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Trends and insights of AI in mathematics education: A bibliometric analysis

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ABSTRACT

Human intelligence is related to cognitive skills such as the acquisition of new knowledge, problem-solving and abstract thinking in learning processes. These processes are of great importance in mathematical education. Artificial intelligence (AI) can help students develop these cognitive skills by providing customized teaching methods according to their individual needs. Examining how AI can be used in mathematics education can provide information on how students can learn mathematics more effectively. This can help students gain access to scientific knowledge in other disciplines and support them to succeed in applied sciences. The purpose of this study is to systematically investigate the trends of studies on the use of AI in mathematics education using bibliometric analysis. R-studio program with the biblioshiny package was used. The analysis was carried out with 313 publications obtained from Scopus and Web of Science databases and published between 1987-2023. According to the research results, the United States, China, and Australia are the top three nations in terms of publications and citations. The resulting collaborative network shows that research has been carried out in 28 countries. This research underscores the importance of leveraging AI in education to support sustainable development by enhancing learning processes that are foundational to the applied sciences and global knowledge economies.

Keywords: mathematics education, bibliometric analysis, artificial intelligence, Biblioshiny, Web of Science, Scopus

INTRODUCTION

Education plays a pivotal role in achieving sustainable development by equipping individuals with the knowledge and skills necessary for addressing complex global challenges (Yapıcı, 2003). Mathematics, as a core discipline, underpins many areas of science, technology, and innovation, making it essential for sustainable progress in applied sciences and beyond (Ersoy, 2003). However, traditional teaching methods often fall short of addressing diverse learning needs, highlighting the need for innovative approaches to education (Deniz, 2019). Artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize educational practices (Nedungadi et al., 2024). By providing personalized learning experiences, AI can help students develop critical cognitive skills such as problem-solving, ab-stract thinking, and the acquisition of new knowledge-abilities that are foundational to mathematics education (Zawacki-Richter et al., 2019). This integration of AI into education aligns with the goals of the 2030 agenda for sustainable development, particularly SDG 4 (quality education), by promoting inclusive and equitable access to high-quality learning (Arruda & Arruda, 2024).

It is not possible to give a single, meaningful, and all-encompassing definition that is valid for all times to the question "what is mathematics?" (Nasibov & Çakar, 2005). The literature offers various definitions, including "knowledge of numbers and shapes," "collection of operations and rules," and "science of patterns and orders" (Toluk, 2003). Mathematics education arises from the intersection of mathematics and education, interacting with disciplines like sociology, psychology, anthropology, and philosophy. Research highlights the political, social, and cultural aspects of mathematics teaching and learning, revealing the field's multidimensional nature (de Lima et al., 2022). From this perspective, mathematics education impacts both individuals and society. It addresses problems by integrating knowledge from multiple fields (Umland & Black, 2016). Civil and Bernier (2018) define mathematics education as an educational process involving complex and challenging tasks that aim to improve students' problem-solving competence. For many students, learning mathematics is a huge difficulty (Kaushik et al., 2021). Therefore, mathematics education researchers are attempting to create a variety of teaching methods and resources to enhance students' learning outcomes in mathematics (Bray & Tangney, 2017). AI is one of these tools, providing a chance to help students solve and improve their mathematics and teaching and learning performance (bin Mohamed et al., 2022).

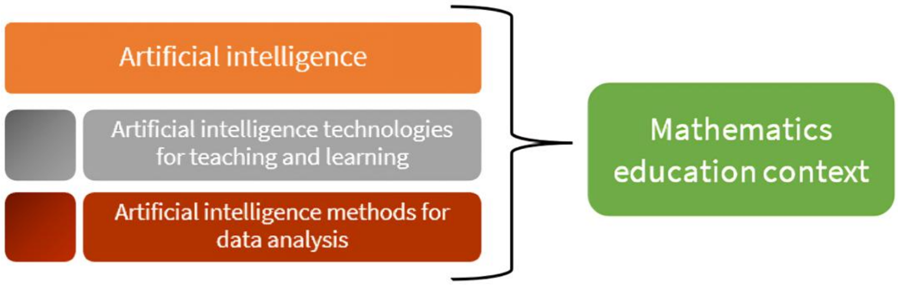

Figure 1. Conceptual framework (Source: Authors' own elaboration)

Since the first half of this century, AI-one of the key fields of study in computer engineering-has been regarded as the engine of technological advancement (Arslan, 2020), is applied in different fields: finance, medicine, law (Salas-Pilco & Yang, 2022), astronomy, business, computer vision (Urbina Nájera & Calleja Mora, 2017). In education, AI refers to systems that perform human-like tasks: adapting, learning, self-correcting, and synthesizing data for complex operations (Popenici & Kerr, 2017). The ongoing digital transformation continues to create new educational opportunities through AI (Sullivan & Bers, 2016). These days, AI is regularly used in the classroom by both educators and students. Depending on its goals, there are two ways that AI in education can be used: for teaching and learning (1) and for data analysis (2). These two goals served as the foundation for the research's theoretical framework (**Figure 1**).

AI applications in mathematics education can be performed through different methods: robotics, coding and programming, several tools and systems, etc. Research results indicate that educational robotics kits and virtual robotic animations from AI applications have significant effects on improving mathematics education (e.g., Brender et al., 2021; Gomes et al., 2022; Lopez-Caudana et al., 2020; Nickels & Cullen, 2017; Samuels & Haapasalo, 2012; Zhong & Xia, 2020). Studies exist that provide AI approach examples of coding and programming (Cui & Ng, 2021; Kadijevich, 1999; Stigberg & Stigberg, 2020), AI systems (Baral et al., 2022; Engelbrecht & Borba, 2023) for learning mathematics. These interactive and immersive learning environments, which blend entertainment and education, attract great attention from educators and researchers. The positive effects of AI applications, proven by research results, strengthen the ideas about including AI in educational environments.

Several AI techniques are being used in the use of AI to instruct mathematics such as data mining (Güre et al., 2020; Roslan & Chen, 2023; Simsek, 2022), fuzzy logic (Doz et al., 2022), deep learning (Aslam et al., 2021; Shield & Dole, 2013), machine learning (ML) methods (Lee et al., 2023; Lezhnina & Kismihók, 2022; Mgonja & Robles, 2022).

AI in mathematics education has the potential to improve students' understanding of mathematical concepts, formulas, and algorithms (Çetin et al., 2024). It offers learning that is more effective based on specific characteristics of the students. It might increase students' motivation and assist in resolving difficult mathematics problems (Dabingaya, 2022). The integration of AI into mathematics education is evaluated within the framework of cognitive learning theories and pedagogical approaches. AI-based systems reduce cognitive load and support learning by providing learning experiences tailored to students' individual needs. These systems can provide immediate feedback by monitoring students' learning processes and provide teachers with valuable information about students' learning behavior (Toptaş, 2024). Applications of AI in mathematics education include intelligent tutoring systems, adaptive testing systems, virtual reality applications and AI-supported games. These tools help students develop mathematical thinking, problem-solving and analytical skills. For example, intelligent tutoring systems can analyse students' learning processes to provide personalised content and optimise the learning process (Nayıroğlu & Tutak, 2024). For the effective use of AI in mathematics education, teachers' competences for these technologies should be increased, curricula should be restructured in accordance with AI integration and students' ability to use AI tools effectively should be improved (Kara, 2024). In conclusion, AI increases students' achievement by providing individualised learning experience in mathematics education and helps teachers to manage teaching processes more effectively. However, the ethical and social dimensions of these technologies should be considered and necessary measures should be taken to ensure equal opportunities in education.

Few bibliometric analysis studies that incorporate the research above and offer a comprehensive view of AI research in education in mathematics exist. Hwang and Tu (2021) examined the roles and research trends of AI in mathematics education through bibliometric mapping and systematic analysis. The top three journals with the most publications on AI in mathematics education between 1996-2020 were Computer & Education, Journal of Educational Psychology, and Journal of Computer Assisted Learning, while the top three most cited journals were Journal of Educational Psychology, Computers & Education, and Learning and Instruction. In a paper presented at the 2nd International Conference on Computational Methods in Science and Technology in 2021, Kaushik et al. (2021) showed that 6 studies were published between 1996-2010, 12 between 2011-2015 and 25 between 2016-2020. Comparing the current two periods to the preceding one, the total number of publications has nearly doubled. bin Mohamed et al. (2022) carried out a systematic literature review of AI research in mathematics education. The researchers looked at 20 AI studies that were published between 2017 and 2021 in the ScienceDirect, Springer Link, Scopus, EBSCO Host, and ProQuest databases without using any bibliometric analysis software. The findings showed that the AI approach used in mathematics education is through robotics, several tools and systems, teachable and autonomous agents, and a comprehensive approach. Most of the research was carried out in Mexico and the United States (USA).

The recent increased interest in the use of AI in mathematics education makes the study important, but more research is needed to identify open issues and trends in current research, enrich the knowledge base and get a complete picture of AI research in mathematics education. Research utilizing bibliometric analysis to investigate AI in mathematics education will yield valuable quantitative data, particularly for scholars wishing to pursue this area of study in the future.

This study's objective is to methodically look into research trends regarding AI applications and analysis in mathematics education. Considering the previously mentioned details, the study was carried out under the umbrella of the research question, "What key trends and research patterns emerge in the application of AI in mathematics education, based on a bibliometric analysis of literature published between 1987 and 2023?" The following sub-problems were addressed within the context of this research problem:

1. What are the trends in publication types, annual growth rates, and citation patterns in AI-focused mathematics education research?
2. Which countries contribute the most to AI research in mathematics education, and how are international collaboration networks distributed?
3. Which journals are most influential in AI research in mathematics education, based on publication count, h-index, and citation performance?
4. What are the primary research themes and focal areas in the literature on AI in mathematics education?

BACKGROUND

Artificial Intelligence Technologies for Teaching and Learning

These days, AI is regularly used in the classroom by both educators and students. Adaptive learning systems, teaching robots, and intelligent lesson applications are a few examples of these technologies and tools (Chen et al., 2020).

There are several justifications for integrating AI into teaching and learning processes. Learning may be personalized (Chatterjee & Bhattacharjee, 2020), and learning-disabled students can be recognized early on and given specialized solutions through AI (Drigas & Ioannidou, 2012). Several academics have shown the value of AI, especially in helping students with tasks that are complex or difficult (Chih-Ming & Ying-You, 2020; Wang et al., 2021). In teaching-learning environments, AI is characterized as an intelligent teacher, student, learning tool, and educational partner (Hwang et al., 2020). One of the researchers, using Google Teachable Machine, Toivonen et al. (2020) organized a series of co-design workshops where elementary school students investigated and created their own ML-powered applications. The findings indicate that Google Teachable Machine is a useful teaching AI tool for grades K-12.

The latest review study on AI in education was conducted by Zhang et al. (2023). A bibliometric and visual analysis of 517 publications on social robots promoting children's learning and development was conducted for this study. Unlike most studies, this study used a combination of two complementary visualization tools, VOSviewer and CiteSpace. The two countries with the highest productivity in this area are the USA and the Netherlands. The results also have implications for the development and use of kid-friendly social robots that are outfitted with generative AI methods. In another research, Talan (2021) examines the bibliometric features of the research that have been published in the literature about the application of AI in education. The data was gathered via the Web of Science (WoS) database. 2,686 papers altogether, published between 2001 and 2021, on the topic were discovered. Most of the research was carried out in the USA. "International Journal of Emerging Technologies in Learning" and "Computers & Education" were found to be the most often published journals. Furthermore, a mapping of the collective keywords revealed a higher frequency of usage for the words machine learning, artificial intelligence, intelligent tutoring systems, deep learning, and higher education.

Dabingaya (2022) examined the effectiveness of AI-supported adaptive learning systems in mathematics education to explore how they affect student engagement and learning outcomes. The results showed that the experimental group using the AI-supported platform had higher engagement metrics in terms of frequency and length of interaction than the control group. Moreover, the post-assessment scores of the experimental group increased significantly, showing better mathematical proficiency. Martínez-Téllez and Camacho-Zuñiga (2023) investigated through action research how the use of Bing Chat could improve a flipped collaborative learning activity in a mathematics class. The activity was carried out in a private Mexican institution with 32 students who solved a task to verify homework completion and stimulate discussion within the class. The results show that technological competence is an important skill and is particularly relevant to STEM education, as an AI chatbot could potentially enhance students' autonomous and active learning, as well as promote the development of critical thinking skills. Lee and Yeo (2022) developed an AI-based chatbot to develop in-service teachers' inquiry skills, especially through practice approaches, by engaging them in an authentic, meaningful and open-ended teaching situation. The chatbot is designed to behave as a virtual student showing misunderstandings about fractions. Two iterations of design, implementation and evaluation were conducted in an elementary mathematics education methods course. These studies provide evidence for the potential of AI applications in mathematics education for student and teacher education.

Artificial Intelligence Methods for Data Analysis

AI-supported analysis and applications aimed at identifying the variables, such as personal traits and prior knowledge gaps, that influence students' performance in mathematics learning, have also become the subject of research. This is because AI is also used in student engagement and assessment and tracking of their academic performance. In addition, AI prevents teachers from wasting time and allows student data to be easily collected and stored (İşler & Kılıç, 2021; Karsenti et al., 2017). AI analysis can be used to help learning in certain areas where students are weak or ineffective (Fahimirad & Kotamjani, 2018). Below are a few examples of educational research that performs AI-supported data analysis.

Göktepe Körpeoğlu and Göktepe Yıldız (2023) suggested the adaptive neural-network-based fuzzy logic (ANFIS) model, which combines fuzzy logic with artificial neural networks to predict students' STEM attitudes. Students' STEM attitude scores are accurately predicted by the ANFIS results. Yoo and Kim (2023) conducted another AI analysis application. They looked and explored how interactions between instructors in an online teacher community of practice (CoP) can impact their pedagogical content knowledge in mathematics education. Natural language processing (NLP) methods, namely word2vec, BERT, and ML classifiers, were used to evaluate data from 26,857 postings. Based on the findings, the majority of texts are able to forecast the degree of instructor interaction in the online CoP. Using the PISA 2012 dataset, Gabriel et al. (2018) employed ML to examine the relationships between math literacy and psychological dispositions in 15-year-old Australians. The paper demonstrates how data-driven modeling strategies can be effectively applied by education researchers to identify unique connections and intricate non-linear correlations within a multidimensional dataset.

METHODOLOGY

Bibliometric analysis involves the quantitative and statistical examination of journals or publications to create some helpful information structures. The general growth pattern, publishing quality, and citation structure of a journal are essentially concluded when this is done for it (Aria & Cuccurullo, 2017; Chen & Ho, 2015; van Raan, 2019). Bibliometric analysis can also be utilized to determine the strengths and weaknesses of the study, to influence authors in the field, to show the best-performing countries, etc. (Shukla et al., 2018). Bibliometric analysis fosters multidisciplinary cooperation and gives researchers and associated stakeholders the chance to learn insightfully about the topic of study (Niu et al., 2014). It is also called bibliometrics or scientometrics (Alvarez-Betancourt & Garcia-Silvente, 2014).

The Process for Selecting Articles

Since its founding in the 1960s, bibliometric analysis has been extensively employed to investigate the scientific progress of many research subjects on a local and global level (Pritchard, 1969). This study employed bibliometric analysis to systematically investigate the trends and key contributors in the field of AI in mathematics education. The methodology was designed to capture a comprehensive view of the key contributors, collaboration networks, and publication patterns across the field. The following subsections describe the bibliometric analyses performed, along with the tools and software used in each phase of the study. The research followed a structured approach to ensure methodological rigor and clarity.

The data for this study were collected from two major academic databases: WoS and Scopus. These databases were selected due to their extensive coverage of high-quality peer-reviewed academic literature and their frequent use in bibliometric studies. Both WoS and Scopus are considered reputable and comprehensive sources for academic publications, ensuring a robust dataset for bibliometric analysis. Additionally, they provide detailed citation data, enabling the examination of citation trends and collaboration networks across countries and institutions.

To ensure the relevance and quality of the publications included in this study, we established clear inclusion and exclusion criteria.

- A systematic approach was followed in the selection of research words. Firstly, the purpose of the study was clearly defined. "AI" and "mathematics education" were determined as the basic concepts to reflect the research question. For each concept, synonyms and related variations are listed. At this stage, common terms were analysed through a literature review. This is to cover cases where different authors refer to the same subject in different terms. For AI, terms such as "machine learning, deep learning, intelligent systems" were used. To find publications in the categories of "education/educational research, education scientific disciplines, computer science AI, computer science interdisciplinary applications, and computer science information systems" we searched the WoS database using the following two keyword substrings: "AI" ("artificial intelligence" or "machine learning" or "machine intelligence" or "neural network" or "fuzzy logic" or "deep learning" or "genetic algorithm" or "intelligent support" or "expert system" or "robotics" or "natural language processing" or "data mining" or "ANFIS*" or "ANN*") and "mathematics education". We searched the Scopus database using the same above two keyword substrings in the subject areas: "social sciences, computer science, mathematics, psychology, neuroscience, multidisciplinary" in the titles, abstracts, or keywords of all original articles, review papers, book chapters, and conference papers in the databases.
- Two major academic databases, Scopus and WoS, were selected due to their comprehensive coverage of high-quality peer-reviewed academic literature.
- The study examined research published between 1987 and 2023 to identify historical trends and recent developments. Early examples of AI in education date back to 1987. In addition, this study is the output of a project in which the authors took part. This project also covers the years 2023-2024. Since the literature reviews for the project were also conducted by including the year 2023, 2023 was taken as the final date.
- Regarding language, we limited our analysis to works published in English. Although this may exclude relevant studies written in other languages, we chose English due to its prevalence as the primary language for academic discourse and the availability of comprehensive databases. This approach ensures that the study focuses on widely accessible, peer-reviewed research while recognizing the potential limitation of excluding non-English publications.

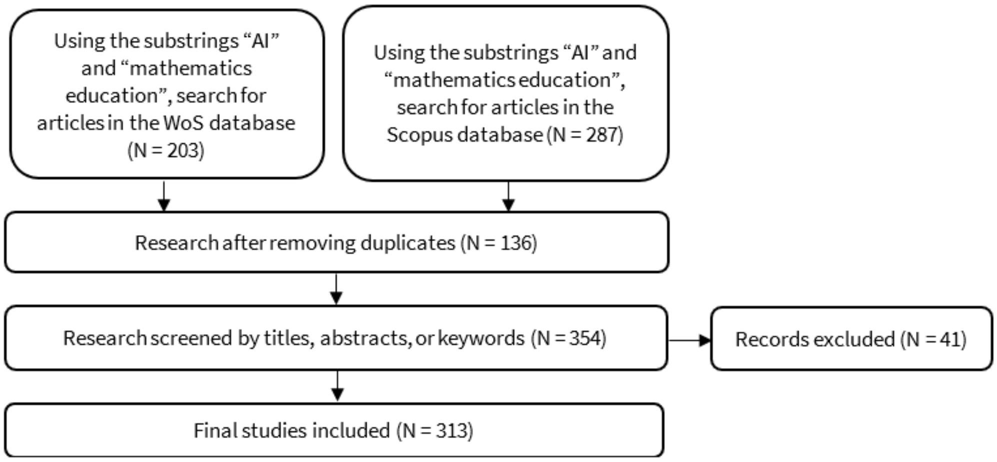

Figure 2. Flowchart of publication selection process (Source: Authors' own elaboration)

- No specific exclusion criteria were applied based on the type of study design or methodology, as the aim was to capture a broad view of research trends in this area. However, duplicate records were removed during the data cleaning process, ensuring that each publication was counted only once.

The inclusion criteria were created to include current research on AI in mathematics teaching. Exclusion criteria made ensuring that the emphasis was on excellent, peer-reviewed research that was in line with the goals of the study. English's dominance as the main language for scholarly discourse in this topic is reflected in the decision to exclusively include English-language publications. In addition, information on the tools and processes used to increase the reproducibility of the research is detailed in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) diagram.

We found 203 records in the WoS database and 287 records in the Scopus database. 136 duplicated records were removed from the combined database, and the remaining 354 publications were filtered again in the biblioshiny platform. All articles written other than English language were removed. Subsequently, the final collection of 313 publications was retained for bibliometric mapping analysis (**Figure 2**).

The data selection process followed the PRISMA guidelines, as outlined in **Figure 2**. This systematic process ensures transparency in how studies were selected, screened, and included in the final analysis. After searching the databases, we identified an initial set of 490 publications. These were then filtered to remove duplicates and non-relevant studies, resulting in a final collection of 313 publications for analysis.

Coding and Analysis of Data

The study employed the following bibliographic analyses, each designed to address different aspects of research trends in AI in mathematics education:

Publication and citation trends: The study analyzed the annual growth in publications and citations to capture the overall trajectory of the field. This analysis helps identify periods of rapid development and interest in the topic.

Country and institution analysis: The study assessed the geographical distribution of publications and citations to identify the most active countries and institutions. This analysis highlights where most research activity is concentrated and which institutions are leading the field.

Keyword and topic trends: The most frequently used keywords were analyzed to detect emerging topics and research foci within AI in mathematics education. This provides insights into the evolving nature of the field and the key areas of interest for researchers.

To ensure the accuracy and efficiency of the bibliometric analyses, Biblioshiny for Bibliometrix software tool was used. This tool, integrated with the R programming environment, was applied for the bibliometric analysis of publications. Biblioshiny enables a wide range of visualizations and statistical analysis of bibliometric data. While alternative bibliometric analysis packages exist, such as CitNetExplorer (van Eck & Waltman, 2014) and VOSviewer (van Eck & Waltman, 2010), Biblioshiny is one of the preferred tools for educational research as it can use WoS and Scopus data together (e.g., Dallaqua et al., 2023; Dao et al., 2023). The decision to use Biblioshiny was based on its flexibility and ability to handle large datasets while providing detailed insights into author collaboration, citation networks, and keyword trends. The R programming environment was utilized to create this application because of its adaptability, simplicity in integrating it with other graphical and statistical tools, and speedy upgrades and integration. Consequently, the most popular author keywords, the most productive nations, and international cooperation networks, as well as citations in the publications were examined using the Biblioshiny package in the R environment. The search query was first used on January 15, 2024.

Table 1. The main data of the collection

Description	Value
Timespan	1987-2023
Sources (journals, books, etc.)	254
Articles	166
Conference papers	82
Book chapters	27
Book	13
Proceedings papers	49
Average citations per document	5.730
Authors	927
Authors of single-authored documents	77
Single-authored documents	82
Co-authors per document	3.130
International co-authorships percentage	8.902

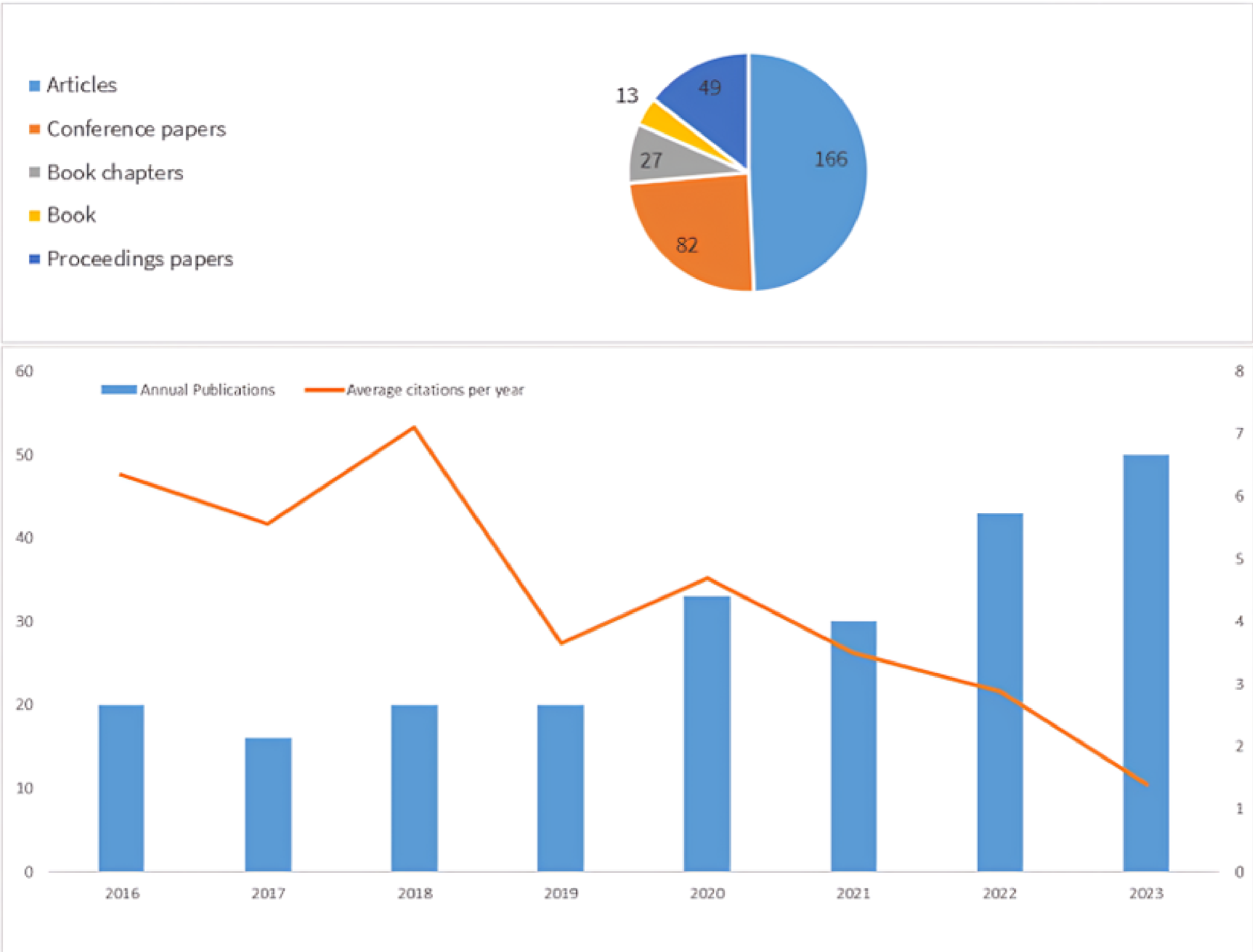

Figure 3. From 2016 to 2023, annual publications and average citations per year on AI in mathematics education (Source: Authors' own elaboration, using Biblioshiny software)

RESULTS

Results of the First Research Question

Table 1 contains general information about the dataset examined in the study. 254 distinct sources published 313 publications. The collection's percentages of articles (n = 166) and conference papers with proceeding papers (n = 131) were 49% and 39%, respectively. Book and book chapters (n = 40) made up only 12% of the overall collection. Since the first article related to AI in mathematics education was published in 1987, the number of articles has significantly expanded annually, with 20 published in 2018, 33 in 2020, 43 in 2022, and 50 in 2023, respectively (**Figure 3**).

There are 1,011 author appearances in the publishing collection, written by 927 different writers (with an average of three co-authors per document). 82 single-authored documents were published by 77 single writers. With 1,931 citations obtained by the

Table 2. Ranking of the top ten countries of output in terms of publications and citations

Order	Country	Total papers	Percentage (%)	Total citations	Percentage (%)
1	The USA	241	49.8	624 (#1)	60.9
2	China	62	12.8	88 (#3)	8.7
3	Australia	31	6.4	109 (#2)	10.7
4	Portugal	27	5.5	3 (#10)	0.2
5	Spain	26	5.4	36 (#6)	3.5
6	Canada	23	4.8	64 (#4)	6.3
7	Germany	21	4.4	14 (#8)	1.3
8	South Africa	21	4.4	21 (#7)	2.2
9	Turkey	16	3.4	60 (#5)	5.8
10	Brazil	15	3.1	4 (#9)	0.4

publication collection at the time of this analysis, the average number of citations for each publication was 5.73. Nonetheless, 112 documents, or 33.2% of the collection, have not been cited.

AI technologies were introduced into mathematics education in the 1980s, with early applications focusing on computer-based tutoring systems and problem-solving tools. Over time, advancements such as ML and NLP revolutionized these tools, enabling more sophisticated interactions. Rule-based intelligent tutoring systems designed to provide step-by-step solutions emerged in the 1980s. The emergence of dynamic geometry software integrating AI for visualisation tasks is in the 1990s. The adoption of ML algorithms for performance prediction and personalised feedback occurred in the 2000s, and the expansion towards deep learning models for analysing student behaviour and cognition occurred in the 2010s. Increasing integration with robotics and gamified environments for collaborative learning became common in the 2020s.

Figure 3 displays further data regarding the yearly amount of publications and average citations per year from 2016 to 2023.

Results of the Second Research Question

Table 2 presents the ranking of the top ten countries with the most publications and citations. **Table 2** also shows how the study has received global attention, which countries have contributed more to this field, and which countries have the highest scientific impact. First place went to the USA (n = 241), next to China (n = 62), and Australia (n = 31). With 27 and 26 publications, Portugal and Spain ranked fifth and sixth, respectively. With between 15 and 23 publications for each, the remaining five countries are Canada, Germany, South Africa, Turkey, and Brazil. The USA scored first again (n = 624) according to the number of citations, followed by Australia (n = 109), China (n = 88), and Canada (n=64). Following in order were Turkey and Spain with 60 and 36 citations, respectively, then South Africa and Germany with 21 and 14 citations. The first result that stands out in **Table 2** is the leadership of the USA. The USA accounts for 49.8% of the publications on AI in mathematics education with a total of 241 articles. According to **Table 2**, China and Australia are in the top 3. China ranks second with 62 publications, accounting for 12.8% of the total publications. China ranks third in this field, receiving 8.7% of citations, indicating that it has an important place in the literature. Australia is third in total publications with 31 articles (6.4%) and has the second highest number of citations with 109 citations (10.7%). When looking at the rankings of other European and Latin American countries, Portugal is fourth with 27 articles and Spain is fifth with 26 articles. However, Portugal has a lower impact in terms of citation counts with 0.2%. Spain has a relatively higher academic impact with 36 citations (3.5%). Brazil is another country in Latin America that enters **Table 2** with 15 articles (3.1%) and 4 citations (0.4%). Canada is sixth in the publication rankings with 23 articles (4.8%). Canada has a high academic impact in this field with a total of 64 citations (6.3%). Germany ranks seventh with 21 articles (4.4%) and 14 citations (1.3%). South Africa is included in **Table 2** with 21 articles (4.4%) and 21 citations (2.2%). Turkey ranks ninth with 16 articles (3.4%) and has a high academic activity with a total of 60 citations (5.8%).

Figure 4 provides a detailed visualization of the global research network of 28 countries involved in cross-border collaboration. **Figure 4** also allows us to better understand the academic connections between countries, their collaborations,

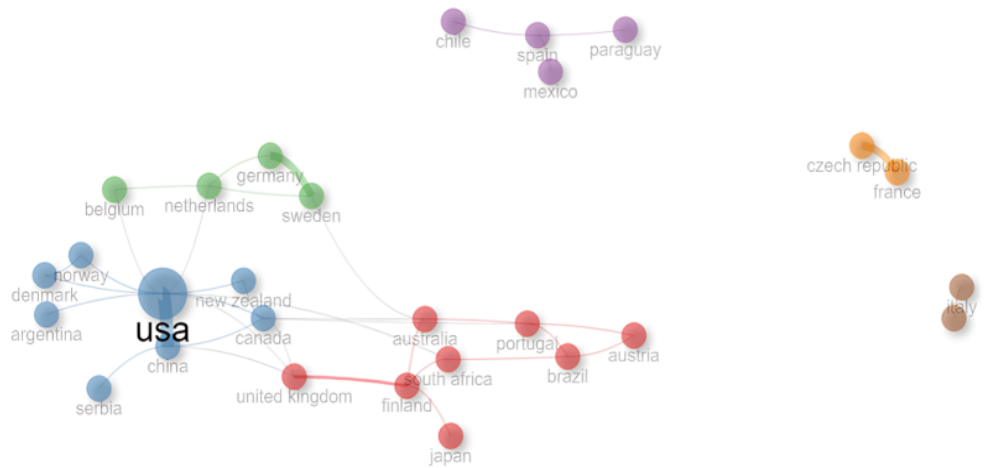

Figure 4. Network of 28 countries that are partners engaged in cross-border collaboration (Source: Authors' own elaboration, using Biblioshiny software)

Table 3. Top ten sources with the most papers published

Source	h-index	TC	n	WoS core collection
Lecture Notes in Computer Science	5	59	17	N/A
Educational Studies in Mathematics	4	96	6	SSCI-Q2
Canadian Journal of Science Mathematics and Technology Education	3	12	5	ESCI-Q1
International Journal of Mathematical Education in Science and Technology	3	52	4	ESCI-Q3
Mathematics Education Research Journal	3	26	3	ESCI-Q2
ZDM–Mathematics Education	3	37	7	SSCI-Q2
Australian Educational Researcher	2	13	2	SSCI-Q3
Ceur Workshop Proceedings	2	13	6	N/A
Cognitive Science and Mathematics Education	2	23	2	N/A
Computers & Education	2	63	3	SCIE-Q1

Note. TC: Total citations & n: Number of publications

and the contribution of international collaboration to the field. In **Figure 4**, every node stands for a country. Numbers of publications are represented by the sizes of nodes, while the thickness of the lines connecting nodes indicates the degree of cross-country collaboration. Six distinct clusters can be found. The United Kingdom (UK) and seven other countries (Finland, Japan, Australia, South Africa, Brazil, Portugal, and Austria) make up one of the two largest groups (red). Eight nations make up the second largest cluster (blue), with the USA at the center. The USA appears to be the country with the most collaborations, strengthening the USA's scientific influence in the field of AI in mathematics education. Group 3 and group 4 both have four elements. The third group consisted of Spain, Chile, Mexico, and Paraguay (purple), and the fourth group (green) had Belgium, Germany, Sweden, and the Netherlands. Countries from the European continent such as Germany, Spain, and Portugal play an important role in the network and other European countries. **Figure 4** also includes countries with more limited cooperation. These countries are usually represented by smaller nodes surrounding the network and are connected to a limited number of countries. The last two clusters, the Czech Republic and France, and Italy and Bulgaria, respectively, have just two partners.

A few nations that are absent from **Table 2** but included in **Figure 4** are the UK, Finland, Japan, Austria, Chile, Mexico, and Paraguay. These nations do not rank in the top 10 with the highest production because they engage in international collaboration in this area.

Results of the Third Research Question

Table 3 lists the top ten sources including information on h-index, total number of citations, and number of published articles. The ranking in **Table 3** is made according to the h-index values of the journals. The h-index is an important metric that measures the impact of a journal or resource in the field. This list provides researchers with access to the key publications in the field. Lecture Notes in Computer Science (LNCS) stands out as the source with the most publications with 17 articles. "LNCS" series stands out with its h-index of 5. This shows that LNCS is strong not only in terms of the number of articles but also in terms of their impact. Educational Studies in Mathematics, The Canadian Journal of Science Mathematics and Technology Education, and the Mathematics Education Research Journal are important sources where studies focusing on mathematics education are published. Especially, "Educational Studies in Mathematics" journal is the most cited journal with 96 citations. It is considered a reference source on the integration of AI in mathematics education. The journal "Computers & Education" is included in the science citation index expanded (SCIE)-Q1 index and has a high academic impact with 63 citations. ZDM–Mathematics Education journal has an SSCI-Q2 index and attracts attention with 37 citations. The book series LNCS, including its subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics published 17 papers at the time of this analysis, while other journals and proceeding books published more than ten articles. The top 10 publications obtained 340 citations overall (1,931), which made up just 17.6% of all citations, and published 55 articles in total (245), which made up 22.4% of the collection. Of the 10 most popular publications, in the WoS core Collection, two of them are in the first quartile (Q1), three of them are in the second quartile (Q2), and two of them are in the third quartile (Q3). Furthermore, only one journal is qualified for the SCIE collection, three journals are qualified for the emerging sources citation index (ESCI) collection, and three journals are for the social science citation index (SSCI) collection

Results of the Fourth Research Question

Figure 5 displays a word cloud analysis of the 50 most frequent author keywords in the collection. Higher frequency keywords are displayed in a larger font size and are positioned closer to the clouds' centers. Bigger keywords in these word clouds indicate more significant areas for AI in mathematics education study. The most crucial term is mathematics education, which is followed by education, mathematics, STEM education, and AI. Robotics, computational thinking, intelligent tutoring systems, active learning, and ML are the other crucial keyword terms.

Figure 6 provides a more thorough examination of the co-occurrence network of these 37 author's keywords. Every node is a keyword, and a node's size corresponds to how frequently a term occurs. These authors' keyword terms are grouped into five distinct categories. Articles focusing on mathematics education, AI, computational thinking, problem-solving, and other seventeen terms compose the largest cluster (red). The second cluster (blue) includes articles discussing mathematics, education, robotics, STEM, ML, and four other keywords. The third cluster (green) includes articles focusing on three keywords; technology, science, and engineering. Articles concentrating on problem-solving and intelligent tutoring systems are included in the fourth cluster (purple). The last cluster (orange) includes two keywords, natural language and processing.

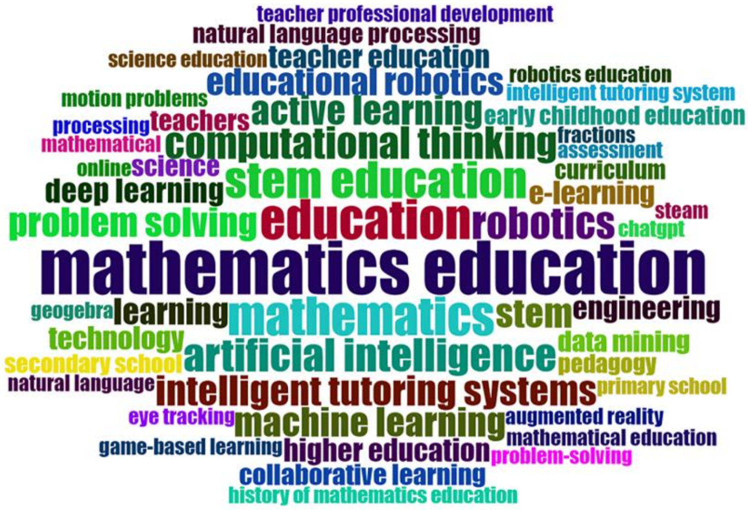

Figure 5. 50 most popular author keywords as word clouds (Source: Authors' own elaboration, using Biblioshiny software)

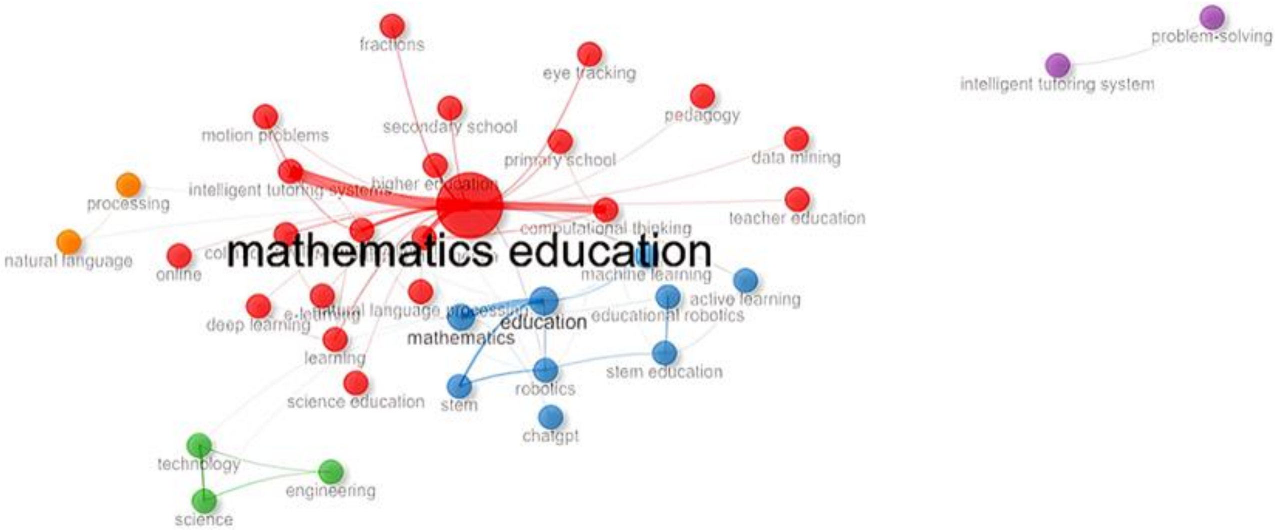

Figure 6. Co-occurrence network for the top 37 author keywords in popularity (Source: Authors' own elaboration, using Biblioshiny software)

Important themes in a subject of study can be visualized with a thematic map. We produced a thematic map based on author keywords (**Figure 7**). The research field's topics are identified and keyword clusters are produced by this analysis. Centrality (x-axis) and density (y-axis) are the two dimensions of the map. Density describes how a subject develops, whereas centrality describes how significant a given theme is. The thematic map's 2 × 2 matrix produces four quadrants, with the size of the cluster representing the keywords' frequency of recurrence. The motor themes that receive the most discussion in the field are located in the upper right quadrant. The literature has several specialized themes, which may indicate that the idea is now used in a wide range of fields, including studies on deep learning, computational thinking, engineering education and data mining.

The niche themes, which are distinct but well-developed, are located in the upper left quadrant. The literature has several niche themes, including studies on learning analytics, data handling, meta-analysis, and mathematics education research. The topics that are regarded as basic, with relatively small degrees of development but high levels of centrality and relevance to the literature are located in the lower right quadrant. The map shows that the majority of the themes are basic, covering mathematics, AI, students and instruction. The themes that are emerging or declining are located in the lower left quadrant. In this quadrant, there are not many themes including behavioral data, system, and computer science.

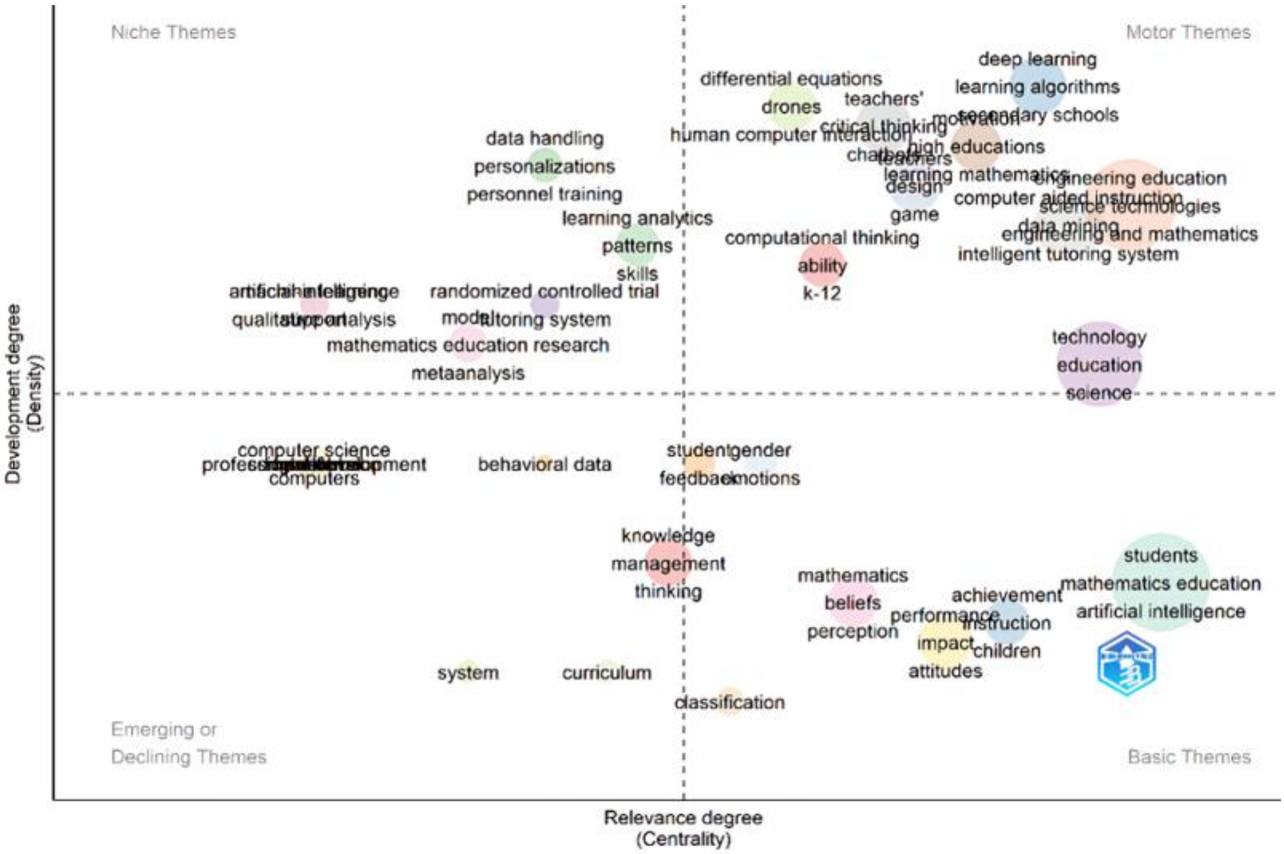

Figure 7. Thematic map of research (Source: Authors' own elaboration, using Biblioshiny software)

DISCUSSION

Discussion of the Results of the First Research Problem

Articles are the most numerous publication type in the dataset. It shows that the subject of AI in mathematics education is intensively covered, especially in the form of academic articles. This number is an expected result since journal articles are considered the most frequently consulted source in academic research and generally have the highest scientific value. In the context of mathematics education, this suggests that the field is becoming increasingly theoretically grounded and researchers are adopting stricter scientific standards to validate their findings. Among conference papers, which are among the types of academic research that enable the exchange of ideas at the international level, 82 studies were found as conference papers and 49 studies were found as proceeding papers. Because these types of research have the chance to be discussed in academic environments, they are strong candidates for being developed and published as articles in a journal. In addition, the high number of conference proceedings and proceeding type publications allows for the rapid sharing of information in this field and suggests that the field has a dynamic structure. In most countries, researchers mostly use articles and conference proceedings for academic promotion. Therefore, they prefer to publish their research in these genres. Books and book chapters are sources that include more in-depth and comprehensive analyses. It is seen that the theoretical foundations of this field and detailed academic reviews are covered with 27 book chapters and 13 books. Books and book chapters are valuable as sources that form the theoretical basis of the field and provide in-depth discussions. AI applications in mathematics education require theoretical analyses on how it can be integrated with pedagogical models by going beyond mere instrumental use. The existence of these types of publications shows that such comprehensive analyses are also being conducted in the field.

The fact that 927 different authors contributed indicates that the subject is addressed by a wide range of researchers and that there is a multifaceted academic collaboration. 927 different authors contributed and the prevalence of multi-authored publications reflects the multidisciplinary approach and the culture of collaboration in the field. This situation points to a new research ecosystem formed at the intersection of disciplines such as mathematics education, computer science and educational technologies. The 82 single-authored studies show that individual research also has an important place in the field and that some studies are conducted by certain researchers alone. The average number of authors per document is 3.13, indicating that multi-authored studies are common in the field and that research carried out through teamwork is gaining ground. The 8.9% international collaboration percentage emphasizes that cross-border academic interactions also have an important place in the studies and that this topic attracts international attention. 8.9% of international co-operation shows that common solutions are developed for globally shared problems. Since the use of AI in mathematics education is a universal transformation process, different country practices provide opportunities for comparative studies. The increasing number of publications from 2016 to 2023 also shows that this topic is attracting more and more academic attention. The average number of citations is 5.73, measuring the academic interest in these studies and the contribution of each publication to the field. The increase in the annual number of publications reveals that the research field is becoming increasingly popular and the interest in studies in the relevant field is increasing. Despite this being a relatively new topic, our analysis reveals an increase in academic interest, as evidenced by the annual number of publications increasing from 20 in 2016 to 50 in 2023.

The results of a limited number of studies examining AI in mathematics education through bibliometric analysis indicate a similar trend (bin Mohamed et al., 2022; Kaushik et al., 2021). It can be seen in **Figure 3** that despite the increase in the number of publications in recent years, the number of scientific studies has been irregular until the last 3 years. While the number of publications tends to rise over time, there have been instances where fewer studies have been published in comparison to the same period last year. Consistent with the results of this study; Chen et al. (2020) found that the number of publications generally increased every year. In research on AI, it can be said that the trend is mostly upward, but the growth rate is not sharp. This situation reveals that there is a need for more studies on AI in mathematics education. Despite the increase in publications, the fact that the growth rate is not sharp indicates that research capacity is still developing and more work is needed in certain areas. For example, AI-supported learning analyses, learner models, automated feedback systems and ethical issues may not yet be adequately addressed.

Discussion of the Results of the Second Research Problem

AI in teaching and learning mathematics is spreading across countries. The majority of nations employ AI to raise educational standards. Articles on AI in mathematics education were published in 57 countries. The USA has the most publications in this field and makes a strong contribution to the literature. The USA also has the highest number of citations in this field. These results show that studies from the USA are frequently referenced in other countries and that these studies have a high academic impact. The US-centred international co-operation cluster is connected to a large number of countries. This may be indicative of network metrics such as high degree centrality and high betweenness centrality (mediating position). The fact that the USA receives a large number of citations shows that it is a determinant not only in the production of publications but also in the circulation of scientific knowledge. Australia’s high citation rate highlights the impact of the articles published and the academic impact of this country. bin Mohamed et al. (2022), who examined AI studies in mathematics education with systematic analysis, concluded that the majority of the research was conducted in the USA. Hwang and Tu (2021) and Kaushik et al. (2021) also stated that the majority of research is concentrated in the USA and the UK. At the point of this study, the USA and Australia were the only two nations to obtain more than 100 citations. Academics from underdeveloped or developing countries are absent, as developed countries (such as the USA, the UK, China, Canada, or Australia) often make significant contributions to the global literature. Countries such as the USA, Australia, the UK and Canada stand out with their advanced universities, research centres and funding systems. Thanks to this infrastructure, more research is carried out, high quality and cited publications are produced, and international collaborations are supported. Germany has made a strong contribution in terms of the number of publications, but the academic impact is more limited. We can say that South Africa has made a significant contribution in this field, but the academic impact remains at a moderate level. South Africa has significant academic activity in the topic of AI in mathematics education, despite the limited number of contributions from the African continent. Brazil’s low citation rate suggests that the publications have a more limited international impact. Portugal and Brazil rank in the top 10 in terms of total publications, yet they only have 3 and 4 citations, respectively, to their publications. Turkey’s citation percentage reflects that a significant portion of the published studies have received inter-national attention and highlights Turkey’s scientific contribution in this field. However, studies from countries with low development levels have almost never been found.

Since most of the publications are in English, countries whose mother tongue is English are in an advantageous position. This makes countries such as the UK, the USA, Australia and Canada more effective in information production. The low number of contributions from non-developed countries can be attributed to a lack of both technical infrastructure and a culture of academic co-operation. As seen in the example of South Africa, some countries show potential but the number of connections in the network remains limited. This situation shows that global inequality in knowledge production persists and developing countries need to be supported in this field.

Of the 57 countries producing research on the subject, 28 have entered into international cooperation. The intensive cooperation between these countries indicates the existence of a regional scientific network. The UK and seven other countries form one of the two largest groups. Eight other countries, with the USA at the center, constitute the second largest cluster. According to the inference obtained from these results, AI studies in mathematics education are mostly produced by two large groups based in the UK and the USA with international collaboration. Group 3 and group 4 both cooperate with four countries. In the third group, Spain, Chile, Mexico and Paraguay; the fourth group includes Belgium, Germany, Sweden and the Netherlands. Collaborations between European countries (e.g., Germany, Sweden, Belgium, and the Netherlands) show that geographical and cultural proximity facilitates research partnerships. This is also the case among Latin American countries (Chile, Mexico, and Paraguay). This suggests that regional clustering is widespread. In the third group, a country from Europe, two countries from South America and one country from North America interact. In the fourth group, 4 European countries cooperated. The Czech Republic and France, as well as Italy and Bulgaria, constitute groups with only two partners. In these collaborations, the cooperation of countries from the European continent comes to the fore. Germany, in particular, is a prominent center on the European continent and has cooperation connections with many European and American countries. Asian countries such as China are also included in the cooperation network and have close connections, especially with the USA. South Africa is the country participating in this cooperation network from the African continent and its connections are more limited. South Africa’s presence in the international network shows that the African continent is still developing in the field but has potential for cooperation. The most general result from international collaborations is that research is generally carried out by researchers from countries in Europe and the Americas. The most striking result is that countries with less developed levels do not participate in cooperation.

Based on these results, there is a need to analyze the cultural contexts of the countries where research is concentrated. This will also contribute to future cross-cultural studies. Another interesting result obtained in this section is that countries such as the UK, Finland, Japan, Austria, Chile, Mexico, and Paraguay, which are not among the top 10 countries in the list of countries that conduct the most research, are among the countries that have initiated international cooperation in this field. This result may have been obtained because researchers in these countries attach importance to collaborative research rather than individual work. Countries such as the UK, Japan, and Finland are not in the top 10 in terms of number of publications, but they play active roles in the network. This is very important in terms of scientific visibility and strategic partnership.

It has been demonstrated that collaborations improve the quality of publications, especially between nations with developed research infrastructure and those with developing research capacity. Because of the added value of different viewpoints and combined resources, co-authored papers in these networks frequently appear in high-impact journals. International collaborations frequently result in topical diversity, which makes it possible to investigate subjects like region-specific issues or cross-cultural uses of AI in mathematics education. Collaboration networks can let teachers share cuttingedge teaching strategies and resources, allowing them to modify AI applications for different learning environments and enhance student performance. By bridging gaps in access to technology and expertise, international collaborations can advance educational equity and allow underrepresented regions to reap the benefits of AI-driven advancements.

Discussion of the Results of the Third Research Problem

The most published source on the subject is LNCS with 17 publications. LNCS is a series where conference proceedings are usually published and offers a wide range of articles on computer science and AI. This shows that current developments in how AI is applied in mathematics education are frequently shared in this resource. Prominent journals related to mathematics education (Educational Studies in Mathematics, Canadian Journal of Science Mathematics and Technology Education, Mathematics Education Research Journal, ZDM–Mathematics Education, Cognitive Science and Mathematics Education) stand out when the distribution of journals with the most publications on the topic is analyzed. The articles in these journals include theoretical and applied studies on how to integrate AI into mathematics education processes. International Journal of Mathematical Education in Science and Technology and Computers & Education are effective resources in both computer science and education fields. These results showed that the studies published in these journals convey how AI can be used in education and its contributions to mathematics education to a wide audience. Since the subject of AI is also related to technology and computer science, journals that included computer applications in education are among the most popular ones (Lecture Notes in Computer Science, Computers & Education). Apart from these, two sources that publish on education are on the list of the most published ones (Australian Educational Researcher and Ceur Workshop Proceedings). In a similar study, Hwang and Tu (2021) found that the publications were published in educational journals such as Computer & Education, Journal of Educational Psychology, Journal of Computer Assisted Learning. Computer & Education journal was obtained jointly for both studies. One of the other two journals is an education journal and the other is a computer education journal. Cognitive Science and Mathematics Education is a book that provides a general introduction to basic ideas in cognitive science as well as an overview of cognitive theory and its direct implications for mathematics education.

Of the top 10 most popular publications in the WoS core collection, two were included in the Q1, three in Q2, and two in the Q3. According to the quartile values, it can be concluded that more publications are needed in Q1. In addition, only one journal was included in the SCIE collection, three in the ESCI collection and three in the SSCI collection. According to these results, it can be said that the number of publications in SSCI and SCIE journals is not sufficient, and more publications are needed in these indexes. These findings suggest that additional publications are required in these indexes and that the quantity of articles in SSCI and SCIE journals is insufficient.

Discussion of the Results of the Fourth Research Problem

Keywords such as “mathematics education”, “artificial intelligence”, and “STEM education” are written in large fonts, indicating that these topics are heavily covered in research. Terms such as AI, robotics, and STEM also come to the fore, highlighting the basic trends in research on AI in education. This shows that the increasing interest in the field is not limited to mathematics education but also creates a field of study integrated with STEM and educational technologies. Concepts such as “computational thinking” and “intelligent tutoring systems” are also written in capital letters, indicating that innovative approaches in education are gaining interest among researchers. These terms emphasize the potential of AI-supported teaching systems and their contribution to the development of thinking skills in education. Similarly, Chen et al. (2020) stated that the most frequently used keywords related to AI in education are education, ML, robotics, AI, deep learning, system and educational robotics.

The co-occurrence network of keywords is divided into five different clusters, with the red cluster, which includes terms such as “mathematics education,” “artificial intelligence,” and the largest cluster, focusing on how AI is integrated into mathematics education. The other clusters are subcategories of research, focusing on more specific themes, particularly STEM, robotics, and learning systems. The connections between terms like “problem-solving” and “intelligent tutoring systems” illustrate the impact of AI on mathematics education. This suggests that research highlights the importance of technological tools for improving students’ problem-solving skills. Terms like “machine learning,” “robotics”, and “computational thinking” also have striking connections. This diversity shows that AI applications are not limited to one field but are used in a variety of educational disciplines and require different methodological approaches.

CONCLUSIONS AND RECOMMENDATIONS

This is the study to offer comprehensive quantitative statistics on the worldwide research subject of AI in mathematics education utilizing extensive bibliographic data. This research is highly helpful in examining and giving a thorough summary of how this field of study has developed, as well as identifying the major contributors and their partnerships. The results show a steady increase in publications over the past decade, indicating growing interest in AI's role in enhancing mathematics education. The findings of this study show that AI is increasingly used and widespread in mathematics education in the most general sense. Studies in the literature also indicate that AI-based learning systems provide lesson plans tailored to students' individual needs, allowing them to personalize their learning processes. This situation shows the potential of AI-supported systems to evaluate student performance more quickly and effectively in the future and to increase the quality of education by providing feedback to teachers. In addition, the rapid development of AI technologies and the tools that AI provides to develop students' problem-solving and some higher-level thinking skills may have a profound impact on mathematics education in the future. In particular, with the further spread of AI-supported learning environments, it is possible for teaching processes to become more efficient, effective and motivating. These developments may lead to the strengthening of mathematics education not only in classroom environments but also on digital platforms. In the future, educational platforms supported by AI can analyze students' problem-solving processes, provide them with instant feedback and make individual learning paths more effective. AI-supported teaching tools can deepen students' mathematical understanding. In this context, teachers can use intelligent courseware that provides students with personalized feedback based on AI in the classroom. In addition, intelligent software systems that guide students in problem-solving processes can be used to develop students' mathematical thinking skills. Professional development opportunities need to be increased for teachers to effectively implement such software.

The interaction between AI and mathematics education can not only contribute to the field of mathematics but can also play an important role in disciplines such as engineering and science. Developing AI-based problem-solving skills in these disciplines can help students solve complex engineering problems. Similarly, AI-supported tools that improve mathematical analysis skills in social sciences can provide more effective acquisition of data analysis and statistical skills.

The integration of AI technologies into mathematics education will shape not only the learning processes in the classroom but also the future of education policies. Education politicians and decision-makers should create strategic plans for the adaptation of these technologies to the education system and provide the necessary infrastructure and training opportunities for teachers to use these tools effectively. In this context, it is essential for governments and educational institutions to develop policies that encourage the wide-scale integration of AI-supported educational technologies.

The points that need to be investigated after these inferences from the results of the research can be listed as follows:

1. The geographical distribution of research highlights the dominance of developed countries, such as the USA, China, and Australia, in contributing to this field. However, there is a clear underrepresentation of studies from developing regions, suggesting the need for more global collaboration.
2. AI-driven tools like intelligent tutoring systems and adaptive learning environments are gaining traction in mathematics education, but there remains a gap in their practical application and integration in real-world classrooms.
3. Most current research focuses on short-term outcomes, leaving room for future studies to explore the long-term impacts of AI on student learning and engagement.
4. While AI holds great promise for transforming mathematics education, more research is needed to address the identified gaps, particularly in fostering collaborative learning environments, ensuring equitable access to AI tools, and conducting longitudinal studies to assess sustained impacts.
5. These days, AI is developing so quickly that more studies addressing its effects on mathematics education will be published. This implies that the data presented in this re-search will change and evolve quickly in the future. As a result, it is important to regularly do this kind of analysis to closely track the advancement of this field of study.
6. The current study incorporates certain dynamics of AI in mathematics instruction using bibliometric analysis. Future researchers must carry out further study on the effects and advantages of AI in education, particularly with regard to the improvement of students' mathematical skills, to further expand our understanding of and applications for AI in education. The adoption of AI in mathematics education is in serious demand, but the possibility that practitioners, namely teachers, may lack the necessary skills in this regard should not be ignored. If further studies demonstrate the success of AI in learning with diverse student populations, this will be a positive incentive for teachers to incorporate AI into their classroom instruction.
7. Teachers must have confidence in their students' ability to utilize AI technology. Because the new generation, called generation Z, is already constantly intertwined with technology. Therefore, it has a significant predisposition to use AI applications. It may be recommended to expand the use of AI applications that enable mathematics teaching by providing personalized guidance or support to students. The use of educational data mining, one of the AI data analysis methods, can offer innovative results to investigate the factors affecting students' learning outcomes and find relationships between students' learning behaviors and performances. Future research could specifically focus on how the adoption of AI approaches (both in terms of teaching application and data analysis) contributes to mathematics education. In this way, AI-mathematics education interaction can be achieved in a more practical way.
8. Although everything seems positive in the short term regarding the application of AI to mathematics education, it is recommended that longitudinal studies are required in various educational institutions to determine whether negative

results will arise in the long term. Long-term studies will allow researchers and interested parties to conduct critical analysis in which both the good and bad aspects of AI can be evaluated.

9. This study addresses the applications of AI in mathematics education from a broad perspective, but more specific areas of research are needed in the future. In particular, it is important to examine how AI-supported learning systems affect students from different socio-economic levels. In addition, further research aimed at understanding teachers' interactions with AI can redefine teacher-student relationships. The widespread application of AI-based learning tools should be further developed both pedagogically and technically. In this context, more training opportunities are needed for teachers to use these tools effectively. Although AI has the potential to make students' learning processes more dynamic and personalized, the ethical and security dimensions of these technologies should also be considered. By continuing to advance both theoretical and practical applications of AI in education, researchers and policymakers can drive meaningful progress in achieving sustainable educational systems globally.

Limitations

While this study provides valuable insights into AI research in mathematics education, there are some limitations that need to be recognized. The analysis was restricted to publications in English. This approach, while common in bibliometric studies, may have missed important contributions published in other languages, especially in non-English speaking regions. However, these studies are thought to be in the minority.

Cleaning, data scanning, and correction were completed manually before the analytic procedures; as a result, errors may have occurred that affected our study. Keywords were chosen at the discretion of the researchers. Nonetheless, due diligence has been exercised in the keyword selection process, with the study's fundamental theme serving as the exclusive focal point.

Data are only from WoS and Scopus databases, which are comprehensive but may not cover all relevant publications. Studies published in other databases such as IEEE Xplore, Google Scholar, or regional academic repositories may also be included.

Biblioshiny tool was used for the study. This tool combines metadata files with different structures created from Scopus and WoS databases. This file cannot be read by VOSviewer, CiteSpace, or any other bibliographic tool including SciMAT. Therefore, a new data processing scheme will be needed when it comes to data processing and data analysis for different bibliographic tools. In future research, other analysis tools (such as BibExcel and Gephi) that can provide different analyses and produce a larger number of clusters may be considered instead of Biblioshiny.

Future Research Directions

In this section, in line with the results and discussions obtained in the research, suggestions for future research on the role of AI in mathematics education are presented.

1. In teacher education programmes, seminars and project-based courses should be increased to discuss current issues such as the use of AI in mathematics teaching at the academic level.
2. The use of AI in mathematics learning processes should not only be an instrumental support but should also be associated with basic teaching theories such as constructivist learning, individualisation and cognitive load theory.
3. Joint projects with disciplines such as computer engineering should be encouraged in graduate thesis studies in the field of mathematics education. Thus, both technical infrastructure and pedagogical knowledge can be produced together.
4. In developing countries such as Turkey, how AI-based mathematics education solutions differ in cultural contexts should be investigated and models appropriate to local needs should be developed.
5. Experimental studies focusing on the potential of AI algorithms extracting meaning from student performance data to detect mathematical misconceptions should be increased.

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