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A Bibliometric Analysis on Sustainable Research in Mathematics Education

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Abstract

This study evaluates the trend of past research in mathematics education with the purpose of identifying research gaps and suggesting scopes for new studies. In respect to students' mathematical learning and achievement, this study specifically identifies the key contributors and the dominant themes in research pertaining to these areas. The study employs bibliometrics on Scopus database for a period of 23 years. Analysis using VOSviewer software included the publication-related metrics and science mapping to generate information on annual productivity, research areas, prominent publishing journals, authors, countries, and keywords. The findings confirm that the annual production of journal articles in the English language in mathematics education has been on an increasing trend since 2000. However, United States has been making significant contributions to the publications, which has limited the research to problems and difficulties specific to that nation. The findings also point to underlying problems, such as lack of knowledge and resources in some nations, including Malaysia. The study urges increased international collaboration in research as well as more publications from less prominent countries. Furthermore, instead of merely presenting numerical findings, mathematics educators and researchers need to carry out in-depth qualitative investigations that can enhance mathematics teaching and learning, and student achievement. This study also demonstrates the need for more research on equity and equality in mathematics education, which are crucial components of high-quality sustainable education.

Keywords: Network Maps, Scientific Publications, Similarity Visualizations, Quality Education, Vosviewer

Introduction

Mathematics education has undergone many transformations over the years influenced by changes in epistemology, introduction of new teaching methods, and the use of visual and technological tools. Regarding year 1968 as the beginning of modern scientific research, Inglis and Foster (2018) observed that mathematics education research experienced some major turning points since then. Among these are the declining interest in research related to geometry and space in the 1970s, and increased interest in research related to mathematical

problem solving in the 1980s and research related to social issues in mathematics teaching and learning in the 1990s. There was also a shift in the focus of mathematics education research from cognitive theories to social theories from 1990s to 2000s. In particular, the analysis by Inglis and Foster (2018), of English language articles from year 1968 to year 2015 revealed that topics or research interest pertaining to mathematics education included curriculum reform, equity, teaching approaches and the reformation of mathematics education around the world.

Meanwhile, from their analysis, Gokce and Guner (2021) found that the significant common areas of interest in mathematics education research are curriculum and curriculum reformation, policies, assessments, equity, problem solving in mathematics, affective factors, and motivation factors. It is quite difficult to have a universally agreeable direction for research in mathematics education because as of now research in mathematics education is still culturally, regionally, and technologically reliant. For instance, in some countries, gender equality is a cultural issue not an educational opportunity issue. Moreover, with the advancement of automated and technology-aided learning, and the emphasis on STEM (science, technology, engineering, mathematics) education and sustainable education, mathematics is not a stand-alone subject. As such, the evolution in mathematics education and in other stem subjects inadvertently influences the development in mathematics education research.

There has been little study of the trends in mathematics education research pertaining to students' learning and performance specifically. Thus, the present study uses a bibliometric approach to analyse patterns and identify trends in research in mathematics education, in these areas. The study has reviewed existing literature on mathematics education, in the past two decades, to discern the possible future research scopes for a sustainable mathematics education research, that can provide valuable and constructive inputs to academicians and researchers for quality mathematics teaching and learning. Bibliometric analysis is chosen instead of systematic literature review because, as said by Herfort et al. (2023), the latter is limited in terms of scope and adheres to specific set of methodologies. Moreover, systematic literature review is narrower in context, albeit providing in-depth analysis, because it synthesizes existing literature with a definite purpose. On the other hand, researchers found bibliometric analysis is quantifiable (e.g., AM et al., 2023; Fu et al., 2023) because it employs mathematics and statistics to determine the relationships of publications, contributors, themes, and countries for a particular area of research.

The research questions of this study are: (1) What have been the prominent themes or areas in mathematics education research pertaining to students' learning and achievement?; (2) Who are the prolific contributors to the mathematics education research pertaining to students' learning and achievement?; and (3) What is the direction of future research pertaining to students' learning of mathematics and achievement in mathematics? This study employs a bibliometric analysis because it provides precise and reliable information on the current state-of-art in mathematics education. This study differs from earlier bibliometric studies in that it focuses specifically on students' mathematics learning and their achievement. This is important because students' mathematics learning and mathematics achievement are testament of a successful teaching and learning process whereby sustainable mathematics education is evident through successful learning which is reflected by the students' achievement.

Literature Review

Past research revealed that students' learning of mathematics and their achievement in mathematics is influenced by many factors including the students' attitudes Mazana et al (2019), support from parents Wardat et al (2022), school environment Mazana et al (2019), library resources Wardat et al (2022) and use of virtual reality technologies (Su et al., 2022). The study by Mazana et al (2019) established significantly positive but weak correlation between students' attitude and their mathematics performance. The study also noted that the students' positive attitudes decreased as they progressed to higher level of mathematics such as moving from primary level to secondary level. On the other hand, Mazana et al (2019) found that students' low performance in mathematics is attributed by factors such as their learning strategies, lack of interest and poor time management. It is also a known fact that in the past few years there has been many studies on e-learning or digital learning due to the paradigm shift in education caused by the recent pandemic (e.g., Alabdulaziz, 2021; Irfan et al., 2020; Mamolo, 2022; Mulenga & Marbán, 2020; Yaniawati et al., 2020; Zuniga-Quispe et al., 2021).

With regards to students' mathematical ability, Muhammad and Angraini (2023) found that most studies involved augmented reality, mathematics literacy, critical thinking, and technology. Bakker et al (2021) found that the eight pertinent themes of research pertaining to mathematics education, not listed in order of importance, are: (1) affect, (2) assessment, (3) equity, (4) goals, (5) practical applications, (6) professional development, (7) teaching practices, and (8) technology. However, according to Daud et al (2020), there is lack of research on the perception of mathematics, students' mathematical skills and mathematics achievement, suggesting for more studies involving students and their learning of mathematics. Cai and Mamlok-Naaman (2020) commented that for research in mathematics education to have significance, it should provide a better understanding of the teaching and learning of mathematics. The authors stressed the importance of research containing clearly defined constructs, measures, and methodologies, and to be meaningful to the mathematics education community either theoretically or practically. In a nutshell, the findings and recommendations of earlier studies make it very evident that there are issues with mathematics learning that require further investigations.

Prior to the use of bibliometric analysis in educational research, there has been other types of empirical studies in mathematics education research. In their writing, Inglis and Foster (2018) mentioned few of the earlier empirical studies such as (Sierpinska and Kilpatrick, 1998; Hanna and Sidoli, 2002; Lerman et al., 2002). Sierpinska and Kilpatrick (1998) analysed papers published in a particular journal to identify the areas of research interest, research methods, and issues and concerns in mathematics education. Hanna and Sidoli (2002) identified research goals and orientations pertaining to mathematics education, and the evolution of research paradigms. Meanwhile, Lerman et al (2002) analysed the changes in the theories used by researchers, and the relationship between mathematics education and mathematics education research. In general, research in mathematics education in the past has typically focused on theories, topics or contents, geographical regions, gender, teachers' professional development and pedagogical aspects.

Bibliometric analysis has its origins in statistical bibliography such as studies by Lotka (1926), as cited in Danesh & Mardani-Nejad (2021) and by Bradford (1934, as cited in Danesh & Mardani-Nejad, 2021). The expansion of research and the growth of information technology which provided access to large databases gave rise to big scientometrics Danesh & Mardani-Nejad (2021) that evolved to bibliometric analysis as it is known today. The two main sources

of data for bibliometric analysis are the Scopus database (e.g., Julius et al., 2021; Muhammad & Angraini, 2023; Saefudin et al., 2023) and the Web of Science database (e.g., Cansiz Aktas, 2022; Dede & Ozdemir, 2022). Past bibliometric studies on mathematics education have focused on different areas or topics, and for different time periods (e.g., Gokce & Guner, 2021; Julius et al., 2021; Muhammad et al., 2023). The bibliometric analysis by Julius et al. (2021) aimed to establish the distribution pattern of published articles and trend of research, among others. They conducted data search from year 1980 to year 2020 and retrieved 12670 documents from the Scopus database using the keywords 'mathematics education' as the principal theme. They found that the research topics in the published articles are extensive and covered all the different domains of mathematics education.

Gokce and Guner (2021) conducted a bibliometric analysis on research in mathematics education from the year 1980 to the year 2019 using the Web of Science database. Their study identified four clusters of mathematics education research which are: (1) theoretical framework, (2) mathematics instruction, (3) concepts related to mathematics education, and (4) international assessments. In addition, it was found that the dominant themes from the year 1995 to year 2010 were curriculum and teacher factors while after the year 2010 research in mathematics education was more topic-specific. Muhammad and Angraini (2023) analysed 157 articles published between year 2011 and year 2022, obtained from the Scopus database, to determine prominent research topics pertaining to students' mathematical abilities. Meanwhile, the bibliometric analysis by Muhammad et al (2023) established the trend, from year 2016 to year 2022, in the usage of interactive media to teach mathematics, in Indonesia. Analysis of 442 documents retrieved from Google Scholar showed an increase in the usage of interactive media during the study period.

Review of literature indicates a need for more studies pertaining to students' mathematics learning and achievement because they are dependent on many contributing factors (e.g., Mazana et al., 2019; Su et al., 2022; Wardat et al., 2022). In addition, researchers found that there has been lack of studies in some areas of mathematics learning and achievement (e.g., Cai & Mamlok-Naaman, 2020; Daud et al., 2020). More importantly, students' mathematics learning and achievement are not identified as prominent research areas in the existing bibliometric analyses (e.g., Gokce & Guner, 2021; Julius et al., 2021; Muhammad & Angraini, 2023). This study attempts to fulfil the mentioned research gap by conducting a bibliometric analysis on existing literature to identify research scopes pertaining to students' mathematics learning and achievement.

Methodology

Data Source and Search Procedure

The bibliometric data from the year 2002 to year 2022 were extracted using the Scopus database. Scopus is a choice of database in bibliometric studies because it has extensive interdisciplinary coverage that provides pertinent and detailed bibliographic information on published academic articles, and data exported from Scopus can be easily analysed by many bibliometric software (Julius et al., 2021; Muhammad & Angraini, 2023; Saefudin et al., 2023). This bibliometric analysis uses VOSviewer to generate network maps of similarity visualizations (e.g., Julius et al., 2021; Muhammad & Angraini, 2023; Muhammad et al., 2023). Data search procedure is described in Table 1.

Search began with articles titled 'Mathematics' which yielded 42,663 results. Restricting the results to article-type documents reduced the number to 25,390 articles and further restricting the time frame from year 2000 to year 2022 (23 years) reduced the number to

18,668 articles. Confining the search to only articles in the English language reduced the number further to 16,984 articles. Then, refining the search to journal articles yielded a total of 16,748 articles comprising of 16,556 published articles and 192 articles in press, of which this study only included the published articles.

Table 1
Details of data search

Topic	Mathematics
Scope & Coverage	Database: Scopus Search field: Article title Time frame: 2000-2022 Language: English Source type: Journal Document type: Article
Keywords & Search String	Limited to "mathematics" or "mathematics education" or "mathematics achievement" or "mathematics learning" or "mathematics anxiety" or "mathematics performance" or "learning mathematics"
Date Extracted	15 August 2023
Record Identified & Screened	$n = 4{,}866$
Record Removed	$n = 0$
Record Included for Analysis	$n = 4866$

Since the study is concerned with students' learning, the keywords search, and screening were limited to "mathematics" or "mathematics education" or "mathematics achievement" or "mathematics learning" or "mathematics anxiety" or "mathematics performance" or "learning mathematics". The final number of data used in the analysis is 4866 published journal articles. Data was extracted in a single day that is on 15 August 2023 to avoid search errors (AM et al., 2023). The downloaded data was saved as .csv (comma summative value) files to be run in VOSviewer. VOSviewer is a free software that can be downloaded from https://www.vosviewer.com website. The saved file is opened using the open tab on the left-hand side of the VOSvievew screen as shown in Figure 1. After that, the selected analyses are run as discussed in the next section. VOSviewer can present the results of the analyses in tabulated form or in graphical form as visualization maps.

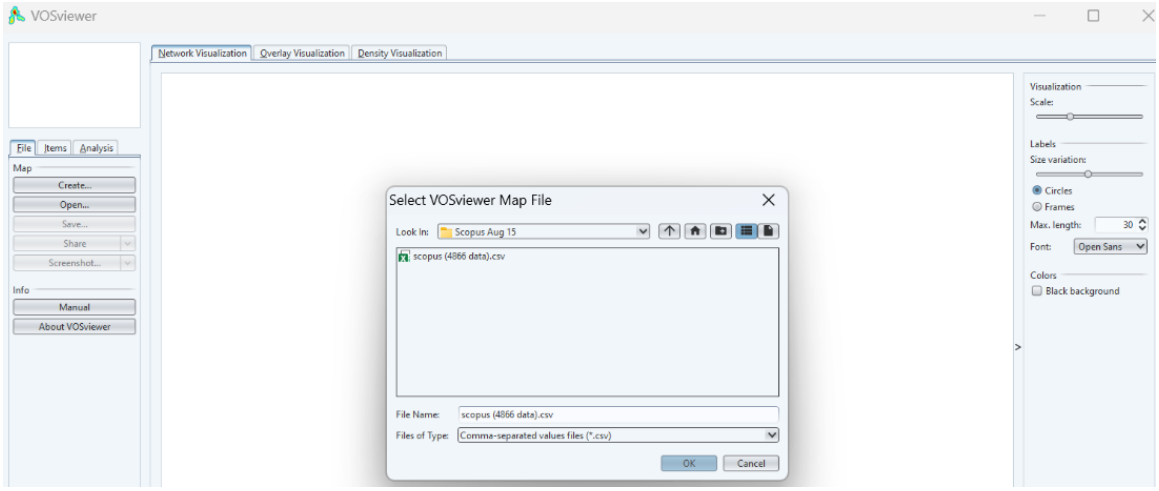

Figure 1
VOSviewer screen

Results

This section presents the results of analysis using VOSviewer for: (1) yearly productivity for the 23 years period (2000 – 2022), (2) publications by subject areas, (3) number of articles published in the different journals indexed in Scopus database, (4) trends of keywords including author keywords and index keywords, (5) highly cited articles, (6) publications from different countries, and (6) analysis of sponsorships.

Analysis of Yearly Productivity

Figure 2 shows the yearly productivity increased in the 23 years period indicating an ongoing interest in the research of students' learning of mathematics for the past two decades on an annual basis.

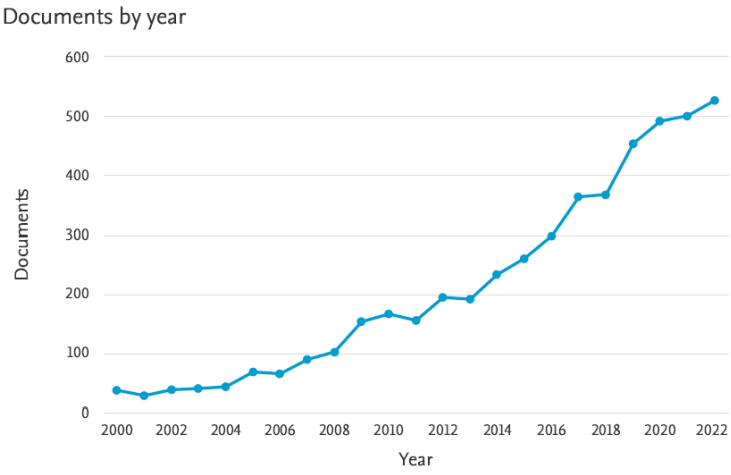

Figure 2: *Yearly productivity (2000 – 2022)*

Meanwhile, Table 2 shows the number and the percentage of publications on a five-year basis from the 4866 published journal articles. There is a notable increase in productivity from one five-year period to another particularly from 2010-2014 to 2015-2019.

Table 2
Number of publications for five-year periods

Years	Number of publications	Percentages
2000 – 2004	186	3.82%
2005 – 2009	477	9.80%
2010 – 2014	939	19.30%
2015 – 2019	1744	35.84%
2020 – 2022	1520	31.24%

Analysis of articles by subject area

Table 3 show the subject areas in which the 4866 journal articles are published. The five subject areas in which research articles are highly published are: (1) social sciences (44.2%), (2) psychology (14.2%), (3) mathematics (11.7%), (4) computer science (5.4%), and (5) arts and humanities (4.3%). Meanwhile, Appendix A shows the detailed information for the 'other' category.

Table 3
Percentages of publications by subject area

Subject area	Percentages
Social sciences	44.2%
Psychology	14.2%
Mathematics	11.7%
Computer science	5.4%
Arts and humanities	4.3%
Engineering	3.7%
Medicine	3.0%
Health professions	2.0%
Neuroscience	2.0%
Multidisciplinary	1.5%
Other	8.1%

Analysis of Journals of Publications

Table 4 displays ten journals with the highest number of published articles, in descending order. The top five journals with highest publications are: (1) Eurasia Journal of Mathematics, Science and Technology Education (99 articles), (2) International Journal of Science and Mathematics Education (92 articles), (3) International Journal of Mathematical Education in Science and Technology (88 articles), (4) Educational Studies in Mathematics (79 articles), and (5) ZDM Mathematics Education (67 articles).

Table 4
Number of publications by journals

Name of journal	Number of publications
Eurasia Journal of Mathematics, Science and Technology Education	99
International Journal of Science and Mathematics Education	92
International Journal of Mathematical Education in Science and Technology	88
Educational Studies in Mathematics	79
ZDM Mathematics Education	67
Plos One	52
Education Sciences	50
Learning and Individual Differences	50
Mathematics Education Research Journal	48
Frontiers in Psychology	46

Analysis of Keywords

Using VOSviewer, 12,048 keywords were identified out of which 1110 keywords met the threshold of occurring a minimum of five times. Of these, the top five keywords are: (1) mathematics (3,028 times), (2) mathematics education (1,158 times), (3) human (835 times), (4) humans (651 times), and (5) article (637 times), as shown in Table 5. Table 5 shows only the list of keywords that appear more than two hundred times. Figure 3 shows that the significant clusters are with the main keywords ‘mathematics’ (red cluster), ‘human’ (purple cluster), ‘article’ (blue cluster), ‘female’ (green cluster) and ‘achievement’ (yellow cluster).

Table 5
Number of occurrences of keywords

Keywords	Number of occurrences
Mathematics	3028
Mathematics education	1158
Human	835
Humans	651
Article	637
Female	563
Male	562
Child	422
Mathematics achievement	407
Education	391
Students	320
Learning	280
Teaching	269
Student	263
Achievement	249
Problem solving	229
Adolescent	206

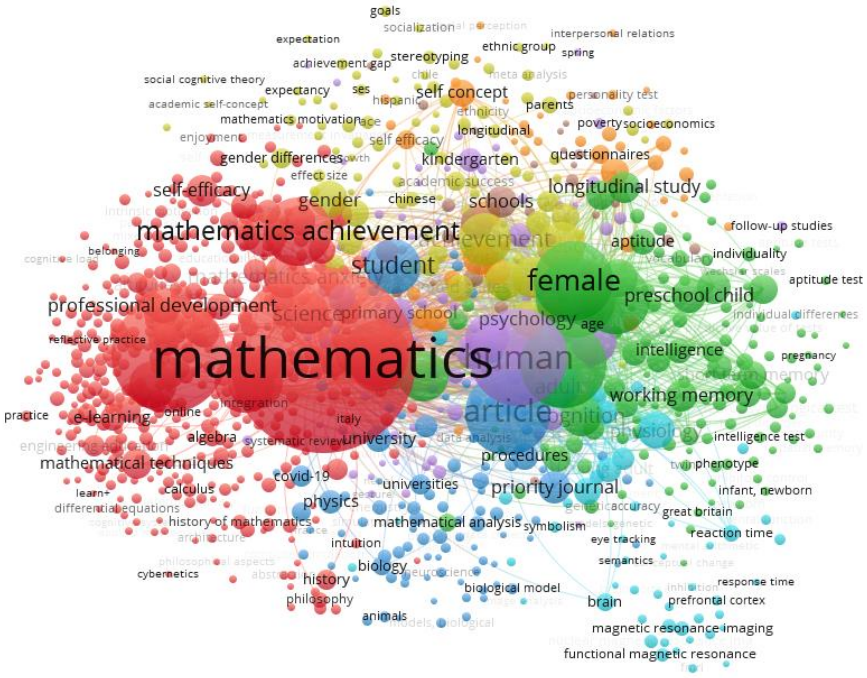

Figure 3
Trend of keywords

Further, this study identified 8,770 author keywords out of which 600 keywords met the threshold of occurring a minimum of five times. Of these, the top five keywords are: (1) mathematics (2,231 times), (2) mathematics education (1,103 times), (3) mathematics achievement (407 times), (4) mathematics anxiety (169 times), and (5) mathematics learning (156 times). This study also identified 4538 index keywords out of which 580 keywords met the threshold of occurring a minimum of five times. Of these, the top five keywords are: (1) mathematics (1,001 times), (2) human (834 times), (3) humans (651 times), (4) article (637 times), and (5) female (561 times).

Analysis of Articles

Table 6 shows ten of the most influential journal articles in terms of the number of citations. Although the highly cited articles involve different themes, indicating a broad spectrum of research, the ten most cited articles are at least a decade old. On the other hand, the top five highly cited articles since year 2018 are: (1) Stoet and Geary (2018) (455 citations), (2) Bano et al (2018) (151 citations), (3) Mulenga and Marban (2020) (143 citations), (4) Krukowski et al (2021) (136 citations), and (5) Namkung et al. (2019) (131 citations). The themes of these papers are gender, Covid-19 pandemic, and school level mathematics education.

Table 6
Ten most influential articles

Authors and year	Article title	Number of citations
Freeman et al. (2014)	Active learning increases student performance in science, engineering, and mathematics	4558
Bull & Scerif (2001)	Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory	1063
Else-Quest et al. (2010)	Cross-National Patterns of Gender Differences in Mathematics: A Meta-Analysis	895
Remillard (2005)	Examining key concepts in research on teachers' use of mathematics curricula	646
van Es & Sherin (2008)	Mathematics teachers' "learning to notice" in the context of a video club	623
Jordan et al. (2009)	Early Math Matters: Kindergarten Number Competence and Later Mathematics Outcomes	620
Stout et al. (2011)	STEMing the Tide: Using Ingroup Experts to Inoculate Women's Self-Concept in Science, Technology, Engineering, and Mathematics (STEM)	600
Good et al. (2012)	Why do women opt out? Sense of belonging and women's representation in mathematics	587
Diekman et al. (2010)	Seeking Congruity Between Goals and Roles: A New Look at Why Women Opt Out of Science, Technology, Engineering, and Mathematics Careers	574
Lindberg et al. (2010)	New Trends in Gender and Mathematics Performance: A Meta-Analysis	535

Analysis of Countries

This study identified 151 countries out of which 75 countries met the threshold of producing a minimum of five journal articles. With reference to Table 7, which displays the list of countries with at least one hundred publications, the five top countries are: (1) United States (1,685 journal articles), (2) United Kingdom (430 journal articles), (3) Australia (301 journal articles), (4) Turkey (251 journal articles), and (5) Canada (204 journal articles).

Table 7
Number of publications and citations by countries

Countries	Number of publications	Number of citations
United States	1685	54567
United Kingdom	430	11505
Australia	301	5972
Turkey	251	2152
Canada	204	6034
Germany	189	5537
South Africa	177	1357
China	165	2281
Spain	164	2121
Malaysia	145	1094
Indonesia	128	776
Netherlands	117	2281
Italy	102	1449
Sweden	101	952

Analysis of Sponsorship

Table 8 displays the list of the main sponsors for research in mathematics education and the number of publications sponsored by them. Apart from the Australian Research Council in Australia, the Economic and Social Research Council in the United Kingdom, and the Social Science and Humanities Research Council of Canada in Canada, the other seven agencies are in the United States.

Table 8
Number of publications by sponsorship

Sponsors	Number of publications
National Science Foundation	243
Institute of Education Sciences	123
U.S. Department of Education	113
Eunice Kennedy Shriver National Institute of Child Health and Human Development	71
National Institute of Child Health and Human Development	47
Australian Research Council	45
Economic and Social Research Council	33
Social Sciences and Humanities Research Council of Canada	32
National Institutes of Health	28
Directorate for Education and Human Resources	27

Discussion and Limitations of Study

This bibliometric analysis shows that the annual production of journal articles in the English language, in mathematics education, has been increasing from year 2000 to year 2022. United States is the main contributor to research in mathematics education be it in terms of the

number of the publications (1,685 articles) or the number of citations (54,567 citations). United States contributed 34.63% of the published journal articles from the total of 4,866 articles. United Kingdom is the second highest contributor both in terms of number of publications (430 articles) and number of citations (11,505 citations). Meanwhile, Australia is in the third place for the number of publications (301 articles) but Canada is in the third place for the number of citations (6,034 citations). In addition, United States provided the highest number of sponsorships whereby the top three funding sponsors are US-based agencies that is the National Science of Foundation, Institute of Education Sciences, and the U.S. Department of Education. These three agencies have sponsored a total of 479 or 9.84% of the published journal articles.

Table 9
Comparison of studies

	Gokce and Guner (2021)	Present study
Database	Web of Science	Scopus
Period	1980 – 2019 (40 years)	2000 – 2022 (23 years)
Top ten countries	United States Turkey England Netherlands Canada Australia Germany South Africa Spain China	United States United Kingdom Australia Turkey Canada Germany South Africa China Spain Malaysia

Table 9 shows the comparison of results in terms of the top ten publishing countries, in descending order, between Gokce and Guner (2021) and this study. United States holds the first place in both studies for the different time periods. United States was also found to be the highest contributor in the study by Yig (2022) who employed bibliometric analysis and social network analysis. These results validate that United States consistently has been publishing the highest number of articles for forty decades. Interestingly, Malaysia which is not in the top ten list of the study by Gokce and Guner (2021), is found to be in the tenth place in this study. It is likely that there are more publications in the last two decades from Malaysian researchers and their work are mostly published in Scopus indexed journals. However, Netherlands is not in the top ten list of this study although it ranked fourth in the previous study. Except for United States, Canada and Spain, the other countries are ranked differently in both studies. The primary reasons for the different ranking are the different time periods and different databases. The different search strings used in the two studies also contributes to the difference in the rankings.

The top five journals in terms of number of publications are: (1) Eurasia Journal of Mathematics, Science and Technology Education, (2) International Journal of Science and Mathematics Education, (3) International Journal of Mathematical Education in Science and Technology, (4) Educational Studies in Mathematics, and (5) ZDM Mathematics Education. In the study by Yig (2022), the five top journals are: (1) Educational Studies in Mathematics, (2)

International Journal of Science and Mathematics Education, (3) Mathematical Thinking and Learning, (4) Journal of Mathematics Teacher Education, and (5) Journal for Research in Mathematics Education. These lists are influenced by the scope of search, that is in this study the search was limited to mathematics learning and achievement whereas the study by Yig (2022) had a broader scope.

The study by Gokce and Guner (2021) showed different dominant research themes from year 1980 to year 2019. In the early 1990s, research was more student-centric whereas between year 1995 and year 2010 research focus shifted to curriculum and teacher factors. From 2010 onwards, research has included all stakeholders of mathematics education. Accordingly, the prevailing keywords during the different time periods changed. For instance, the focus of mathematics education research in the early 2000s was students' cognitive skills and domain-specific studies. Keywords such as achievement, conceptual knowledge and algebra shaped the intent and structure of the studies. After the year 2005, more emphasis was given to the teachers and therefore research centred around teacher education, and teacher development and quality. Research at this time also gave more weightage to algebraic thinking, mathematical thinking, and language and mathematics (Gokce & Guner, 2021).

This bibliometric analysis is domain specific whereby only articles pertaining to mathematics learning and achievement were included. However, this serves as one of the limitations because the search strings have limited the data extracted from Scopus database. There is a possibility that other documents pertaining to students' mathematics learning and achievement have been excluded in this study. To include all the keywords would have greatly increased the amount of extracted data and may provide an inundating amount of information from the analysis. One way to overcome this is to break down the analysis to smaller time periods with less domain specific search strings. The important themes identified in this study have been generated for a period of 23 years, and only in learning and achievement which yielded the keywords mathematics, mathematics education and mathematics achievement.

An important aspect of quality education is equity and equality. The recent health crisis has revealed the inadequacies and inequities of education systems, including access to technology, the environment, and misalignments between resources and needs (Schleicher, 2020) especially when students from the disadvantaged backgrounds were left behind in the urgent transition to digitalized learning. To ensure inclusive and equitable quality education for everyone, Dash et al. (2021) stressed that particular focus must be given to students who have constantly been excluded from even minimal educational opportunities. As said by Xiao (2021), equity in education cannot be discussed without discussing equality in education since causes of inequality have to be resolved first to ensure equity is achieved. However, this study shows that there has not been much research concerning equity and equality in mathematics education, suggesting for more research pertaining to these aspects.

Conclusion and Implications of Study

This study showed that research in mathematics education is highly significant, as evidenced by the rise in annual production of papers tracked in the bibliometric analysis. Before and after 2000, the United States was the leading contributor to the field of mathematics education research. This study found that 34.63% of the publications are from the United States, invariably making it the dominant player in determining the course of global mathematics education and research. In addition, United States is also the main sponsor of publications. However, there are underlying issues, such as a lack of knowledge and technology, that are specific to mathematics education and mathematics education research, in other

communities especially from the underdeveloped countries. As a result, it is imperative to have more contributions from other countries in future, to provide a more global perspective of the problems and difficulties that mathematics education faces. Since the concerns and challenges differ across different locations and situations, sustainable research in mathematics education must represent a global scenario rather than being community- or country-specific. To build long-term solutions that are both specific to the local context and transferable to larger communities of mathematics learners, educators, and researchers, there is a need for more collaborative but focused and in-depth study in the future.

The keyword analysis showed that research is centred around certain aspects such as mathematics, human and females. In order to achieve sustainable mathematics education that meets the needs of present mathematics learners, educators, and researchers without compromising the ability of the future mathematics learners, educators, and researchers to meet their own needs, there is a need to have studies in many other aspects of mathematics education. Therefore, sustainable mathematics education research should ensure inclusive and high-quality research in mathematics education that promotes educational and research opportunities for everyone. To attain quality mathematics education, it is necessary to conduct further in-depth study on pedagogy, instructions, and assessments. Since the difficulties in learning algebra, for example, may be different from those in learning calculus and may be influenced by levels of study or student characteristics, research on students' mathematics learning should be more content-specific but involving a wider and more diverse communities of learners. To create sustainable mathematics education research, research interests must be relevant, progressive, beneficial, and inclusive.

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References

Alabdulaziz, M. S. (2021). COVID-19 and the use of digital technology in mathematics education. *Education and Information Technologies*, *26*(6), 7609-7633. https://doi.org/10.1007/s10639-021-10602-3

AM, M. A., Hadi, S., & Istiyono, E. (2023). Trend research mapping of differentiated instruction: A bibliometric analysis. *Journal of Pedagogical Research, 7*(3), 194-210. https://doi.org/10.33902/JPR.202320544

Bakker, A., Cai, J., & Zenger, L. (2021). Future themes of mathematics education research: An international survey before and during the pandemic. *Educational Studies in Mathematics*, *107*(1), 1-24. https://doi.org/10.1007/s10649-021-10049-w

Bano, M., Zowghi, D., Kearney, M., Schuck, S., & Aubusson, P. (2018). Mobile learning for science and mathematics school education: A systematic review of empirical evidence. *Computers & Education*, *121*, 30-58. https://doi.org/10.1016/j.compedu.2018.02.006

Bradford, S. C. (1934). Sources of information on specific subjects. *Engineering*, *137*, 85-86.

Cai, J., & Mamlok-Naaman, R. (2020). Posing researchable questions in mathematics and science education: Purposefully questioning the questions for investigation. *International Journal of Science and Mathematics Education*, *18*, 1-7. https://doi.org/10.1007/s10763-020-10079-5

Cansiz Aktas, M. (2022). Problem-posing research in mathematics education: A bibliometric analysis. *Journal of Pedagogical Research*, *6*(4), 217-233. https://doi.org/10.33902/JPR.202217414

Dash, D., Sinha, M., & Ghosh, S. (2021). How does the socio-economic status (SES) affect quality education during Covid-19? A pre and post pandemic observational study of language comprehension performance among native bangla speaking students in rural India. *Open Journal of Social Sciences*, *9*, 414-430. https://doi.org/10.4236/jss.2021.97030

Danesh, F., & Mardani-Nejad, A. (2021). 1.1 A historical overview of bibliometrics. In R. Ball (Ed.)*, Handbook Bibliometrics* (pp. 7-18). Berlin, Boston: De Gruyter Saur. https://doi.org/10.1515/9783110646610-003

Daud, A. S., Abd Aziz, M. K. N., Ali, W. N. A. B. W., Adnan, N. S. M., & Embong, Z. (2020). Students' perception in learning mathematics across gender and ethnicity. *Journal of Physics: Conference Series, 1529*(3). https://doi.org/10.1088/1742-6596/1529/3/032019

Dede, E., & Ozdemir, E. (2022). Mapping and performance evaluation of mathematics education research in Turkey: A bibliometric analysis from 2005 to 2021. *Journal of Pedagogical Research*, *6*(4), 1-19. https://doi.org/10.33902/JPR.202216829

Fu, Y., Mao, Y., Jiang, S., Luo, S., Chen, X., & Xiao, W. (2023). A bibliometric analysis of systematic reviews and meta-analyses in ophthalmology. *Frontiers in Medicine*, *10*, 1135592. https://doi.org/10.3389/fmed.2023.1135592

Gokce, S., & Guner, P. (2021). Forty years of mathematics education: 1980-2019. *International Journal of Education in Mathematics, Science and Technology*, *9*(3), 514-539. https://doi.org/10.46328/ijemst.1361

Hanna, G., & Sidoli, N. (2002). The story of ESM. *Educational Studies in Mathematics*, *50*(2), 123-156. https://doi.org/10.1023/A:1021162617070

Herfort, J. D., Tamborg, A. L., Meier, F., Allsopp, B. B., & Misfeldt, M. (2023). Twenty years of research on technology in mathematics education at CERME: A literature review based on a data science approach. *Educational Studies in Mathematics*, *112*(2), 309-336. https://doi.org/10.1007/s10649-022-10202-z

Inglis, M., & Foster, C. (2018). Five decades of mathematics education research. *Journal for Research in Mathematics Education*, *49*(4), 462-500. https://doi.org/10.5951/jresematheduc.49.4.0462

Irfan, M., Kusumaningrum, B., Yulia, Y., & Widodo, S. A. (2020). Challenges during the pandemic: Use of e-learning in mathematics learning in higher education. *Infinity Journal*, *9*(2), 147-158. https://doi.org/10.22460/infinity.v9i2.p147-158

Julius, R., Halim, M. S. A., Hadi, N. A., Alias, A. N., Khalid, M. H. M., Mahfodz, Z., & Ramli, F. F. (2021). Bibliometric analysis of research in mathematics education using Scopus database. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(12).

https://doi.org/10.29333/ejmste/11329

Lerman, S., Xu, G., & Tsatsaroni, A. (2002). Developing theories of mathematics education research: The ESM story. *Educational Studies in Mathematics*, *51*(1-2), 23-40. https://doi.org/10.1023/A:1022412318413

Lotka, A. J. (1926). The frequency distribution of scientific productivity. *Journal of the Washington academy of sciences*, *16*(12), 317-323. https://www.jstor.org/stable/24529203

Krukowski, R. A., Jagsi, R., & Cardel, M. I. (2021). Academic productivity differences by gender and child age in science, technology, engineering, mathematics, and medicine faculty during the COVID-19 pandemic. *Journal of Women's Health*, *30*(3), 341-347. https://doi.org/10.1089/jwh.2020.8710

Mamolo, L. A. (2022). Online learning and students' mathematics motivation, self-efficacy, and anxiety in the new normal. *Education Research International*, *2022*, 1-10. https://doi.org/10.1155/2022/9439634

Mazana, M. Y., Montero, C. S., & Casmir, R. O. (2019). Investigating students' attitude towards learning mathematics. *International Electronic Journal of Mathematics Education*, *14*(1), 207-231. https://doi.org/10.29333/iejme/3997

Muhammad, I., & Angraini, L. M. (2023). Research on students' mathematical ability in learning mathematics in the last decade: A bibliometric review. *Journal of Holistic Mathematics Education*, *7*(1), 108–122. https://doi.org/10.19166/johme.v7i1.6867

Muhammad, I., Mukhibin, A., do muhamad Naser, A., & Dasari, D. (2023). Bibliometric analysis: Research trend of interactive learning media in mathematics learning in Indonesia. *Prisma Sains: Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *11*(1), 10-22. https://ejournal.undikma.ac.id/index.php/prismasains/article/view/6595/3989

Mulenga, E. M., & Marbán, J. M. (2020). Is COVID-19 the gateway for digital learning in mathematics education?. *Contemporary Educational Technology*, *12*(2), ep269. https://doi.org/10.30935/cedtech/7949

Namkung, J. M., Peng, P., & Lin, X. (2019). The relation between mathematics anxiety and mathematics performance among school-aged students: A meta-analysis. *Review of Educational Research*, *89*(3), 459-496. https://doi.org/10.3102/0034654319843494

Saefudin, A. A., Wijaya, A., & Dwiningrum, S. I. A. (2023). Mapping research trends in mathematical creativity in mathematical instructional practices: A bibliometric analysis. *Journal of Pedagogical Research, 7*(4), 439-458. https://doi.org/10.33902/JPR.202322691

Schleicher, A. (2020). *The impact of COVID-19 on education insights from education at a glance 2020*. https://www.oecd.org/education/the-impact-of-covid-19-on-education-insights-education-at-a-glance-2020. pdf.

Sierpinska, A., & Kilpatrick, J. (Eds.). (1998). *Mathematics education as a research domain: A search for identity: An ICMI study.* Dordrecht, the Netherlands: Kluwer.

Stoet, G., & Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological science*, *29*(4), 581-593. https://doi.org/10.1177/0956797617741719

Su, Y. S., Cheng, H. W., & Lai, C. F. (2022). Study of virtual reality immersive technology enhanced mathematics geometry learning. *Frontiers in Psychology*, *13*, 760418. https://doi.org/10.3389/fpsyg.2022.760418

Wardat, Y., Belbase, S., Tairab, H., Takriti, R. A., Efstratopoulou, M., & Dodeen, H. (2022). The influence of school factors on students' mathematics achievements in trends in international mathematics and science study (TIMSS) in Abu Dhabi Emirate schools. *Education Sciences*, *12*(7), 424. https://doi.org/10.3390/educsci12070424

Xiao, J. (2021). From equality to equity to justice: Should online education be the new normal in education? In A. Bozkurt (Ed.)*, Handbook of research on emerging pedagogies for the future of education: Trauma-informed, care, and pandemic pedagogy* (pp. 1-15). IGI Global. https://doi.org/10.4018/978-1-7998-7275-7.ch001

Yaniawati, P., Kariadinata, R., Sari, N., Pramiarsih, E., & Mariani, M. (2020). Integration of e-learning for mathematics on resource-based learning: Increasing mathematical creative thinking and self-confidence. *International Journal of Emerging Technologies in Learning (iJET)*, *15*(6), 60-78. https://doi.org/10.3991/ijet.v15i06.11915

Yig, K. G. (2022). Research trends in mathematics education: A quantitative content analysis of major journals 2017-2021. *Journal of Pedagogical Research*, *6*(3), 137-153. https://doi.org/10.33902/JPR.202215529

Zuniga-Quispe, R., Cacha-Nunez, Y., Gonzales-Macavilca, M., & Iraola-Real, I. (2021). Online learning and mathematics in times of coronavirus: Systematization of experiences on the use of Zoom® for virtual education in an educational institution in Callao (Peru). In M. Botto-Tobar, J. Leon-Acurio, A. D. Cadena & P. M. Diaz (Eds.), *Advances in Emerging Trends and Technologies* (pp. 91–102). Springer Nature. https://doi.org/10.1007/978-3-030-63665-4_7

Appendix

Appendix A

Details of 'other' category

Subject area	Number of publications
Biochemistry, genetic and molecular biology	107
Business, management, and accounting	80
Environmental science	77
Physics and astronomy	77
Economics, econometrics, and finance	67
Agricultural and biological sciences	60
Energy	59
Earth and planetary sciences	28
Nursing	28
Decision sciences	26
Pharmacology, toxicology, and pharmaceutics	26
Chemical engineering	16
Chemistry	16
Immunology of microbiology	9
Materials science	8
Dentistry	1
Veterinary	1