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Mathematical modelling in higher education: Evolving research and emerging trends (1980–2023)

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Abstract

Mathematical education in higher education plays a significant role in training future citizens with problem-solving skills to meet professional requirements. One of the trends in teaching mathematics at universities that has received much focus is teaching mathematics through modelling. The article uses the bibliometric analysis method through Bibliometrix and VOSviewer software to analyze 271 publications extracted from the Scopus database to provide an overall picture of mathematics modelling research in higher education from 1980 to 2023. The results indicate that the growth trend of publications is unstable, with a significant increase in the last 5 years. The United States and China are the two leading countries in terms of the number of published publications and citations; Tecnológico de Monterrey (Mexico) is the affiliation with the highest number of publications; the Book series "International Perspectives on the Teaching and Learning of Mathematical Modelling" is the most release source on this topic. The article also analyzes co-occurring keywords and identifies 03 research trends on this topic, including using technology and computer programming in mathematics modelling curriculum for students of technical universities, teaching mathematic modelling in universities, as well as using technology in teaching modelling and STEM education, innovating teaching methods of mathematics modelling and applying information technology in teaching mathematics modelling in pedagogic training programs. This is the first bibliometric study on mathematics modelling. These important research results help scholars interested in this research direction have an overview through useful quantitative information regarding mathematical modelling research in higher education worldwide, thereby developing appropriate research trends.

Keywords:
Bibliometric analysis, Higher education, Mathematical modelling, Scopus database

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1. INTRODUCTION

Higher education has become an important pathway for the development of a nation's human resources and the social advancement of individuals (Van Damme & Zahner, 2022). It is a place where young people acquire high-level general and specialized skills to meet the professional demands of an increasingly knowledge-based economy and society. Higher education systems also help students develop social and emotional skills to become useful citizens (Van Damme & Zahner, 2022).

Teaching Mathematics is currently receiving attention in the formal education systems. Mathematics helps students better understand everyday life; provides students with the necessary skills to meet the requirements of future careers; and creates opportunities for students to participate in life as intelligent and meaningful citizens (Rogovchenko & Rogovchenko, 2022). In addition, mathematics is also a tool for solving problems in other subjects (Abassian et al., 2020). Therefore, Mathematics is considered one of the important subjects in higher education, especially in technical fields.

Despite the emphasis on mathematics teaching in universities, there is still debate about the teaching contents and methods (Wong et al., 2022). The authors, Huang (2012) argue that the teaching of mathematics in schools has created a view among students that mathematics is boring, abstract, and irrelevant to the real world. Many university students do not have the opportunity to appreciate the deep connections between different areas of mathematics or the richness of the connections between mathematics and other disciplines (Poladian & Zheng, 2016). Wedelin et al. (2013) also argue that technical students often fail to connect and apply what they learn in basic mathematics to other subjects, sometimes leading to the belief that mathematics is irrelevant to them.

In order to address this issue, mathematical modelling is increasingly considered as a more enlightened approach to teaching applications of mathematics (Oke, 1980). Depending on the purpose and object of the research, there are different approaches to mathematical. Abassian et al. (2020) conducted a review research and presented perspectives on modelling in mathematics education such as: Realistic modelling; Educational modelling; Models and modelling perspective; Socio-critical modelling; Epistemological modelling; and Emergent modelling. Mathematical modelling allows students to link their learning to real-life situations (Juarez Ramirez et al., 2020). Although there are many different approaches, researchers agree that mathematical modelling involves formulating a real-world problem in mathematical terms, solving the resulting equations, and interpreting the solutions (Oke, 1980).

The teaching of mathematical modelling has been included in many courses in Polytechnic universities since early times. Berry and O'Shea (1982) highlighted its pivotal role in developing students' mathematical thinking. Cardella (2013) investigated how engineering students applied mathematical modeling through real-world projects, providing evidence of its effectiveness. Carrejo and Marshall (2007) introduced a physics course for pre-service mathematics and science teachers, demonstrating how mathematical models connect to physical phenomena. More recently, Merck et al. (2021) designed an online module aimed at developing students' modeling skills, thereby enhancing their ability to solve practical problems.

Numerous studies have focused on modeling courses for educators and engineering students, aiming to provide interdisciplinary learning experiences throughout their university education (Cardella, 2013; Wiechert, 2002). For example, Farràs et al. (2011) examined the role of mathematical modeling in first-year courses for experimental science students. Additionally, Fontana and Groenwald (2023) implemented the "Operational Research" course at Fisul College, enabling business administration students to apply mathematical modeling to everyday situations.

Furthermore, several studies have explored the modelling competence of pedagogical students. Jacobs and Durandt (2016) emphasized that such competence can be developed through appropriate teaching methods. Palharini and de Almeida (2015) also highlighted that the ability to construct and solve problems using mathematical models is crucial for teaching in schools. Asempapa and Sastry (2021) conducted a survey of 208 student teachers across 10 universities in the United States, evaluating their understanding and experience with mathematical modeling. Similarly, Huang (2012) examined the capability of first-year engineering students to participate in mathematical modeling activities.

However, teaching mathematics, especially improving the modelling skills of mathematics education students – the future teachers of mathematics – also faces limitations. Galligan et al. (2019) pointed out limitations such as insufficient experience with modeling processes, a lack of confidence, and inadequate personal competency. These factors hinder pre-service mathematics teachers from becoming effective educators, subsequently affecting student learning outcomes. Asempapa and Sastry (2021) also noted that many student teachers misunderstand mathematical modeling due to the absence of formal training on modeling-related activities in teacher preparation programs.

Aiming to provide a comprehensive picture of the research topic of mathematical modelling in higher education (from 1980 to 2023); In this article, we use bibliometric research based on Scopus data to give answers to the following questions: (1) What are the number and growth trends of publications related to mathematical modelling in higher education from 1980 to 2023? (2) Which countries have made outstanding contributions to research on mathematical modelling in higher education? (3) Which educational institutions are interested in publishing on mathematical modelling in higher education? (4) What are the main sources of publications on mathematical modelling in higher education? (5) Who are the authors with the most publications in research on mathematical modelling in higher education? (6) What are the research trends in Mathematical Modelling in higher education?

2. METHOD

Bibliometric analysis is a method of collecting data to analyze and search for information about scientific publications and citations. This method was first used in 1969 by Pritchard (1969), and is gradually becoming a method used by many scientific researchers when giving an overview of a certain research problem, as well as identifying research gaps to create new research directions (Mongeon & Paul-Hus, 2016). We use Scopus as our research data source, because, for the social sciences, Scopus and Web of Science are the two main reference sources. Moreover, compared to Web of Sciences, Scopus has the advantage of coverage in all research fields, number of journals, number of documents in many different languages (Mongeon & Paul-Hus, 2016).

We collected data using advanced search algorithms and appropriate search operators in the Scopus database. The detailed process is as follows:

Step 1: Identification

We used the main keyword as "Mathematical modelling", and similar phrases such as "realistic modelling", "models and modelling perspective", "socio–critical modelling". These keywords were combined with the keyword of educational level that the research is aiming at, which is higher education ("higher education" OR university OR college OR "tertiary education"). We started searching in the abstract, keywords, and titles of full-text publications in English on Scopus to find publications on mathematical modelling in higher education. The data query string is presented specifically below:

> TITLE-ABS-KEY (("modelling competenc*" OR "Mathematical modelling" OR "Realistic modelling" OR "models and modelling perspective" OR "socio-critical modelling" OR "epistemological modelling") AND (teach* OR learn* OR educat*) AND ("higher education" OR university OR college OR "tertiary education")) AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "bk")) AND (LIMIT-TO (LANGUAGE, "English"))

With the above search command statement, we obtained 619 publications (data collected on April 16, 2024).

Step 2: Screening

In this step, we reviewed the dataset again and selected to download and export it as a CSV file containing information about titles, keywords, abstracts, doi, etc. for the 619 publications obtained in Step 1. At the end of Step 2, we obtained an Excel file containing complete summary information about publications on mathematical modelling in higher education from 1980 to 2023.

Step 3: Eligibility

In this step, we first agreed on the screening criteria, selecting only publications related to mathematical modelling activities in higher education. Then, we read and screened the data based on information about titles, abstracts, and keywords. We eliminated publications not related to the context of higher education research, or not using mathematical modelling in education and publications using mathematical modelling to study a certain economic or social issue, such as publications of Elena, Morales and colleagues (Elena et al., 2022; Morales et al., 2023). As a result, we eliminated 348 publications and retained 271 publications as a basis for research. We conducted an initial analysis using tools provided by Scopus to collect additional information about authors, affiliations and journals, and extracted information from the analysis results in CSV and Bibtext files.

Step 4: Included

In this step, we mainly used Bibliometrix and VOSviewer software to analyze the above 271 publications to find answers to the research questions raised in the Introduction section. In addition, we also used Microsoft Excel software in our research to analyze some statistical results and synthesize data. Figure 1 records our data screening process according to the PRISMA diagram.

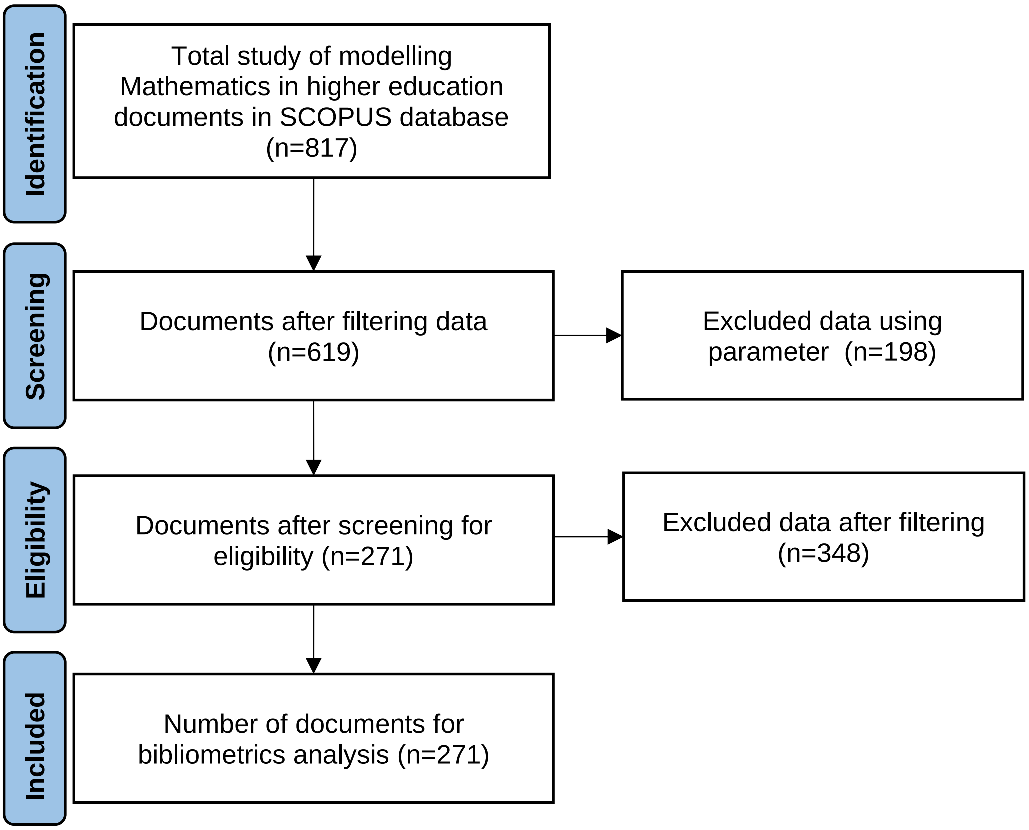

Figure 1. Steps for data screening in accordance with PRISMA diagram

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Number of publications and growth trends

General information on the collection such as number of publications, authors, citation index, and document type is presented in Table 1. The statistical results in Table 1 reveal that the first publication on this topic was published in 1980. From 1980 to 2023, a total of 271 publications were published in 142 different sources with an annual growth ratio of 7.34%. The total number of citations of the entire collection is 1261 and the average citation index per document is nearly 4.7. The publications in the collection used 6775 references, so each publication in the collection used an average of 25 references. In the collection, there are a total of 574 authors participating in publications on this topic; of which 87 authors have only one publication (authors of single – authors docs). Among 271 publications in the collection, 91 were published by 01 author (single-authored docs), accounting for 33.6%; the average collaboration ratio among authors (co-authors per document) was 2.38, meaning that, on average, less than 3 authors collaborated with each other in a publication. The international co-authorship ratio was nearly 9.6%. The authors used 643 keywords in their publications in the collection. According to our method of searching for data sources on Scopus, out of 271 publications in the collection, 115 were published in the form of articles; 97 were conference proceedings, the remaining 47 were published in the form of book chapters and 12 publications were books.

Table 1. General information on the dataset

Description	Results
Timespan	1980:2023
Sources (Journals, Books, etc)	142
Documents	271
Annual Growth Ratio %	7.34
Document Average Age	9.93
Average citations per doc	4.653
References	6775
DOCUMENT CONTENTS	
Keywords Plus	905
Author's Keywords	643
AUTHORS	
Authors	574
Authors of single-authored docs	87
AUTHORS COLLABORATION	
Single-authored docs	91
Co-Authors per Doc	2.38
International co-authorships %	9.594
DOCUMENT TYPES	
Article	115
Book	12
Book chapter	47
Conference paper	97

The growth trend in the number of publications and the cumulative number of citations per year of the collection is shown in Figure 2. In general, the research trend on this topic in the period 1980 - 2023 is unstable. Based on the number of published researches in each year, we divided the authors' research process into 3 stages. In the period from 1980 to 2000, the number of publications related to mathematical modelling in higher education was generally insignificant, there was only 1 or no publication published each year, except in 1981 there were 02 publications. From 2001 to 2019, the number of publications published each year was more than 4 publications, but the growth trend was unstable. There were years with more than 15 publications such as 2008, 2011, 2015, 2015 and 2017; there were years with 10 publications but less than 15 publications such as 2003, 2012, 2013, 2018 and 2019; but there were years with less than 10 publications such as 2001, 2002, 2004, 2005, 2006, 2007, 2010, 2014 and 2016. In 2009 alone, there were no publications published on this topic. From 2020 to present, the number of publications published annually has increased, compared to previous years (over 15 publications), the year with the least publication is 2022, with 18 publications.

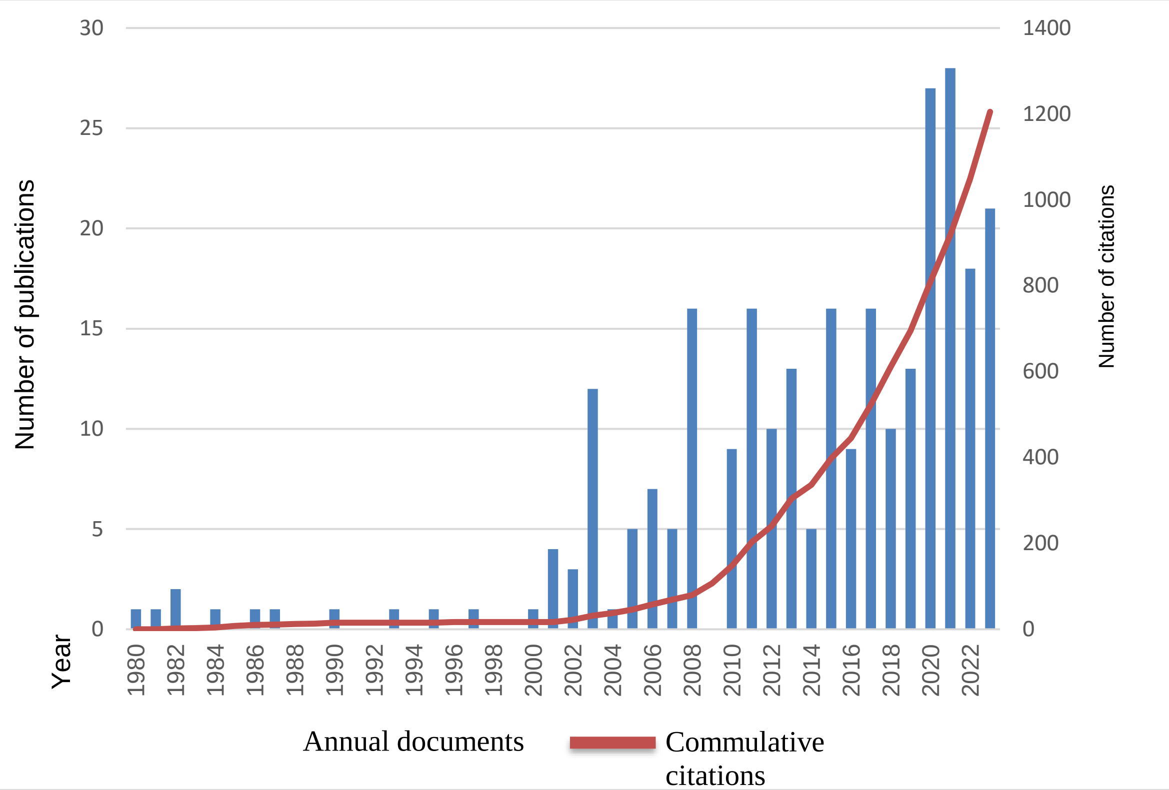

Figure 2. Cumulative number of publications and citations from 1980 to 2023 of research on modelling in higher education

3.1.2. Contribution by Nations

According to data from Scopus, 46 countries contributed to publications related to mathematical modelling in higher education between 1980 and 2023. Information on the eight countries that published the most is presented in Table 2; accordingly, these eight countries published 196 publications out of a total of 271 publications, accounting for 72.3%. The United States, with 63 publications, is the leading country in the ranking and it is also the country with the most citations with 215, accounting for a ratio of 3.4 when comparing to publications; it means that, on average, 1 publication in the country's bibliography has more than 3 citations. China is the only Asian country in the ranking, ranking second with 40 publications, and ranking fifth with 21 citations; Therefore, the citation ratio per publication in China is quite low at 0.5. Germany is the third country in the ranking with 23 publications, having the second-highest total number of citations at 120. The United Kingdom is the fourth country with 19 publications and 99 citations. Brazil and the Russian Federation both have 14 publications, but Brazil's citations are 14, while the Russian Federation has no publications cited. At the bottom of the ranking are Mexico and Australia with 12 and 11 publications, respectively.

Table 2. Top 8 countries leading in publishing publications on mathematical modelling in higher education

Rank	Country	TP	%	TC	%	TC/TP	SCP	MCP
1	United States	63	23.2	215	17.0	3.4	38	3
2	China	40	14.8	21	1.7	0.5	25	1
3	Germany	23	8.5	120	9.5	5.2	13	0
4	United Kingdom	19	7.0	99	7.9	5.2	6	1
5	Brazil	14	5.2	14	1.2	1.0	9	2
5	Russian Federation	14	5.2	0	0.0	0.0	1	1
7	Mexico	12	4.4	11	0.9	0.9	4	1
8	Australia	11	4.1	45	3.6	4.1	7	2

Note: TP: total publications, TC: total citations, TC/TP: citation per paper, SCP: Single country publications; MCP: Multiple country publications

Germany and The United Kingdom both have a TC/TP ratio of 5.2; these are the two countries with the highest TC/TP ratio in the top 8. This means that a publication of these two countries has an average of 5 citations. Australia and The United States are the next countries with TC/TP ratios of 4.1 and 3.4 respectively. Brazil is the country with a TC/TP ratio of 1.0, with the number of publications and the number of citations as 14. Mexico and China both have TC/TP ratios of less than 1.0. Russia is the country with 14 publications with no citation. The United Kingdom has 19 publications published during this period with 99 citations, TC/TP value of 4.1, the third-highest in the Top 8, of which, the publication 'Recognizing constructs within mathematical modelling' alone has 45 citations. In general, these publications all address the assessment of students' cognitive development of mathematical modelling through experiences in specific courses (Blum & Leiß, 2007; Haines & Crouch, 2001; Haines et al., 2007; Taylor et al., 2008).

It is very interesting point that among the 8 countries that publish the most publications on this topic, Germany publishes independently without any collaboration with other countries; while the remaining 7 countries have collaboration between scientists in different countries when publishing. Although, this collaboration is quite small, with only 1 to 3 publications; The United State of America is the country with the most collaboration in publishing on modelling in higher education, with 3 publications, in the collection.

3.1.3. Contribution by Institutions

From the Scopus data source of the collection, there are up to 160 educational institutions participating in publishing publications on mathematical modelling in higher education in the period from 1980 to 2023, however, the number of publications published by each institution is quite small, with up to 99 institutions releasing only 1 publication during this period. Table 3 shows the top 8 educational institutions with the number of authors publishing 04 publications or more. Tecnológico de Monterrey of Mexico is leading institution, with 8 publications and a total of 24 citations. This is also the total number of citations of Universität Kassel in Germany, although this institution only has 6 publications. Although the United States of America is the leading country in the top 10 countries in Table 2, only 1 institution, Purdue University, appears in Table 3, with 4 publications. However, this institution has the highest number of citations, with 87; Models and Modelling in Engineering education: Designing experiences for all students of this institution alone contributed 74 citations. Six out of eight institutions in Table 3 are all in the top countries with many publications, only Universitetet of Agder and Universitat Autònoma de Barcelona have 4 publications, however, Norway and Spain are not in the top 08 countries with many publications.

Table 3. Top 8 institutions with the most publications

Rank	Affiliation	Country	Total Publications	Total citations
1	Tecnológico de Monterrey	Mexico	8	24
2	Universität Kassel	Germany	6	24
3	Universidade Federal de Ouro Preto	Brazil	5	21
3	Universitetet of Agder	Norway	5	36
5	Purdue University	USA	4	87
5	Ulster University	UK	4	13
5	Universitat Autònoma de Barcelona (UAB)	Spain	4	47
5	The University of Queensland (UQ)	Australia	4	30

3.1.4. Journals publishing

The researches in the entire bibliography were published in 142 sources, the top 10 most prominent publishing sources are shown in Table 4, including 01 Book series, 04 conference proceedings and 05 journals, of which, there are 3 sources with the number of publications over 10, which are the book series: International Perspectives on the teaching and learning of mathematical modelling with 27 publications; the journal: International Journal of Mathematical Education in Science and Technology with 13 publications and the Journal of Physics: Conference Series with 11 publications. There are 02 journals in Q1: Teaching Mathematics And its Applications publishing 9 publications with 108 citations and ZDM - Mathematics Education publishing 6 publications with 43 citations.

Table 4. Top 10 publishing sources

Rank	Sources	Type	TP	TC	Scopus Quartiles	CiteScore 2023*	SJR 2023
1	International Perspectives on the Teaching and Learning of Mathematical Modelling	Book series	27	86	-	-	-
2	International Journal of Mathematical Education in Science and Technology	JN	13	69	Q2	3.3	0.634
3	Journal of Physics: Conference Series	CP	11	23	Q4 Discontinue from 2020	1.2	0.180
4	Teaching Mathematics And its Applications	JN	9	108	Q1	2.4	0.883
5	Primus	JN	8	19	Q3	1.6	0.351
6	Asee Annual Conference and Exposition, Conference Proceedings	CP	7	10	-	-	-

Rank	Sources	Type	TP	TC	Scopus Quartiles	CiteScore 2023*	SJR 2023
7	Acm International Conference Proceeding series	CP	6	4	-	1.5	0.253
8	Zdm - Mathematics Education	JN	6	43	Q1	6.4	1.102
9	Asee Annual Conference Proceedings	CP	5	55	-	-	- (information displayed in 2007)
10	Eurasia Journal of Mathematics, Science and Technology Education	JN	5	31	Q2	4.3	0.451

**: Information updated from Scopus on June 12, 2024*
CP: Conference Proceeding, JN: Journal

We found that the total number of publications published by The Top 10 in Table 4 is 97, accounting for nearly 35.5% of the total number of publications in the entire dataset. In addition to the 4 sources at numbers 1, 6, 7 and 9 in Table 4 that are not ranked, the remaining 6 sources are all ranked journals; there are 02 journals, Teaching Mathematics And its Applications, Zdm - Mathematics Education, ranking Q1 in 2023. Zdm - Mathematics Education is also the source with the highest CiteScore index of 6.4 and SJR index of 1.102 in Table 4.

3.1.5. Contribution by authors

Table 5 shows the top 5 authors with the most publications on modelling in higher education. All 5 authors contributed 4 publications to the collection, however, the number of publications and the total number of citations were different. Galbraith P ranked first with 4 publications and 29 citations, Blum W ranked second with 21 citations. Orey DC and Rosa M ranked third because they both had 19 citations, both of them also published their first publication on this topic in 2016. Although Houston K also had 4 publications, this author ranked fifth because the citation index was 13, though this author published quite early, in 2003.

Table 5. Top authors with the most publications

Rank	Author	Institution/Country	TP	TC	TC/TP	Py_start
1	Galbraith P	University of Queensland, Brisbane, Australia	4	29	7.25	2007
2	Blum W	University of Johannesburg, Germany	4	21	5.25	2003
3	Orey DC	Universidade Federal de Ouro Preto, Brazil	4	19	4.75	2016
3	Rosa M	Universidade Federal de Ouro Preto, Brazil	4	19	4.75	2016
5	Houston K	University of Leeds, United Kingdom	4	13	3.25	2003

Note: TP: total publications, TC: total citation, TC/TP: citation per paper

It is noteworthy that Houston K is the author of all 4 publications published in 2003 and all appeared in the same publication, the Mathematical modelling series, ICTMA 10 and ICTMA11 editions (Lamon et al., 2003; Ye et al., 2003). From 2003 to now, there has been no record of Houston K's publication on this topic. Orey DC and Rosa M both collaborated to publish 4 publications on this topic from 2016, 2017, 2018 and 2022; the latest publication published by these two authors is The mathematical teaching and learning process through mathematical modelling: educational change in Latin America in 2022, with no citations yet (Rosa et al., 2022).

3.1.6. The most influential articles

Table 6 shows the list of the 11 most influential publications out of a total of 271 publications in the bibliography, arranged by the number of citations from 21 to 74, including 3 books, 2 conference proceedings and 6 articles. The publication with the most citations is “Models and Modelling in Engineering Education: Designing Experiences for All Students” by author Zawojewski, published in 2008 with 74 citations (Zawojewski et al., 2008). The article “Mathematical modelling as bridge between school and university” by author Kaiser, Schwarz, is following, with 59 citations (Kaiser & Schwarz, 2006). There are 2 articles with the lowest number of citations in this top: “Study and research courses and mathematical modelling in the natural sciences university teaching” and “To assess students' attitudes, skills and competencies in mathematical modelling” with 21 citations (Farràs et al., 2011; Lingefjärd & Holmquist, 2005). Among these 11 publications with the highest number of citations, seven out of eight publications are published in sources with a 2023 ranking index of Q1, much higher than the publishing year of publication.

Table 6. Top publications with highest citations

Rank	Document Title (DOI)	Source Title	TC	Type	H-index/ Q2023	APA Citation
1	Models and Modelling in Engineering Education: Designing Experiences for All Students (10.1163/9789087904043)	Elsevier	74	Book	-	(Zawojewski et al., 2008)
2	Mathematical modelling as bridge between school and university (10.1007/BF02655889)	ZDM - International Journal on Mathematics Education	59	Article	66/Q1	(Kaiser & Schwarz, 2006)
3	Introduction to SCALE-UP: Student-centered activities for large enrollment university physics	ASEE Annual Conference Proceedings	54	Conference Paper	44	(Beichner et al., 2000)
4	Recognizing constructs within mathematical modelling (10.1093/teamat/20.3.129)	Teaching Mathematics and its Applications	45	Article	22/Q1	(Haines & Crouch, 2001)
5	Do students attend to representational illustrations of non-standard mathematical word problems, and, if so, how helpful are they? (10.1007/s11251-014-9332-7)	Instructional Science	31	Article	89/Q1	(Dewolf et al., 2015)
6	Mathematical modelling in science and mathematics education (10.1016/j.cpc.2010.05.021)	Computer Physics Communications	28	Conference Paper	209/Q1	(Teodoro & Neves, 2011)

Rank	Document Title (DOI)	Source Title	TC	Type	H-index/ Q2023	APA Citation
7	Mathematics in nature: Modelling patterns in the natural world	Mathematics in Nature: Modelling Patterns in the Natural World	27	Book	25/Q1	(Adam, 2011)
8	What is mathematical modelling? Exploring prospective teachers' use of experiments to connect mathematics to the study of motion (10.1007/BF03217449)	Mathematics Education Research Journal	27	Article	41/Q1	(Carrejo & Marshall, 2007)
9	A Concrete Approach to Mathematical Modelling (10.1002/9781118032480)	A Concrete Approach to Mathematical Modelling	22	Book	-	(Mesterton-Gibbons, 2011)
10	Study and research courses and mathematical modelling in the natural sciences university teaching (10.5565/rev/ec/v29n3.519)	Ensenanza de las Ciencias	21	Article	22/Q2	(Farràs et al., 2011)
11	To assess students' attitudes, skills and competencies in mathematical modelling (10.1093/teamat/hri021)	Teaching Mathematics and its Applications	21	Article	22/Q1	(Lingefjärd & Holmquist, 2005)

3.1.7. Keyword Analysis

The keyword network is created using data from publications relevant to ‘mathematical modelling’, ‘higher school’. We use VOSviewer software to analyze this network, including the 67 most popular keywords, which appear in at least 4 publications. Data is retrieved from the Scopus database with publications that have at least one of the phrases in the title, abstract, or keywords. Each keyword is represented by a node, and the association between the keywords is shown by lines with a thickness proportionate to the degree of association between them, which is determined by the number of times they appear together. Synonyms and plurals such as ‘mathematical modeling’, ‘mathematical modelling’, ‘project’, ‘projects’, ‘modeling tasks’, ‘modelling task’, etc. have been standardized to combine into a single node with the corresponding magnitude as the sum of the component nodes. Keywords that are related are grouped and color-coded together. This network is separated into three color clusters: red, blue, and green, respectively.

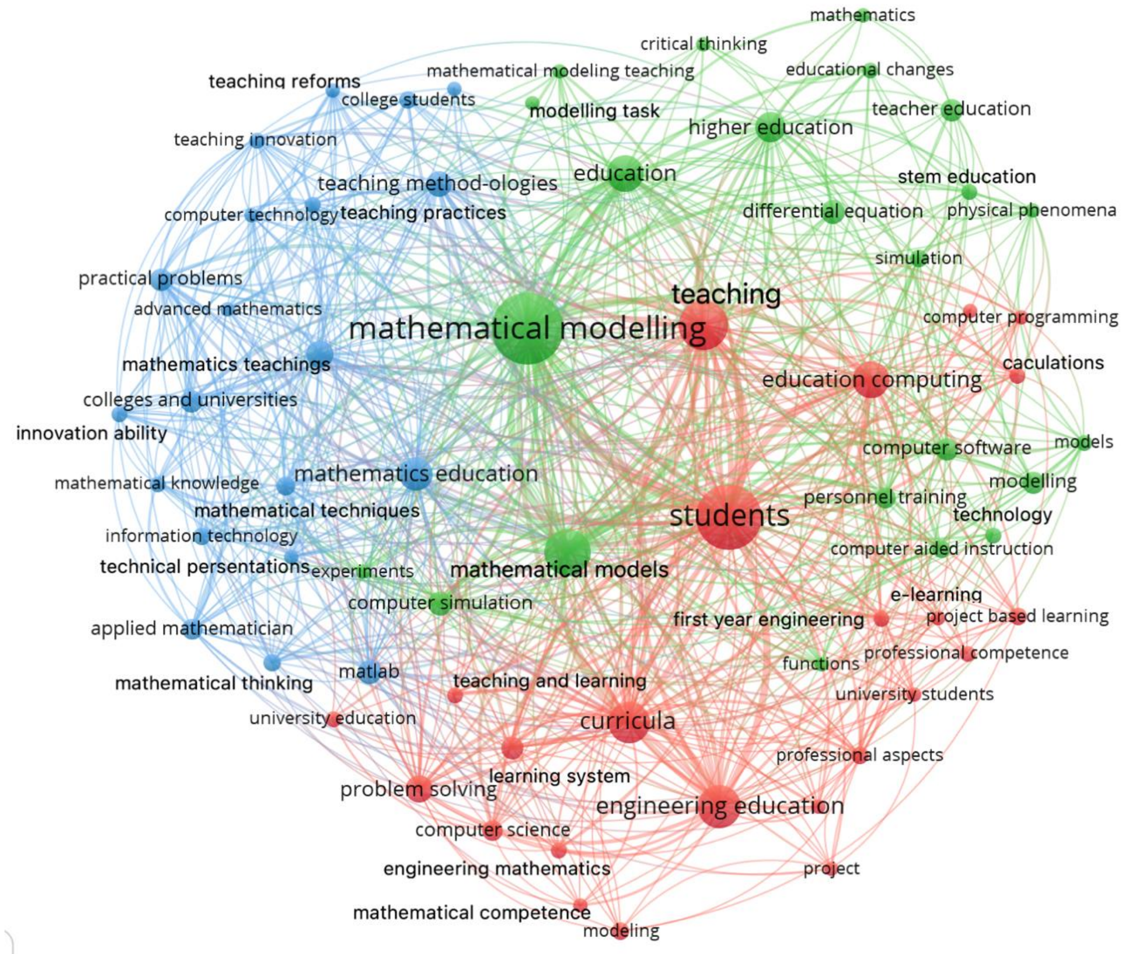

Figure 3. Co-occurring keyword network of 67 most popular keywords, appearing together in at least 4 publications (Image created by VOSviewer)

Based on the colors and the corresponding keywords, we identify 03 main trend topics on mathematical modelling in higher education from 1980 to 2023 as follows:

The Red cluster: includes 24 keywords (see Table 7), with the most outstanding keywords being ‘students’, ‘engineering education’, ‘teaching’, ‘mathematical modelling’, ‘education computing’ and ‘curricula’. This color cluster denotes the tendency to use computer technology and programming in the mathematical modelling curriculum for engineering university students.

Table 7. Frequency of occurrences of red cluster’s keywords

No	Red cluster	Occurrences	Total link strength
1	Students	75	331
2	teaching	42	209
3	engineering education	34	141
4	curricula	31	170
5	education computing	25	142
6	modelling	15	35
7	problem solving	13	57
8	learning systems	9	38

No	Red cluster	Occurrences	Total link strength
9	computer science	8	32
10	professional aspects	6	34
11	project based learning	6	17
12	calculations	5	30
13	engineering mathematics	5	17
14	first-year engineering	5	34
15	professional competence	5	12
16	teaching and learning	5	25
17	university education	5	19
18	computer programming	4	20
19	data collection	4	22
20	e-learning	4	21
21	its applications	4	12
22	mathematical competence	4	14
23	project	4	13
24	university students	4	21

This trend covers various aspects of the application of computer technology and programming to education, particularly in the fields of engineering and mathematics. It ranges from online learning, curriculum development, to professional skills training and problem-solving for undergraduates. Numerous studies in this period focused on clarifying how math is taught to engineering students, notably the use of modelling, so that learners comprehend the meaning of math as a valuable tool to address problems in everyday life as well as problems in other courses (Lopes & da Silva Reis, 2022; Wong et al., 2022). Engineering students must engage in mathematical modelling assignments to reinforce their mathematical understanding by applying it to real-world challenges and design situations (Merck et al., 2021; Ramírez-Sánchez et al., 2023; Rogovchenko & Rogovchenko, 2022). The teaching of mathematics in technical institutions should emphasize on the use of technological models, which can be online modules, so that students are placed in a real-world setting, using digital tools to solve, and thereby developing mathematical skills. Many studies suggest that studying courses in Physics, Construction, Economics, and Business Administration through the process of mathematical modelling and programming tools has helped students have a higher level of mathematics, as well as skills to apply mathematics to solve specialized problems (Barrera et al., 2023; Eyrikh et al., 2021; Fontana & Groenwald, 2023; Megowan-Romanowicz et al., 2023; Pospiech & Fischer, 2021; Tugashova et al., 2022).

Green cluster: Includes 23 keywords (see Table 8), with the most outstanding keywords being ‘mathematical modelling’, ‘mathematical model’, and other keywords such as ‘education’, ‘higher education’, ‘computer simulation’, ‘modelling’. This color cluster denotes to the trend of mathematical modelling teaching in universities, as well as the use of technology in modelling teaching and STEM education.

Table 8. Frequency of occurrences of green cluster's keywords

No	Green cluster	Occurrences	Total link strength
1	mathematical modelling	92	311
2	mathematical model	38	203
3	Education	25	111
4	higher education	16	77
5	computer simulation	11	61
6	differential equation	10	26
7	computer software	9	37
8	Modelling	9	24
9	teacher education	9	14
10	personnel training	8	33
11	Computer aided instruction	6	26
12	Simulation	6	26
13	educational changes	5	22
14	Models	5	26
15	stem education	5	23
16	technology	5	15
17	critical thinking	4	10
18	Experiments	4	30
19	Functions	4	27
20	mathematical modelling teachings	4	20
21	Mathematics	4	9
22	modelling task	4	3
23	physical phenomena	4	24

Mathematical modelling is undeniably important in other undergraduate subjects. However, optimizing mathematical modelling, using the idea of modelling in studying mathematics at university, or using mathematical tools in other subjects is a difficult task for both students and teachers. As a result, many studies in this period focused on analyzing the need to include mathematical modelling ideas in mathematics teaching in universities; pointing out the difficulties lecturers face in conducting modelling teaching activities; and discussing university mathematics teaching methods based on modelling ideas (Hernandez-Martinez et al., 2021; Ledder, 2022; Xu, 2021). The teaching of mathematics at universities must be modified to emphasize the practicality and use of multimedia technology, computer technology, and network resources to increase efficiency (Li, 2023; Molina-Toro et al., 2022). Many studies show that one strategy to increase the quality of modelling teaching is to employ multimedia computers in modelling, promoting students' active engagement in classroom activities and therefore boosting their modelling competence (Zuo, 2021). Alternatively, organizing modelling classes in conjunction with teaching advanced mathematics, calculus, linear algebra, geography, and modelling contests (Hitt & Dufour, 2021; Méndez-Romero et al., 2021; Ramirez-Montes et al., 2023; Zhou et al., 2023) may increase students' math and problem-solving abilities. Another aspect of mathematical modelling that has attracted much interest in recent times is the use of mathematical modelling in STEM majors (González-Peña et al., 2021). This is perfectly congruent with the teaching orientation that combines Science, Mathematics, Engineering, and Technology in this STEM teaching model.

Blue cluster: Includes 20 keywords (see Table 9), with the most outstanding keywords being 'mathematics education', 'mathematics teaching', 'teaching methodologies', 'practical problems', 'Matlab', 'teaching innovation', 'information technology', 'applied mathematician'. This color cluster denotes to the trend of mathematical modelling teaching methods and the use of information technology to teach mathematical modelling in teacher training programs. This trend includes aspects of the teaching and learning of mathematical modelling, the innovation of teaching methods, as well as the use of information technology and Matlab tools to solve practical problems and develop mathematical thinking skills for students in pedagogical universities.

Table 9. Frequency of occurrences of blue cluster's keywords

No	Blue cluster	Occurrences	Total link strength
1	mathematics education	21	81
2	mathematics teachings	14	76
3	teaching method-ologies	12	69
4	Matlab	10	42
5	Colleges and universities	9	45
6	practical problems	9	63
7	applied mathematician	8	36
8	mathematical techniques	7	50
9	college students	6	24
10	information technology	6	34
11	mathematical thinking	6	27
12	innovation ability	5	31
13	mathematical knowledge	5	28
14	teaching innovation	5	38
15	teaching practices	5	42
16	advanced mathematics	4	33
17	computer technology	4	32
18	teachers'	4	10
19	teaching reforms	4	30
20	technical presentations	4	27

Allowing students to engage in mathematical modelling classes and courses is one strategy to help them enhance their mathematical modelling skills. As a result, academics are particularly interested in pedagogical students who will become teachers. This research trend focuses on courses and design projects on mathematical modelling tasks for pedagogical students, particularly mathematics pedagogical students (Kim et al., 2021; Villa-Ochoa et al., 2021). Or develop tests to assess pedagogical students' modelling skills, offering strategies to innovate the way modelling teaching activities are organized at pedagogical universities (Asempapa & Sastry, 2021; Wess et al., 2021). These research results show that, if teachers and students have adequate resources and opportunities to participate regularly in mathematical modelling activities, there will be a significant positive change in students' interest in and motivation to learn mathematical modelling, as well as develop their ability to solve modelling tasks (Durandt, 2021). The experience of mathematics teachers at industrial facilities before teaching mathematics in their classrooms helps them understand the process of designing mathematical modelling activities and can pose real-world problems to their students. This helps the students see the connection between mathematics and working activities in later industries and fosters a positive attitude toward mathematics (Haj-Yahya & Klieger, 2023).

To confirm the new study direction, we did an analysis of the author's keywords in the most recent 5-year period (2018-2023) of the collection using Biblometrix software, and the results are given in Figure 4. During this period, 15 keywords that were present in 03 or more publications includes: ‘technology’, ‘professional competence’, ‘preservice teachers’, ‘teaching methods’, ‘critical thinking’, ‘college mathematics’, ‘mathematical modelling’, ‘university teching’, ‘modelling’, ‘higher education’, ‘teacher education’, ‘project’, ‘mathematics education’, ‘project – based learning’,‘differential equations’.

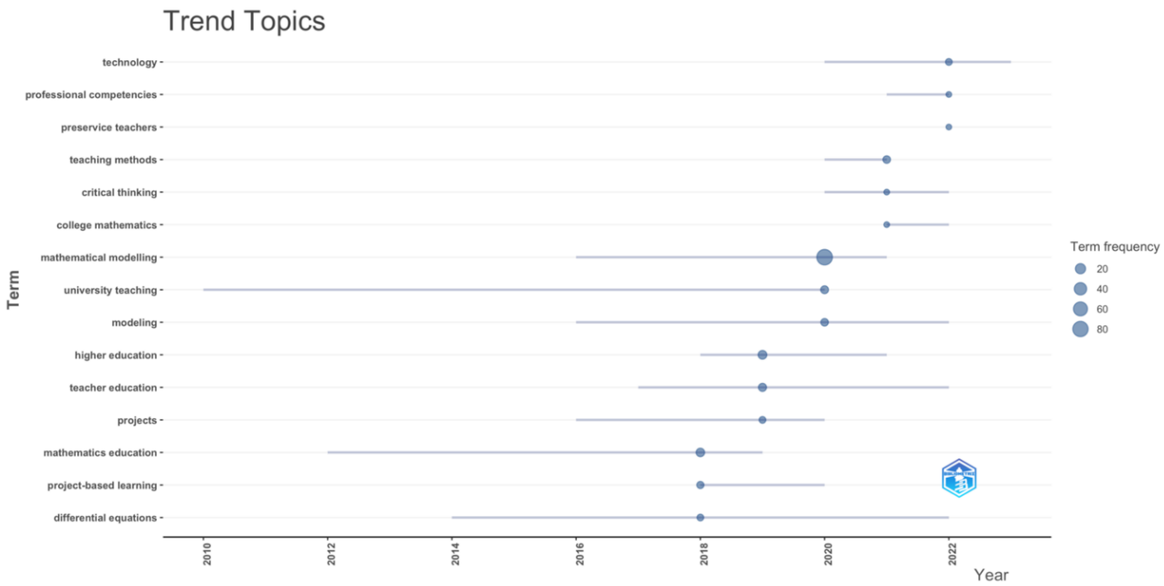

Figure 4. Trend topics from 2018 to 2023

The keywords that appear in the analysis of “Trend topic” in Figure 4 are also the outstanding keywords that appear in Figure 3 and match to the research trend in the aforementioned color clusters.

3.2. Discussion

The study analyzed 271 publications published between 1980 and 2023 relating to the issue of mathematical modelling in higher education, producing an overall picture of the topics, authors, countries, and educational institutions contributing to the research topic. Since the first publication on mathematical modelling in 1980, there has been a tremendous increase in the scientific community’s interest in this issue, notably in the period from 2020 to the present. In 2021, there were 28 publications on mathematical modelling in higher education, making it the year with the largest number of publications on mathematical modelling so far (see Figure 2). In which, 10 publications focus on the use of multimedia approaches in teaching, particularly in the field of STEM. This reflects the increasing interest of the scientific community in this issue over the previous five years, as well as the necessity to educate pedagogical students with knowledge and skills before graduation.

Among 46 countries with publications on this issue, the United States leads with 63 publications and 215 citations (see Table 2). Table 2 includes countries such as China, Germany, the United Kingdom, Brazil, the Russian Federation, Mexico, and Australia. Interestingly, of these eight countries, only Russian Federation and Mexico have never hosted the ICTMA Conference - a conference on applied teaching and mathematical modelling held every two years since 1983. This is a forum to discuss all aspects of teaching and modelling applications in all disciplines and at all levels of mathematics education, from elementary school to universities and colleges. In 23 ICTMA conferences, the United States hosted three ICTMA conferences in 1993, 2003, and 2007; Germany hosted three in 1987, 2009, and 2021; the United Kingdom hosted four in 1983, 1985, 2005, and 2015; China hosted two in 2001 and 2019; Brazil hosted one in 2013, and Australia hosted two in 1997 and 2011 (Houston, 2003). Authors with most publications are listed in Table 5; Top higher education institutions with most publications are listed in Table 3. This also applies to the countries where the International Conference on ICTMA Modelling takes place.

The two institutions with the highest number of publications are Tecnológico de Monterrey (Mexico) and Universität Kassel (Germany), each with 24 publications related to this topic (see Table 3). Most publications are published in reputable journals, with Elsevier being the leading publisher. Notably, the book 'Models and Modelling in Engineering Education: Designing Experiences for All Students' published in 2008, has been cited 74 times. As of 2023, seven of the 11 sources publishing this material are in Q1 of the Scimago Journal Ranks rankings (see Table 4).

Analyzing trend topics in Figures 3 and 4 reveals that the keywords in Figure 4 correspond to the red, green, and blue nodes in Figure 3. After evaluating the publications with a large number of citations in Table 6, we conclude that the study subjects of interest for educational modelling in this time are:

The role of mathematical modelling

As illustrated in "A Concrete Approach to Mathematical Modelling", "Mathematics in Nature: Modelling Patterns in the Natural World", with various examples from daily activities such as the speed of driving a car through the tunnel, the number of workers to be recruited, the amount of goods bought at the supermarket,... Or explain natural phenomena mathematically, from rainbows to cobwebs, beehives, and mud cracks. These are foundational materials for students and experts in the social sciences, engineering, economics, and management, allowing readers to better comprehend and appreciate the application of mathematics (Adam, 2011; Mesterton-Gibbons, 2011).

Learning activities associated with students' professional practice

Zawojewski et al. (2008) provide open problem design and evaluation tools, promote cooperation between engineering and education, and improve the quality of technical education in “Models and Modelling in Engineering Education” to assist engineering students solve problems in complex environments, work in groups, and communicate effectively. The book explains how to include mathematical modelling tasks into a technical class, allowing students from various backgrounds to succeed. It also describes how pedagogical students use modelling to solve practical problems (Kaiser & Schwarz, 2006). “Study and Research Courses and Mathematical Modelling in the Natural Sciences University Teaching” (Farràs et al., 2011) emphasizes the relevance of mathematical modelling in first-year university courses, and proposes course design to assist students link mathematical concepts. Carrejo and Marshall (2007) in “What is Mathematical Modelling?” has developed mathematical models for students of math and science education, examining the idea of integrating mathematical models and physical phenomena.

Teaching methods and assessment of modelling

The use of mathematical modelling engages students through various physical scenarios. The SCALE-UP project reveals that students solve problems better, obtain greater results, have better attitudes, and are more satisfied with teaching (Beichner et al., 2000). Haines and Crouch (2001) in “Recognizing Constructs within Mathematical Modelling” analyze the efficiency of various teaching techniques at two UK universities. Teodoro and Neves (2011) studied the use of Modellus - a free tool on the Internet that allows students to create and explore mathematical models using differential functions and equations in high school and college courses. Dewolf et al. (2015) used illustrations to study students' abilities to apply ordinary knowledge to solve practical problems. Lingefjärd and Holmquist (2005) believe that peer assessment, homework and mathematical model surveys are effective tools to monitor and assess the attitudes, skills and competencies of pedagogical students in teaching mathematical models.

However, the research trend over the previous five years has begun to change (see Figure 4). If the research trends in 2018 are those related to the occurrence of 03 keywords, namely ‘mathematics education’ (10 times), ‘project-based learning’ (5 times) and ‘differential quations’ (4 times), emphasizing on the application of differential equations in project-based mathematics teaching, in 2019, those are placed by another 03 keywords, namely ‘projects’ (4 times), ‘teacher education’ (8 times), and ‘higher education’ (11 times), emphasizing on the research of teacher training projects at universities; In 2020, those are another 3 keywords with a huge difference in the number of occurrences, namely ‘mathematical modelling’ (84 times), ‘teaching university’ (7 times), and ‘modelling’ (6 times); In 2021, there 03 keywords are ‘teaching methods’ (6 times), ‘critical thinking’ (3 times) and ‘college mathematics’ (3 times); In 2022, the keywords are ‘technology’ (4 times), ‘professional competencies’ (3 times), and ‘preservice teachers’ (3 times). This demonstrates that the future research trend in the field of modelling in higher education must focus on training pedagogical capacity, using technology and techniques of pedagogical students, particularly math pedagogical students, to foster their modelling competence in general and personal competence in particular.

Based on the analysis of trend topics, we believe that although scientists' interest in mathematical modelling in higher education has significantly increased, the research directions related to this topic are dispersed and do not concentrate on particular topic groups, except the related topic phrase 'mathematical modelling', which also reflects the vastness and complexity of researches on mathematical chemical modelling; in the view of using mathematical tools to solve practical problems, related to undergraduates' career orientations. In-depth research on the application of mathematical modelling in particular fields and the design of training programs to enhance lecturers' and students' modelling competence are required in order to advance this research direction, as well as solve the problems that are still limited in the studies between 1980 and 2023; at the same time, it is vital to enhance research cooperation between organizations and countries to attain a common level of modelling competence among university students worldwide.

4. CONCLUSION

In this study, we conducted a bibliometric analysis using Scopus data to examine and present a thorough overview of mathematical modelling in higher education. This is the first bibliometric study of its kind. In this study, we conducted a bibliometric analysis using Scopus data to examine and present a thorough overview of mathematical modelling in higher education. This is the first bibliometric study of its kind. The collected data were analyzed using specialized software such as VoSviewer and Bibliometrix, which shed light on the overall picture of the development of the field of mathematical modeling research in higher education from 1980 to 2023.

The results show that the research trend of mathematical modeling in higher education has grown significantly, especially from 2020 to present. The growing interest in this field is reflected in the large number of scientific publications published in many reputable publishing sources; as well as the high citation level of the publications. Many training institutions from different countries and regions have contributed to this development. Most of the studies focus on clarifying the role of mathematical modeling; emphasizing the learning associated with students' professional practice through mathematical modeling methods; training teachers with mathematical modeling capacity to meet teaching requirements at all levels from preschool to high school.

Even though we have worked very hard to read, filter, and choose publications for our collection, as previous studies using the bibliometric method have shown, errors in the filtering process can result in the mistaken removal of publications related to the research topic or the inclusion of publications that are not really related in the analysis. At the same time, in the process of selecting input data, we only chose publications from the Scopus database written in English for analysis, so we may have missed some studies written in other languages, including those studying the development of the modelling competence of students and lecturers in universities; the teaching of mathematical models in universities outside of engineering and industry; students' beliefs and perceptions about mathematical modelling in the career field; the use of mathematical modelling in solving global problems such as climate change, sustainable and green development, information safety, etc. Furthermore, due to restrictions in the Scopus data source, there may be unstandardized information about the author's name, training institution, and country, which may alter our research findings.

Future bibliometric studies should be conducted based on more reliable data sources to ensure comprehensiveness. At the same time, expanding in-depth content studies is necessary to clarify current issues related to mathematical modeling. This will make an important contribution to improving the quality of training at the university level, meeting the needs of the development of educational science.

Declarations

Author Contribution : PNHN: Conceptualization, Visualization, Writing - original draft, and Writing - review & editing; NDN: Formal analysis, Methodology, and Writing - review & editing; LMC: Data curation, Supervision, and Validation; TTPT: Conceptualization, Writing - original draft, and Writing - review & editing.

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