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A bibliometric analysis on artificial intelligence in mathematics education

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ABSTRACT

The research on artificial intelligence in mathematics education has attracted much attention from researchers since the last decade. This study aims to provide holistic information about artificial intelligence in mathematics education research using bibliometric analysis. Data for the analysis were extracted from the Scopus database from 1986 – 2023. The analysis, conducted using R-packages (Bibliometrix) and VOSviewer software, identifies the relevant nations, affiliations, journals, articles, and keywords on artificial intelligence in mathematics education research. The study reveals that 565 documents have been published in 354 journals, with an average annual growth rate of 11.27%. These documents, on average, have received 14.61 citations each. The research field has engaged a total of 1,847 authors, with an average of 3.26 authors contributing to each document. Additionally, 17.17% of these publications involved international co-authorship, indicating a moderate level of global collaboration. Our findings reveal a growing interest in using artificial intelligence as an educational tools and methods, particularly in the United States and China, which lead in publication output and citations. The analysis also reveals emerging trends and research gaps. The keywords such as "virtual reality," "sustainable development," and "COVID-19" reflect recent research focus on artificial intelligence in mathematics education research. Meanwhile, the keywords such as "mathematical literacy," "assessment," and "gamification" identified as underexplored areas, suggesting potential opportunities for future research on artificial intelligence in mathematics education research.

INTRODUCTION

The field of mathematics education presents itself as a complex and hard activity, with the main objective of developing students' aptitude for problem-solving (Civil & Bernier, 2019). Numerous past studies have repeatedly shown that students frequently perceive mathematical assignments to be difficult, especially those requiring several steps to accomplish (Paras, 2001). In order to increase students' aptitude for mathematics, academics have attempted to create a number of instructional strategies and instruments (Bray & Tangney, 2017). Additionally, they have emphasized the significance of identifying factors, such as a lack of specific support for some pupils and insufficient prior knowledge, that affect how well students learn mathematics. A practical answer to these problems has currently been offered by artificial intelligence (AI) development (Chen et al., 2020). A subfield of computer science known as artificial intelligence (AI) is concerned with creating computer programs that are capable of performing mental tasks like speech and image recognition, inference, and decision-making (Yang et al., 2012). The use of AI has also impacted every sector,

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including technology, business, industry, medical, and education. The use of AI in education has a long history, especially when it comes to assisting students with challenging or advanced tasks (Chih-Ming & Ying-You, 2020). For example, AI (Chen & Liu, 2007; Hwang et al., 2020) created a customized method for using computers to help students solve arithmetic problems, and the results showed a notable improvement in both the performance and attitude of the students. Researchers also identified more research about artificial intelligence in mathematics education such as the use of intelligent tutors (Gunel & Asliyan, 2009; Huang et al., 2016; Rebolledo-Mendez et al., 2022).

Every year, more studies about artificial intelligence in mathematics teaching are published. Therefore, in order for a study issue to advance and receive the right support (Li et al., 2020), especially in the case of artificial intelligence in mathematics education, efforts must be made to ascertain its state and trends. Understanding research trends, patterns, innovation, and important studies can be done with the use of bibliometric studies (Aria & Cuccurullo, 2017; Donthu et al., 2021; Park & Yoon, 2018). Through the use of statistics, this study can also evaluate how research has contributed to the advancement of knowledge, particularly in the area of artificial intelligence in mathematics education, and it can give participants a more comprehensive understanding of the entire field at a relatively low cost (Suwarno et al., 2021).

Research questions were established to keep the analysis focused: (1) How is the growth rate of artificial intelligence in mathematics education research every year? (2) What are the leading countries and top institutions most productive on artificial intelligence in mathematics education research?, (3) Which journal is the most productive on artificial intelligence in mathematics education research?, (4) What are the most cited sources (journals) on artificial intelligence in mathematics education research?, and (5) What kind of research topics have researchers on artificial intelligence in mathematics education selected?.

METHODS

A bibliometric analysis utilizing the Scopus database is used in this study. Bibliometric analysis is a type of content analysis that uses visual maps to show how an author, publication, or author who has been referenced is related to other publications and authors (Zupic & Čater, 2014). The author's keywords, title keywords, and other keywords together with the bibliometric analysis would be used to categorize any prospective research trends or research gaps (Chen et al., 2016). The analysis focused exclusively on research papers on the topic artificial intelligence in mathematics education. The selection of our source was based on Scopus journal database and by using Scopus advanced search query and filtering options to reach relevant study. Then we conducted a comprehensive analysis of bibliographic data gathered using the Biblioshiny for Bibliometrix package in R software (Aria & Cuccurullo, 2017) and VOS viewer (van Eck & Waltman, 2010)

To carry out our search, we utilized the query string: TITLE-ABS-KEY ("artificial intelligence" OR "AI" OR "machine intelligence" OR "machine learning" OR "ML" OR "deep learning" OR "deep networks" OR "Big Data" OR "neural networks" OR "natural language processing" OR "NLP" OR "intelligent support" OR "intelligent virtual reality" OR "chat bot" OR "automated tutor" OR "personal tutor" OR "intelligent agent" OR "expert system" OR "chatbot" OR "intelligent system" OR "intelligent tutor" OR "deep learn" OR "thinking computer system" OR "expert system" OR "evolutionary computation" OR "hybrid intelligent system" OR "fuzzy logic" OR "computer vision" OR "genetic algorithm" OR "agent-based systems" OR "intelligent agents" OR "intelligent tutoring" OR "autonomous robots" AND ("Mathematics" AND "Education")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")). The search keyword was chosen after considering earlier research (Hwang & Tu, 2021; Song & Wang, 2020; Talan, 2021). Query string (TITLE-ABS-KEY defines the title, abstract, or keywords to assist the search engine find articles that are pertinent to the main subject. Meanwhile, query string (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) helps the search engine capture only articles from journals (exclude conference proceeding, book series, and book). The results of this search were then exported to Biblioshiny for Bibliometrix package in R software and VOS viewer software.

Our research aimed to provide a comprehensive overview of the literature on artificial intelligence research in mathematics education found in Scopus. By using analytical tools such as

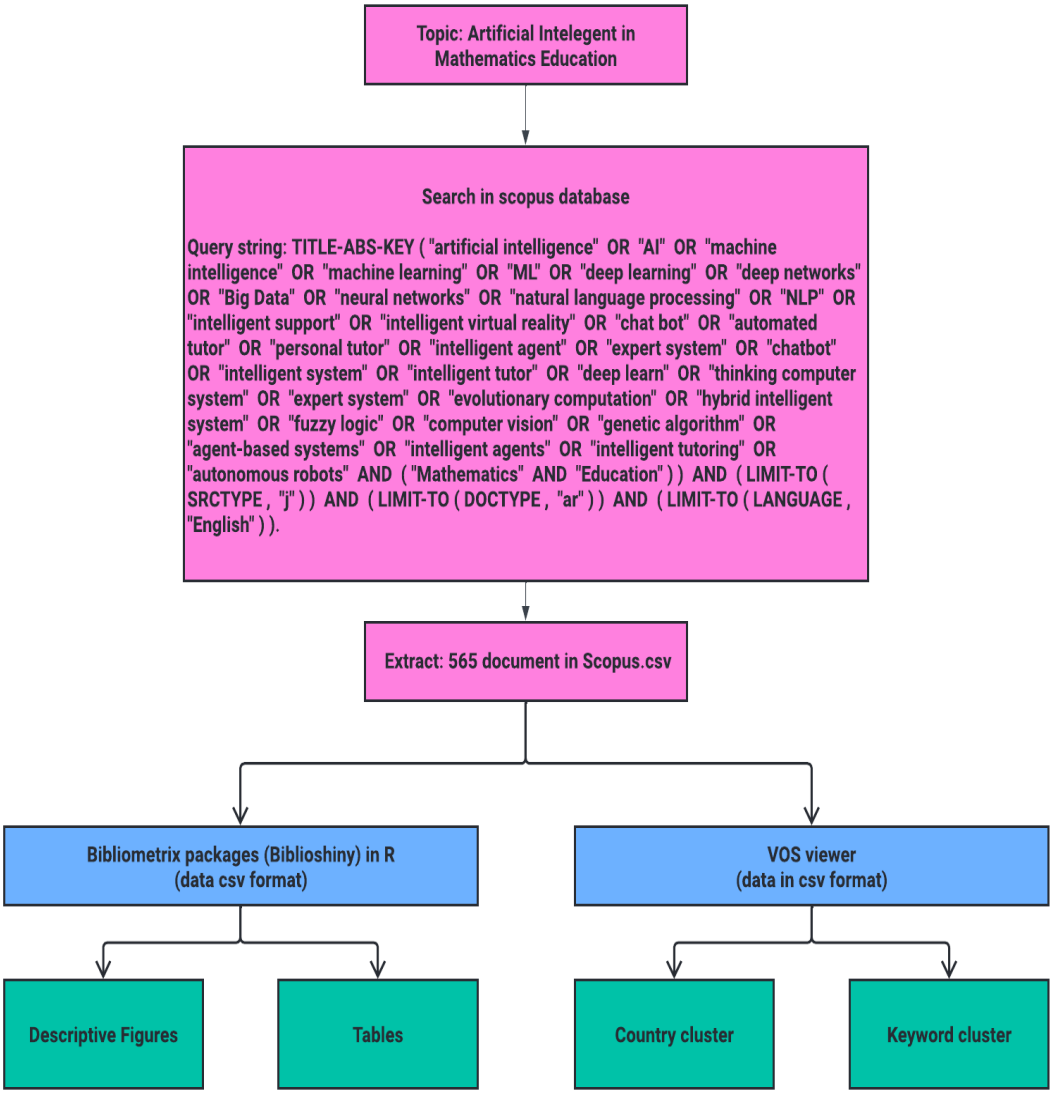

Figure 1. Research procedure diagram

Bibliometrix and VOS viewer, we were able to identify patterns and trends in the literature. These tools examine networks of authors, journals, universities, and nations, as well as keywords based on citations and frequency analysis techniques. We also identified the most commonly used keywords associated with artificial intelligence in mathematics education research. The Bibliometrix packages produce tables, such as: The data summary table, country table, affiliation table, source table, and article tables are produced by the Bibliometrix packages. Additionally, the packages generate descriptive figures such as the annual number of articles and cumulative articles figure, and the annual number of articles and average citation per article annually figure. The VOS viewer software produces a country cluster related to international cooperation in research, and a keyword cluster related to co-occurring keywords in research (Figure 1).

FINDINGS

Table 1 provides information collected from the Scopus database on artificial intelligence in mathematics education research. In total, 565 articles related to Artificial intelligence in mathematics education were identified in journals that were indexed by Scopus from 1986 - 2023. There were 1.847 authors that produced those 565 articles from 354 journals with 11.27% annual growth rate,

Table 1
Data Summary

Content	Result
General Information	
Periode	1986 : 2023
Number of Source (Journal)	354
Number of Documents	565
Annual growth rate	11.27%
Number of citations per document (average)	14.61
Document Content	
Keywords Plus	3,207
Author's keywords	1,820
Author	
Authors	1,847
Authors of single-author document	92
Authors of multi-author document	1,755
Author's collaboration	
Documents of single author	95
Authors per document	3.26
International co-Authorships (%)	17.17%

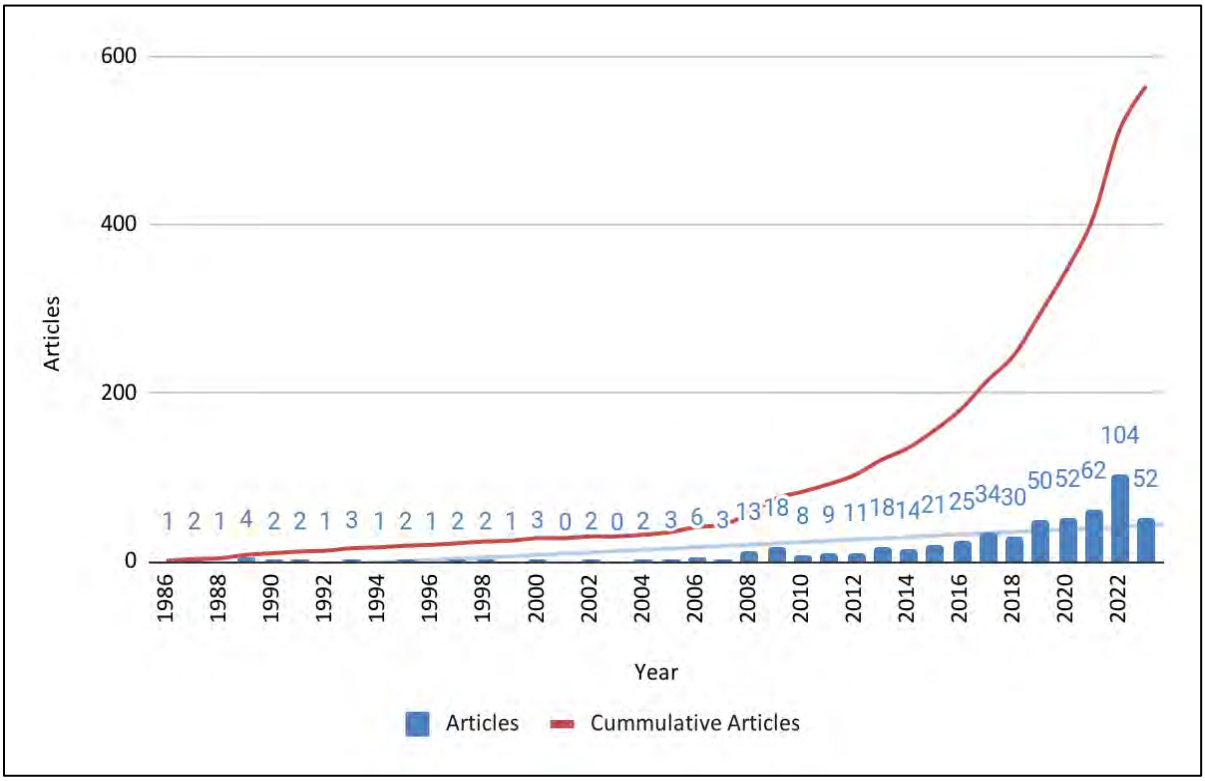

Figure 2. Annual number of articles and cumulative articles

however, the growth rate is uneven between the years and 14.61 average citation per document. In addition, it is seen that an average of 3.26 authors contributed to the production of each article and the international collaboration index in the field is determined as 17.17%.

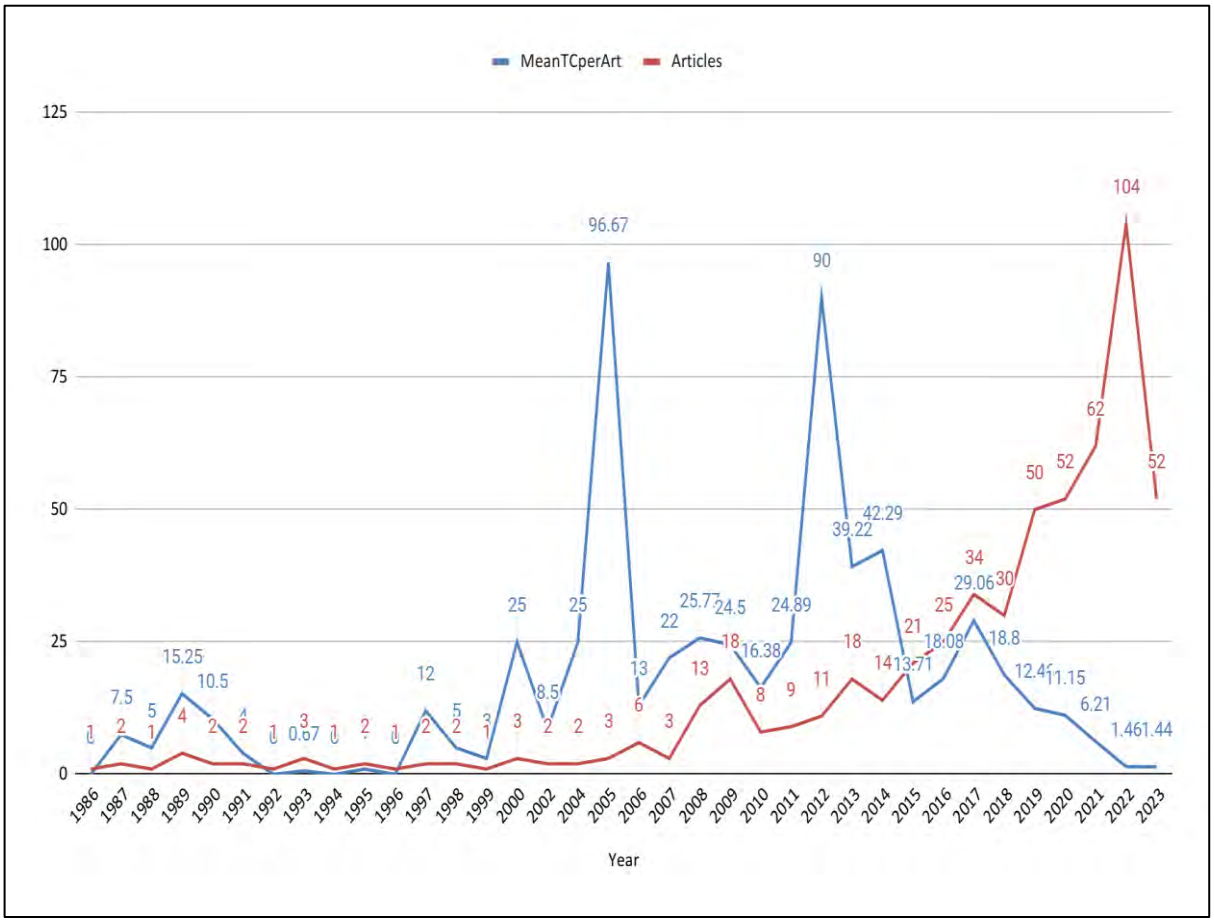

Figure 3. Annual number of articles and average citation per article annually

Figure 2 displays the total number of research on artificial intelligence in mathematics education that are released each year as well as their cumulative total. The publications in this discipline are growing at a 19.1% yearly pace, however the growth rate varies from year to year. Since 2010, when publications on the subject tended to increase annually, scientists have been primarily interested in this area of study.

Figure 3 displays the influence of research conducted over a certain year (i.e., citations). The average number of citations to studies across all studies included in the Scopus database is displayed by the bibliometric metric known as the Mean Total Citation per Articles (MTCA). Both the quantity of articles and the MCTA have seen an upward trend since 2000.

Data from Scopus show that writers from 71 different nations and regions took part in the study of this subject. Table 2 provides information on the top 5 publishing nations. The USA is the nation that provides the most papers in this subject, with 116 published articles (20.53 percent of all publications), 3.757 citations (53.69 percent of all citations), and an average article citation of 32.38. Second on this list is China with 68 published articles (12.04%) with 475 citations (6.79%) and average article citation is 6.98. Other countries Turkey (3), Spain (4), UK (5), on the other hand Indonesia in 29th position produces 3 articles (0.53%) with 32 citations (0.46%) but the average article citation is 9. The authors from the 37 nations represented in Figure 4 have worked with the other nations. The USA, UK, China, and Germany are among the nations that collaborate the most. Although it has been noted, there is often little scientific cooperation in this field. Although there is no cross-border study cooperation, Malaysia and Singapore are the two Southeast Asian countries with the most publications on this topic.

Table 2.
List of the countries with the most article

No.	Country	Total articles	Total citations	Total citations/ Total articles
1	USA	116	3,757	32.38
2	China	68	475	6.98
3	Turkey	19	264	13.89
4	Spain	18	122	6.77
5	UK	18	245	13.61

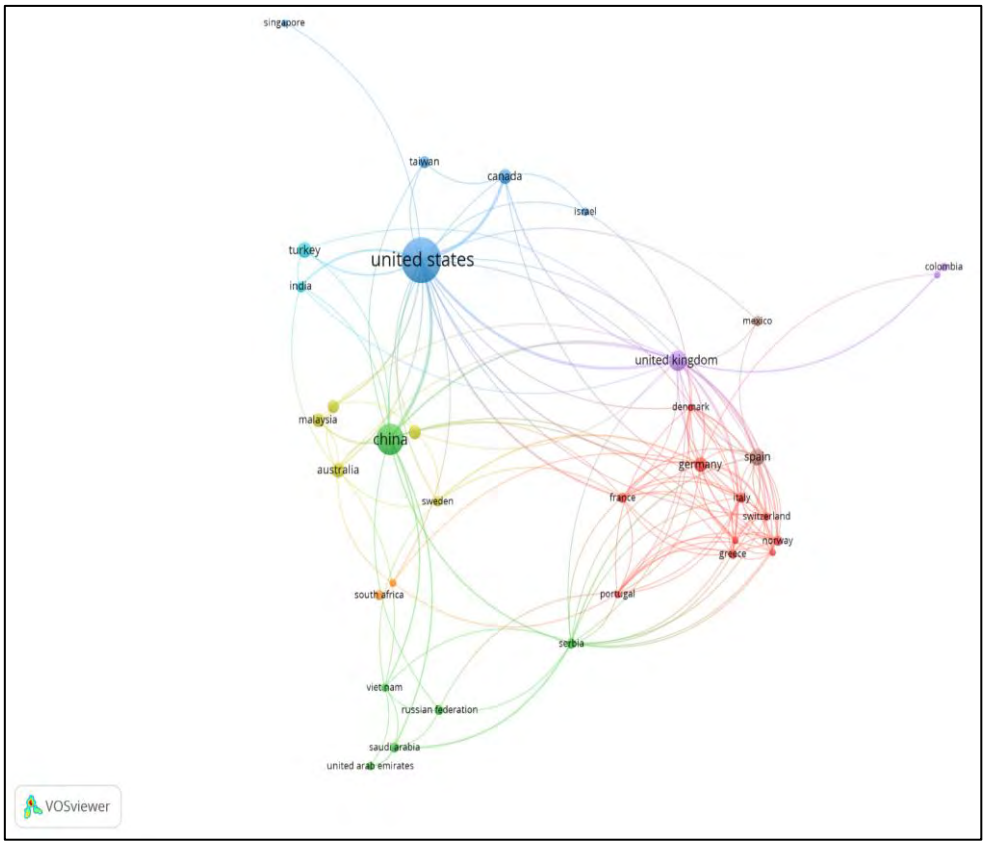

Figure 4. Illustration of international cooperation in research

Figure 5 shows the most relevant institutions that publish articles on Artificial intelligence in mathematics education. The top ten institutions are mostly in the USA. They are San Francisco State University with 46 articles, Carnegie Mellon University with 18 articles, Michigan State University and University of Memphis with 14 articles, Columbia University and University of California with 12 articles and Massachusetts Institute of Technology with 11 articles. The other top relevant institutions outside the United State are Karadeniz Technical University in Turkiye with 22 articles, University of Southern Queensland in Australia with 18 and Sao Paulo State University in Brazil with 11 articles.

Table 3
Articles production based on affiliation

Affiliation	Country	Articles
SAN FRANCISCO STATE UNIVERSITY	USA	46
KARADENIZ TECHNICAL UNIVERSITY	Turkiye	22
CARNEGIE MELLON UNIVERSITY	USA	18
UNIVERSITY OF SOUTHERN QUEENSLAND	Australia	18
MICHIGAN STATE UNIVERSITY	USA	14
UNIVERSITY OF MEMPHIS	USA	14
COLUMBIA UNIVERSITY	USA	12
UNIVERSITY OF CALIFORNIA	USA	12
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	USA	11
SÃO PAULO STATE UNIVERSITY	Brazil	11

Table 4
Articles production based on source

Sources	Scimago Rank	Total Articles	Total Citation
SUSTAINABILITY (SWITZERLAND)	Q1	17	94
INTERNATIONAL JOURNAL OF ARTIFICIAL INTELLIGENCE IN EDUCATION	Q1	15	676
COMPUTERS AND EDUCATION	Q1	13	387
INTERNATIONAL JOURNAL OF EMERGING TECHNOLOGIES IN LEARNING	Q2	9	44
EXPERT SYSTEMS WITH APPLICATIONS	Q1	8	185
COMPUTER APPLICATIONS IN ENGINEERING EDUCATION	Q1	7	64
COMPUTERS IN HUMAN BEHAVIOR	Q1	7	133
IEEE ACCESS	Q1	7	103
INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH	Q2	7	46
EDUCATION AND INFORMATION TECHNOLOGIES	Q1	6	71

The sample of 565 studies on Artificial intelligence in mathematics education was published in 354 academic outlets. Table 4 shows ten journals with the largest number of articles and total citation on Artificial intelligence in mathematics education research. Seventeen articles were published in Sustainability journal, currently Q1 based on Scimago rank and get 94 citations. On the other hand there are some journals that get higher citation numbers but with less than seven articles produces such as: Learning Environment Research (Total citation = 879, Total article = 1), Education Technology Research and Development (266, 2) and Technology, Knowledge and Learning (182, 4).

DISCUSSION

Table 5 showed the 10 articles published with the highest total citations on Artificial intelligence in mathematics education research. This more or less indicates that the articles have taken the studies on Artificial intelligence in mathematics education as important research foci. The article with the highest total citations (240 global citation recorded and 7 local citation recorded) about platform called ASSISTment that connect students, teachers and researchers to improve teaching and learning process in classroom (Heffernan & Heffernan, 2014) that was published in the International Journal of Artificial Intelligence in Education in 2014. With 148 global citations and 4 local citations, the article was published in Review of Educational Research in 2017 about meta-

Table 6
The latest article

Author, Year, Source	Title	Global Citations
KUHAIL MA, 2023, EDUC INF TECHNOL	Interacting with educational chatbots: A systematic review	29
WANG S, 2023, INTERACT LEARN ENVIRON	When adaptive learning is effective learning: comparison of an adaptive learning system to teacher-led instruction	16
SALMI HS, 2023, INTERACT LEARN ENVIRON	Is there deep learning on Mars? STEAM education in an inquiry-based out-of-school setting	6
SAYED WS, 2023, MULTIMEDIA TOOLS APPL	AI-based adaptive personalized content presentation and exercises navigation for an effective and engaging E-learning platform	3
BOLSTAD OH, 2023, MATH EDUC RES J	Lower secondary students' encounters with mathematical literacy	2
HAMMADI SS, 2023, INT J EMERG TECHNOL LEARN	Impact of Deep Learning Strategy in Mathematics Achievement and Practical Intelligence among High School Students	2
SAHA S, 2023, COMPUT MECH	Deep Learning Discrete Calculus (DLDC): a family of discrete numerical methods by universal approximation for STEM education to frontier research	2
ZHOU C, 2023, EDUC INF TECHNOL	Integration of modern technologies in higher education on the example of artificial intelligence use	1
DEL OLMO-MUÑOZ J, 2023, ZDM MATH EDU	Intelligent tutoring systems for word problem solving in COVID-19 days: could they have been (part of) the solution?	1
GIANNOS P, 2023, JMIR MED EDUC	Performance of ChatGPT on UK Standardized Admission Tests: Insights From the BMAT, TMUA, LNAT, and TSA Examinations	1

analysis in STEM education using computer-based scaffolding (Belland et al., 2017). Some other topic that has most-cited related to interactive learning environment, such as to develop tools that can detect whether the student is gaming the system (Baker, et al., 2008), to develop after-school program using intelligent tutoring system for primary students (Huang, et al., 2016; Craig, et al., 2013) and secondary students (Özyurt, et al., 2013; Pareto, 2014).

Table 6 displays the top ten papers from 2023 with the greatest number of references to research on artificial intelligence in mathematics education. A systematic review of chatbot

Table 7
Top 10 co-occurrence keywords of artificial intelligence in mathematics education research

Keyword	Occurrences	Total link strength
student	146	997
education	137	921
human	74	737
mathematics	94	718
artificial intelligence	116	652
teaching	78	568
machine learning	76	483
learning systems	63	441
education computing	58	392
female	32	377

deployment in education across seven dimensions, including the educational field, platform, design principles, the role of chatbots, interaction styles, evidence, and constraints, is the most cited paper (29 global citations were found) and was written by Kuhail et al. (2023) in the journal Education and Information Technologies. The second position in terms of global citation (16) is about the effectiveness of adaptive learning that personalizes instruction to students' individual learning needs and abilities compared to teacher-led instruction(Wang et al., 2023). The publication regarding deep learning in STEAM education outside of school is now ranked third (6). The STEAM intervention appears to have resulted in long-term learning, and the exhibition learning environment has been demonstrated to offer a suitable platform for reaching the deeper layers necessary for successful knowledge retention (Salmi et al., 2023). Some other topics that are also of interest to researchers this year are AI-based adaptive personalized content (Sayed et al., 2023), deep learning in calculus (Saha et al., 2023) and high school (Hammadi et al., 2023), intelligent tutoring system (del Olmo-Muñoz et al., 2023) and ChatGPT performance in standardized tests (Giannos & Delardas, 2023).

We then analyze keywords co-occurrence that was recorded using VOSviewer. The term "occurrences" denotes a link between two terms. Each link has a strength, which is denoted by a positive number value in the VOSviewer documentation. The stronger the relationship, the higher this number. The overall link strength shows how many publications contain two keywords that are used together. Table 7 shows 10 keywords with highest total link strength, based on this result, it can be found that the trends on artificial intelligence in mathematics education research are related with those keywords. It can be noted that student is the most frequently appearing keyword and has the highest total link strength, with 146 and 997, respectively. It is obvious that the main keyword on artificial intelligence in mathematics education study is student. The second order is Education, with 137 occurrences and a total link strength of 921. Human, Mathematics, Artificial Intelligence, Teaching, Machine Learning, Learning Systems, Education Computing, and Female were the following categories.

On the other hand Table 8 shows 10 keywords with lowest total link strength, based on this result, it can be found that those keywords are rarely used on artificial intelligence in mathematics education research. Researchers can use the information about the lowest total link strength to identify potential research gaps and areas for further exploration. Mathematical literacy was a keyword that was rarely used, only 8 occurrences, and also rarely occurred with other keywords (total link strength = 16) on artificial intelligence in mathematics education research.

Table 8
Least 10 co-occurrence keywords of artificial intelligence in mathematics education research

Keyword	Occurrences	Total link strength
mathematical literacy	8	16
applied mathematics	6	17
social robots	5	20
complex networks	5	21
steam	6	22
assessment	5	23
learning analytics	8	23
gamification	6	24
data analytics	6	24
clustering	5	26

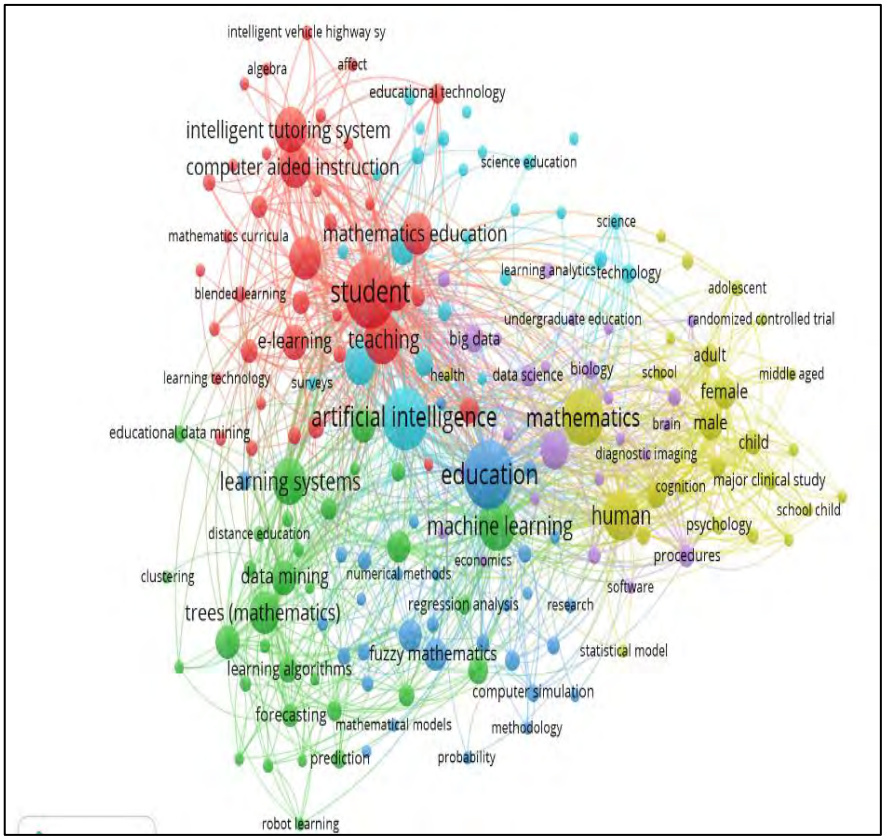

Figure 5. Co-occurrence Keywords of artificial intelligence in mathematics education research

Figure 5 visualizes keywords based on occurrence and total link strength of artificial intelligence in mathematics education research using VOSviewer. The bibliometric data show that there were 178 out of 4,341 total keywords involved in this research, with the minimum occurrence pre-set at 5. There are six clusters of various colors. Relevant terms are frequently provided together, as may be seen in the same cluster. The connections between two circles signify the combined use of the related terms. The diameter of the circle indicates how frequently the event occurs. Visualization

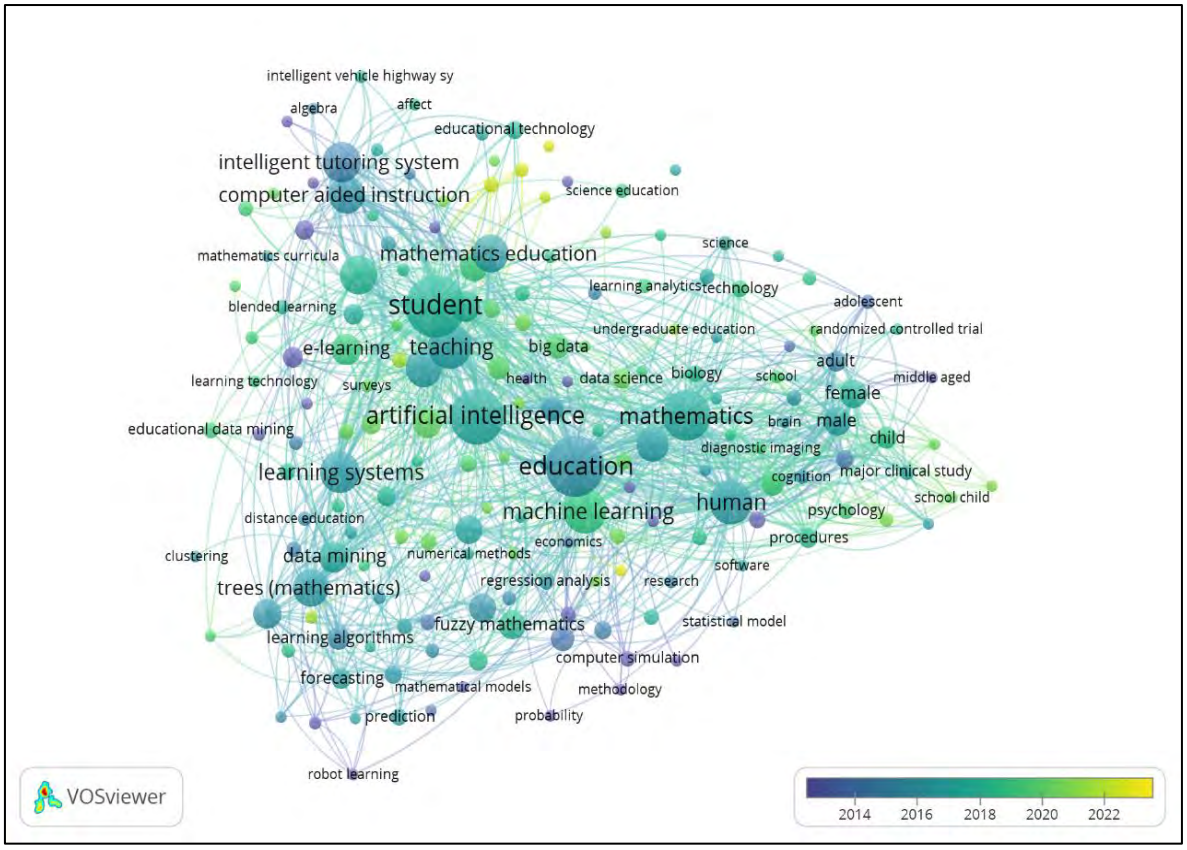

Figure 6. Co-occurrence keywords of artificial intelligence in mathematics education research

co-occurrence keyword analysis is a useful approach for determining the most common subjects in publications in a certain research field and how their occurrence changes over time (Gu et al., 2021).

The first cluster (in red) consists of 34 keywords, when viewed from the circle size in this first cluster, three keywords with the largest diameter are such as “education”, “learning”, and “fuzzy logic”. The second cluster (in green) consists of 34 keywords such as “machine learning”, “learning system”, and “data mining” are the three largest circles in the cluster. The third cluster (in blue) consists of 34 keywords such as “student”, “teaching”, and “intelligent tutoring system” are the three largest circles in the cluster. The fourth cluster (in yellow) consists of 30 keywords and three keywords with the largest diameter are “artificial intelligence”, “engineering education”, and “e-learning”. The fifth cluster (in purple) consists of 26 keywords with “mathematics”, “human", and “female” being the three largest circles in the cluster. Other clusters have more minor keyword occurrence and research focus. Figure 6 shows that the center of the map is where students, education, artificial intelligence, mathematics, teaching, and machine learning are all concentrated. These terms are ideas that have been researched in conjunction with other clusters and were found to be the most popular keywords.

The overlay visualization's classification of the described keywords' co-occurrence from 2013 to 2023 is shown in Figure 6. By comparing an item's color value to the color value (year) in an overlay colors file, the color of the item is decided. Yellow circles denote keywords that are the new theme. In Figure 6, the keywords that are new themes in this field are virtual reality (King et al., 2022), sustainable development (Jeong & González-Gómez, 2020), covid-19 (Christopoulos &

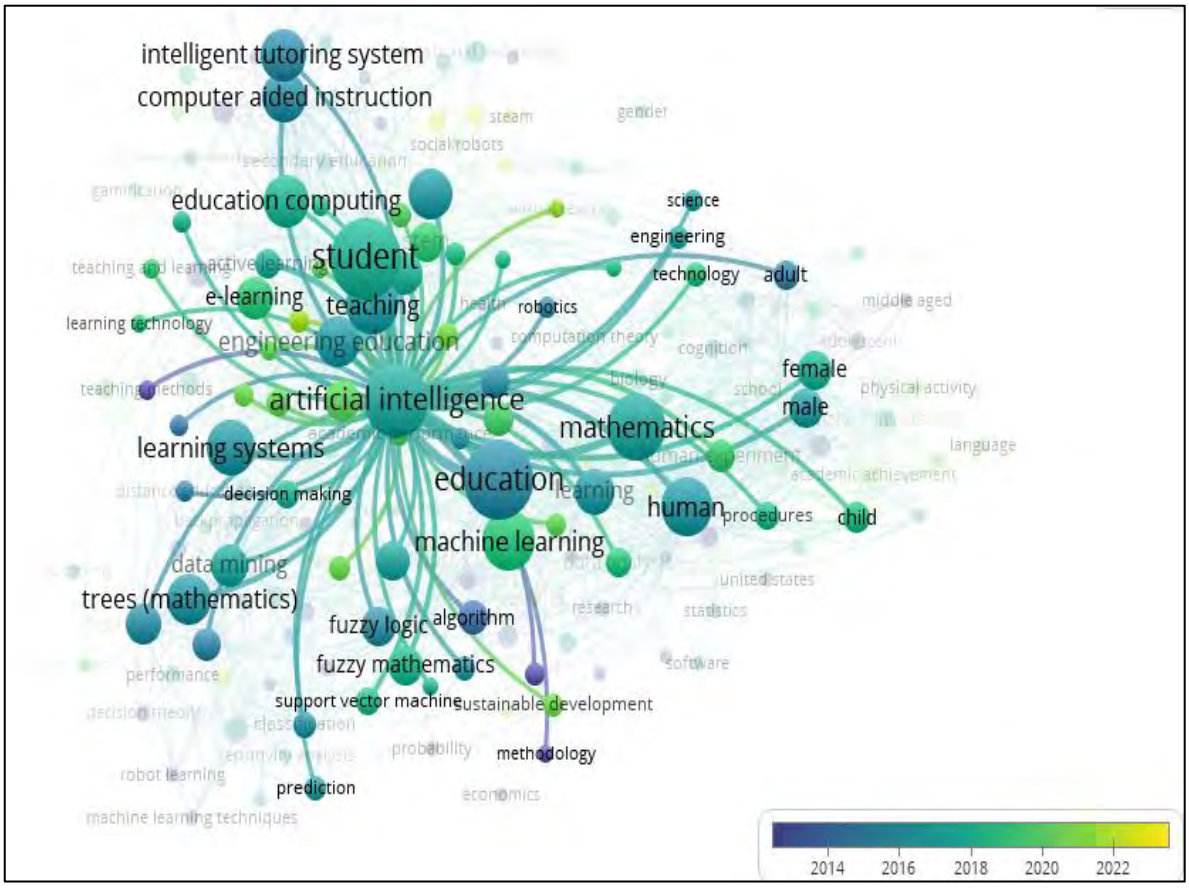

Figure 7. Focus keywords related to artificial intelligence in mathematics education: Artificial Intelligence

Sprangers, 2021; del Olmo-Muñoz et al., 2023). Those new and novel themes are considered the most important keywords emerging recently related to artificial intelligence in mathematics education research.

Figure 7 displays several instances of results from a keyword mapping with a more focused subject matter, such as artificial intelligence. Figure 7 shows co-occurrence between artificial intelligence and other keywords that are already related. For example, if a researcher wants to study the trend aspect of artificial intelligence, they can focus on keywords with the largest diameter and connected to artificial intelligence's nodes such as: education, teaching, student, mathematics, and learning system. If a researcher wishes to study more specialized topics, they can concentrate on terms associated to artificial intelligence's nodes that have the lowest diameter, such as "intelligent tutoring system," "computer aided instruction," and "teaching methods". If a researcher wants to research a relatively new aspect, they can focus on keywords that not-connected to artificial intelligence's nodes such as: mathematical literacy, mathematics curricula, STEAM, and gender.

CONCLUSIONS

We examined 565 publications on artificial intelligence in mathematics education that were published in the Scopus database between 1986 and 2023 in order to conduct this analysis. The analysis's findings led to the following conclusions and implications: 1) Sustainability is the primary publication venue for artificial intelligence in mathematics education research, followed by Computers and Education and the International Journal of Artificial Intelligence in Education. However, Sustainability receives fewer citations than the International Journal of Artificial Intelligence in Education 2) The USA is the nation that provides the most publications in this subject, with 116 articles published and 3,757 citations, with an average citation of 32.38. China is ranked second on this list with 68 articles published and 475 citations, with an average article citation of

6.98. Turkiye comes in third with 19 articles published and 264 citations, with an average article citation of 13.89. The USA, the UK, and China are the nations that collaborate the most. 3) Trend mapping shows that artificial intelligence in mathematics education research trends are related to Teaching, Machine Learning, Learning Systems, Education Computing and Female. 4) Trend mapping also shows the research gap on artificial intelligence in mathematics education research related to mathematical literacy, applied mathematics, gamification, social robots, and complex networks. 5) The top 10 cited papers in the review's top 10 articles frequently touch on the use of AI in mathematics education as a tool to improve communication between students and teachers. The idea of altering the educational system by utilizing artificial intelligence to replace instructors is also covered in other articles.

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AUTHOR'S DECLARATION

Authors' contributions	All authors contributed to the study conception and design. PWS: main idea, conceptualization, and report wrote the manuscript, MM and NNS: analysis data, review and validation, AR: collected the data and report.
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Competing interests	The authors declare that the publishing of this paper does not involve any conflicts of interest. This work has never been published or offered for publication elsewhere, and it is completely original.

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