields of science, technology and engineering. These points of view emphasize the effectiveness of implementing STEM education through modelling activities, involving the application of specific mathematical techniques and tools.

Overall, the visualization highlighted that research on STEM education through mathematical modelling activities in schools focuses on developing and implementing effective curricula and instructional methods, as well as student learning outcomes and teacher professional development. This study also found that some of the key terms and clusters have stimulated another field of study involving the implementation of STEM education through modelling activities in schools.

5 Limitations and future research

As a first limitation, only articles published in the Scopus database were selected for this study. Even though Scopus is recognized as a comprehensive database for academic papers, incorporating other databases might yield additional insightful results. Future research should assess publications in other databases, such as Web of Science, ProQuest, Google Scholar, Dimensions, Lens and PubMed (Nuar & Seah, 2024). The second limitation of this study is its focused only on publications using the English language. Future research should extend the search to non-English publications.

Conclusions

The purpose of this research was to look at the use of mathematical modelling activities in STEM education and its trajectory in educational settings. The research findings may help educators incorporate STEM learning into the classroom through mathematical modelling activities. In terms of publications, the nations that are actively supporting the use of mathematical modelling in STEM education include the United States, Hong Kong, Turkey and South Korea. According to the results of networking visualized by countries, authors, and institutions, collaboration in the recent period shows an impressive trend that can become more actively developed. This collaboration is likely to bring needed new paradigms and perspectives in this area of research (Nyirahabimana et al., 2022). Due to its indirect global influence, this networking tendency has prompted other countries to change their educational practices, especially with regard to the mathematical field.

Therefore, it is necessary to enhance a number of aspects, including teaching materials, teaching methodologies and teaching approaches, in order to encourage the beneficial use of mathematical modelling activities in STEM education (Basu et al., 2016). Additionally, teachers should enhance their abilities to equip themselves for the modern world and its demands (Lämsä et al., 2023). This, in conjunction with a program of mathematical and STEM-based future-oriented problems, can support the development of students' skills and confidence in problem-solving ability. Specifically, mathematical and STEM-based modeling has been promoted as a valuable method of cultivating various cognitive perspectives that encourage adaptive and innovative learners. These learners are characterized by a propensity for discovering new knowledge and skills, as well as a willingness to address complex problems from the present and the future (English, 2023). According to Küçükaydın and Ulum (2025) and Kim et al. (2023), teachers with negative mathematics learning experiences are assumed to possess low self-efficacy and would have an impact on their teaching behaviours. Thus, teachers must engage in professional development to ensure that they can effectively instruct students, encourage critical thinking in them, and support active learning in the classroom.

Research ethics

Author contributions

A.T.: conceptualization, investigation, methodology, project administration, software, data curation, resources, writing—original draft preparation, validation, visualization, and editing
R.R.: conceptualization, supervision, formal analysis, validation, writing—review and editing
A.S.R.: supervision, validation and writing—review.

All authors have read and agreed to the published version of the manuscript.

Artificial intelligence

QuillBot: Grammar Checker

Funding

The research project is funded by the internal university grants of GG-2024-001 from the National University of Malaysia.

Institutional review board statement

Not applicable.

Informed consent statement

Not applicable.

Data availability statement

Not applicable.

Acknowledgements

Not applicable.

Conflicts of Interest

The authors declare no conflicts of interest.

References

Aksnes, D. W., & Sivertsen, G. (2019). A Criteria-based Assessment of the Coverage of Scopus and Web of Science. *Journal of Data and Information Science*, *4*(1), 1–21. https://doi.org/10.2478/jdis-2019-0001

AlAli, R. (2024). Enhancing 21st century skills through integrated STEM education using project-oriented problem-based learning. *Geojournal of Tourism and Geosites*, *53*(2), 421–430. https://doi.org/10.30892/gtg.53205-1217

Asempapa, R. S., & Sturgill, D. J. (2019). Mathematical Modeling: Issues and Challenges in Mathematics Education and Teaching. *Journal of Mathematics Research*, *11*(5), 71. https://doi.org/10.5539/jmr.v11n5p71

Bas-Ader, S., Erbas, A. K., Cetinkaya, B., Alacaci, C., & Cakiroglu, E. (2023). Secondary mathematics teachers' noticing of students' mathematical thinking through modeling-based teacher investigations. *Mathematics Education Research Journal*, *35*(0123456789), 81–106. https://doi.org/10.1007/s13394-021-00389-4

Basu, S., Biswas, G., Sengupta, P., Dickes, A., Kinnebrew, J. S., & Clark, D. (2016). Identifying middle school students' challenges in computational thinking-based science learning. *Research and Practice in Technology Enhanced Learning*, *11*(1). https://doi.org/10.1186/s41039-016-0036-2

Beswick, K., & Fraser, S. (2019). Developing mathematics teachers' 21st century competence for teaching in STEM contexts. *ZDM - Mathematics Education*, *51*(6), 955–965. https://doi.org/10.1007/s11858-019-01084-2

Blum, W., Niss, M. Applied mathematical problem solving, modelling, applications, and links to other subjects — State, trends and issues in mathematics instruction. *Educ Stud Math* **22**, 37–68 (1991). https://doi.org/10.1007/BF00302716

Boers, M. (2018). Graphics and statistics for cardiology: Designing effective tables for presentation and publication. In *Heart* (Vol. 104, Issue 3, pp. 192–200). BMJ Publishing Group. https://doi.org/10.1136/heartjnl-2017-311581

Cevikbas, M., Kaiser, G., & Schukajlow, S. (2022). A systematic literature review of the current discussion on mathematical modelling competencies: state-of-the-art developments in conceptualizing, measuring, and fostering. *Educational Studies in Mathematics*, *109*(2). https://doi.org/10.1007/s10649-021-10104-6

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology*, *62*(7), 1382–1402. https://doi.org/10.1002/asi.21525

Copur-Gencturk, Y., Choi, H.-J., & Cohen, A. (2023). Investigating teachers' understanding through topic modeling: a promising approach to studying teachers' knowledge. *Journal of Mathematics Teacher Education*, *26*(3), 281–302. https://doi.org/10.1007/s10857-021-09529-w

Copur-Gencturk, Y., & Li, J. (2023). Teaching matters: A longitudinal study of mathematics teachers' knowledge growth. *Teaching and Teacher Education*, *121*. https://doi.org/10.1016/j.tate.2022.103949

De Bock, D., & Zwaneveld, B. (2020). From Royaumont to Lyon: Applications and Modelling During the 1960s. In *International Perspectives on the Teaching and Learning of Mathematical Modelling* (pp. 407–417). Springer Science and Business Media B.V. https://doi.org/10.1007/978-3-030-37673-4_35

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Ebbelind, A., & Helliwell, T. (2024). Examining interpersonal aspects of a mathematics teacher education lecture. *LUMAT*, *12*, 113–125. https://doi.org/10.31129/LUMAT.12.1.2147

Echchakoui, S. (2020). Why and how to merge Scopus and Web of Science during bibliometric analysis: the case of sales force literature from 1912 to 2019. *Journal of Marketing Analytics*, *8*(3), 165–184. https://doi.org/10.1057/s41270-020-00081-9

English, L. D. (2023). Ways of thinking in STEM-based problem solving. *ZDM - Mathematics Education*, *55*(7). https://doi.org/10.1007/s11858-023-01474-7

Estrada, M., Hernandez, P. R., & Schultz, P. W. (2018). A longitudinal study of how quality mentorship and research experience integrate underrepresented minorities into STEM careers. *CBE Life Sciences Education*, *17*(1). https://doi.org/10.1187/cbe.17-04-0066

Galbraith, P., Holton, D., & Turner, R. (2020). Rising to the Challenge: Promoting Mathematical Modelling as Real-World Problem Solving. In *International Perspectives on the Teaching and Learning of Mathematical Modelling*. https://doi.org/10.1007/978-3-030-37673-4_22

Göhner, M. F., Bielik, T., & Krell, M. (2022). Investigating the dimensions of modeling competence among preservice science teachers: Meta-modeling knowledge, modeling practice, and modeling product. *Journal of Research in Science Teaching*, *59*(8), 1354–1387. https://doi.org/10.1002/tea.21759

Goos, M., Carreira, S., Immaculate, ·, & Namukasa, K. (2023). Mathematics and interdisciplinary STEM education: recent developments and future directions. *ZDM – Mathematics Education*, *55*, 1199–1217. https://doi.org/10.1007/s11858-023-01533-z

Greefrath, G., & Vorhölter, K. (2016). *Teaching and Learning Mathematical Modelling: Approaches and Developments from German Speaking Countries* (open access). Springer Nature. http://www.springer.com/series/14352

Hallström, J., Norström, P., & Schönborn, K. J. (2023). Authentic STEM education through modelling: an international Delphi study. *International Journal of STEM Education*, *10*(1). https://doi.org/10.1186/s40594-023-00453-4

Hallström, J., & Schönborn, K. J. (2019). Models and modelling for authentic STEM education: reinforcing the argument. *International Journal of STEM Education*, *6*(1). https://doi.org/10.1186/s40594-019-0178-z

Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education*, *13*(5), 1089–1113. https://doi.org/10.1007/s10763-014-9526-0

STEM. *Journal of Educational Psychology*, *105*(1), 89–107. https://doi.org/10.1037/a0029691

Ikeda, T., & Stephens, M. (2020). Using a Mathematical Modelling Activity to Assist Students to Make Sense of a Limit Theorem in Trigonometry. In *International Perspectives on the Teaching and Learning of Mathematical Modelling*. https://doi.org/10.1007/978-3-030-37673-4_25

Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2023). The role of STEM Education in improving the quality of education: a bibliometric study. *International Journal of Technology and Design Education*, *33*(3), 819–840. https://doi.org/10.1007/s10798-022-09762-1

Jan van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*, 523–538. https://doi.org/10.1007/s11192-009-0146-3

Kaab, A., Sharifi, M., Mobli, H., Nabavi-Pelesaraei, A., & Chau, K.-W. (2019). Combined life cycle assessment and artificial intelligence for prediction of output energy and environmental impacts of sugarcane production. *Science of the Total Environment*, *664*, 1005–1019. https://doi.org/10.1016/j.scitotenv.2019.02.004

Kertil, M., & Gurel, C. (2016). Mathematical Modelling: A Bridge to STEM Education. *International Journal of Education in Mathematics, Science and Technology*, *4*(1), 44. https://doi.org/10.18404/ijemst.95761

Kim, E., Mallat, E., & Joutsenlahti, J. (2023). A systematic review of primary school class teachers views of mathematics teaching and learning. *LUMAT*, *11*(2), 60–87. https://doi.org/10.31129/LUMAT.11.2.2055

Küçükaydın, M. A., & Ulum, H. (2025). The mediating role of creative problem solving between design thinking and self-efficacy in STEM teaching for STEM teacher candidates. *International Journal of Technology and Design Education*, *35*(2), 629–645. https://doi.org/10.1007/s10798-024-09923-4

Lämsä, J., Virtanen, A., Tynjälä, P., Maunuksela, J., & Koskinen, P. (2023). Exploring students' perceptions of self-assessment in the context of problem solving in STEM. *LUMAT*, *11*(2), 35–59. https://doi.org/10.31129/LUMAT.11.2.2028

Lantau, J. M., Bracke, M., Bock, W., & Capraro, P. (2020). The Design of a Successful Teacher Training to Promote Interdisciplinary STEM Modelling Projects. In *International Perspectives on the Teaching and Learning of Mathematical Modelling* (pp. 455–465). Springer Science and Business Media B.V. https://doi.org/10.1007/978-3-030-37673-4_39

Ledezma, C., Font, V., & Sala, G. (2023). Analysing the mathematical activity in a modelling process from the cognitive and onto-semiotic perspectives. *Mathematics Education Research Journal*, *35*(4), 715–741. https://doi.org/10.1007/s13394-022-00411-3

Lim, Y. W., Darmesah, G., Pang, N. T. P., & Ho, C. M. (2023). A bibliometric analysis of the structural equation modelling in mathematics education. In *Eurasia Journal of Mathematics, Science and Technology Education* (Vol. 19, Issue 12). Modestum LTD. https://doi.org/10.29333/ejmste/13838

Lubinski, D. (2010). Spatial ability and STEM: A sleeping giant for talent identification and development. *Personality and Individual Differences*, *49*(4), 344–351. https://doi.org/10.1016/j.paid.2010.03.022

Lu, X., & Kaiser, G. (2022). Creativity in students' modelling competencies: conceptualisation and measurement. *Educational Studies in Mathematics*, *109*, 287–311. https://doi.org/10.1007/s10649-021-10055-y

Mayo-Wilson, E., Li, T., Fusco, N., & Dickersin, K. (2018). Practical guidance for using multiple data sources in systematic reviews and meta-analyses (with examples from the MUDS study). *Research Synthesis Methods*, *9*(1), 2–12. https://doi.org/10.1002/jrsm.1277

Meles, C., & Ali, S. R. (2024). Mathematics education values applied among primary school students. *International Journal of Modern Education*, *6*(21), 93–111. https://doi.org/10.35631/ijmoe.621008

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Journal of Clinical Epidemiology*, *62*(10), 1006–1012. https://doi.org/10.1016/j.jclinepi.2009.06.005

Ngu, P. N. H., Nam, N. D., Cuong, L. M., & Thao, T. T. P. (2025). Mathematical modelling in higher education: Evolving research and emerging trends (1980–2023). *Infinity Journal*, *14*(2), 393–418. https://doi.org/10.22460/infinity.v14i2.p393-418

Nuar, A. N. A., & Seah, C. Sen. (2024). Examining the Trend of Research on Big Data Architecture: Bibliometric Analysis using Scopus Database. *Procedia Computer Science*, *234*, 172–179. https://doi.org/10.1016/j.procs.2024.04.010

Nyirahabimana, P., Minani, E., Nduwingoma, M., & Kemeza, I. (2022). A scientometric review of multimedia in teaching and learning of physics. *LUMAT*, *10*(1), 89–106. https://doi.org/10.31129/LUMAT.10.1.1634

Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to design bibliometric research: an overview and a framework proposal. *Review of Managerial Science*. https://doi.org/10.1007/s11846-024-00738-0

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. In *BMJ* (Vol. 372). BMJ Publishing Group. https://doi.org/10.1136/bmj.n71

Pathoumma, T., & Trinh, D. T. (2024). Fostering Critical and Creative Thinking through Mathematics Instruction in High Schools in the Lao People's Democratic Republic. *Pakistan Journal of Life and Social Sciences (PJLSS)*, *22*(2). https://doi.org/10.57239/PJLSS-2024-22.2.000155

Peng, Y. (2023). A Comparative Study of Mathematical Modeling of Senior Middle School in China, German and the United States. In *Proceedings of the 2nd International Conference on Education: Current Issues and Digital Technologies (ICECIDT 2022)* (pp. 415–428). Atlantis Press SARL. https://doi.org/10.2991/978-2-494069-02-2_46

Rehman, N., Zhang, W., Mahmood, A., Fareed, M. Z., & Batool, S. (2023). Fostering twenty-first century skills among primary school students through math project-based learning. *Humanities and Social Sciences Communications*, *10*(1). https://doi.org/10.1057/s41599-023-01914-5

Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021). Beyond the basics: a detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, *3*(1). https://doi.org/10.1186/s43031-021-00041-y

Sengupta, P., Kinnebrew, J. S., Basu, S., Biswas, G., & Clark, D. (2013). Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education and Information Technologies*, *18*(2), 351–380. https://doi.org/10.1007/s10639-012-9240-x

Spooner, K. (2022). What does mathematical modelling have to offer mathematics education? Insights from students' perspectives on mathematical modelling. *Article in International Journal of Mathematical Education in Science & Technology ·*. https://doi.org/10.1080/0020739X.2021.2009052

Stovold, E., Beecher, D., Foxlee, R., & Noel-Storr, A. (2014). Study flow diagrams in Cochrane systematic review updates: an adapted PRISMA flow diagram. *Systematic Reviews*. http://www.systematicreviewsjournal.com/content/3/1/54

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Tuong, H. A., Nam, P. S., Hau, N. H., Tien, V. T. B., Lavicza, Z., & Hougton, T. (2023). Utilising STEM-Based Practices to Enhance Mathematics Teaching in Vietnam: Developing Students' Real-World Problem Solving and 21st Century Skills. *Journal of Technology and Science Education*, *13*(1), 73–91. https://doi.org/10.3926/jotse.1790

Uyen, B. P., Tong, D. H., Loc, N. P., & Thanh, L. N. P. (2021). The effectiveness of applying realistic mathematics education approach in teaching statistics in grade 7 to students' mathematical skills. In *Journal of Education and e-Learning Research* (Vol. 8, Issue 2, pp. 185–197). Asian Online Journal Publishing Group. https://doi.org/10.20448/JOURNAL.509.2021.82.185.197

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Zbiek, R. M., Peters, S. A., Galluzzo, B., & White, S. J. (2022). Secondary mathematics teachers learning to do and teach mathematical modelling: a trajectory. *Journal of Mathematics Teacher Education*. https://doi.org/10.1007/s10857-022-09550-7