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AI in mathematics education: A bibliometric analysis of global trends and collaborations (2020-2024)

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Abstract

This bibliometric study analyzes the scientific production on the use of artificial intelligence (AI) in mathematics education between 2020 and 2024. Based on a sample of 384 documents extracted from 155 international sources, the study evaluates emerging trends, collaboration patterns among authors and countries, and the main themes related to the use of AI in mathematics education. The analysis was conducted using the Biblioshiny tool in RStudio, generating network maps and thematic graphs that visualize the relationships between keywords and international collaborations. The results show that China and the United States lead in terms of scientific productivity and international collaboration. A growing interest in the use of generative AI emerges, including deep learning and ChatGPT, in educational contexts for the purpose of assessment of learning. The present study provides a clear overview of current dynamics in AI research in mathematics education, highlighting opportunities for interdisciplinary collaboration.

Keywords: mathematics education, artificial intelligence, machine learning, collaboration networks, emerging trends

INTRODUCTION

In recent years, artificial intelligence (AI) has emerged as a central topic in the discussion on educational innovation. According to UNESCO, the integration of AI in educational systems can enhance learning personalization and promote inclusion by providing resources and support tailored to the needs of each student (UNESCO, 2019). However, there is a clear paradox: while many educational systems are investing in the implementation of AI, the lack of technological infrastructure and adequate teacher training poses a significant challenge (Kim, 2024; Taani & Alabidi, 2024). Despite these difficulties, various studies suggest that AI can play an important role in education using intelligent tutoring systems and educational data analytics to personalize learning programs (Holmes et al., 2019; Porayska-Pomsta et al., 2023). In this sense, Gouia-Zarrad and Gunn (2024) demonstrated that the use of ChatGPT in a differential equations course not only fostered active learning through interactive numerical methods but also contributed to personalizing the educational process, adapting it to the needs of each student.

The growing interest in AI in education is driving a global trend that promotes its adoption in classrooms to optimize the teaching process and prepare students for a future characterized by automation and the intensive use of digital technologies (Egara & Mosimege, 2024; Wu et al., 2022). This suggests the need for a profound reform of current educational systems, which still prioritize content delivery over the development of critical cognitive skills and abilities. Proposals to incorporate AI include the use of intelligent tutors, adaptive assessment systems, and automated learning platforms that provide real-time feedback and adjust educational materials to meet the individual needs of students (Donnelly-Hermosillo et al., 2020; Jia et al., 2024; Liu et al., 2024). In this context, studies on ChatGPT's performance in solving mathematical problems highlight its effectiveness in basic reasoning and calculation tasks, although difficulties persist with

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Contribution to the literature

- This bibliometric study gives an overview of current dynamics in AI research in mathematics education.
- Some trends highlighted in previous reviews are confirmed, like the interest in students' performance and learning assessment (cognitive domain), and motivation and attitude (affect domain), so as the leadership of USA.
- Other trends are characteristic of recent development of the field, like the focus on generative AI and specific AI tools and the emerging leadership of China. While expected, personalization of learning has not been explicitly detected as a central theme in recent research in AI and mathematics education.

more complex concepts, such as derivatives and spatial geometry, underscoring the need for complementary teacher involvement (Almarashdi et al., 2024; Udias et al., 2024).

The concept of AI in mathematics education refers to the use of algorithms and computational models to enhance the learning and teaching of mathematics. Holmes et al. (2019) define it as a set of techniques that enable machines to imitate human cognitive skills, such as solving mathematical problems or making data-driven decisions. AI includes machine learning algorithms that allow educational systems to adapt to the individual needs of students and tools that foster logical and abstract thinking, both of which are essential in mathematics (Jia et al., 2024). Furthermore, AI offers powerful tools for developing key competencies in mathematics, such as logical thinking, problem-solving, and abstract reasoning (Angeli & Giannakos, 2020; Jia et al., 2024). Recent systematic reviews highlight that AI-driven tools like ChatGPT not only support personalized learning but also foster greater interest and curiosity in mathematical exploration, despite limitations in conceptual representation and modeling (Almarashdi et al., 2024). Similarly, Getenet (2024) emphasized the potential of ChatGPT to support pre-service teachers in developing diverse problem-solving strategies, highlighting its relevance for teaching mathematical concepts in primary education.

Most experts agree that AI is transforming education and creating a demand for more highly qualified professionals (Zhang et al., 2023), capable of understanding and working with these emerging technologies (Engelbrecht & Borba, 2024; Gupta et al., 2023; Hwang & Tu, 2021). Moreover, AI should serve to enhance human capabilities, such as creativity and critical thinking, rather than replace them (Porayska-Pomsta et al., 2023). In the context of university admissions tests, studies indicate that ChatGPT can outperform average students in reasoning tasks, although it still needs to improve its accuracy in advanced-level questions (Udias et al., 2024).

The integration of AI in mathematics education can be considered a methodological approach that leverages computational capabilities to enhance teaching and learning. This approach helps to address educational challenges more effectively by using technologies that simplify instruction, offering new ways to visualize and understand complex mathematical concepts (Jia et al., 2024; Lee, 2024). AI thus facilitates more personalized and effective learning, tailoring content to the pace and learning style of each student (Lee, 2024; Liu et al., 2024).

The inclusion of AI in mathematics education is not limited to the creation of algorithms or the use of advanced software. It can enhance students' cognitive abilities through tools that promote creativity and the resolution of complex problems. Furthermore, recent studies indicate that AI is not an exclusive competence of computer science fields, but can be integrated transversally into the mathematics curriculum, incorporating its applications into various areas of knowledge (Relmasira et al., 2023). In this regard, some experts suggest the need to develop new assessment methodologies to accurately measure the impact of AI on the development of mathematical competencies (Dimitriadou & Lanitis, 2023; Yeo et al., 2024).

One of the key benefits of AI in mathematics education is its ability to personalize learning. Intelligent tutors and adaptive learning systems, which utilize AI algorithms, can assess students' progress in real time, identify their strengths and weaknesses, and adjust content and activities to meet the individual needs of each student. In this regard, a recent study suggests that intelligent math tutors significantly improve conceptual understanding and problem-solving skills compared to traditional teaching methods (Porayska-Pomsta et al., 2023; Zhang et al., 2023). This approach allows students to progress at their own pace, which is particularly beneficial in mathematics, where differences in understanding abstract concepts can create significant performance gaps.

Another advantage of AI is its ability to provide instant and accurate feedback. This helps students correct their mistakes in real time and understand the underlying reasoning behind their incorrect responses. AI-based systems can analyze student answers and generate immediate, specific feedback, saving teachers time and enhancing the learning process by enabling immediate adjustments to students' understanding and approach (Lee, 2024; Liu et al., 2024). Additionally, the feedback provided by AI systems can be far more detailed than what is typically offered by teachers in a conventional classroom, including suggestions for improving conceptual understanding and recommendations for additional resources for independent learning (Park & Lim, 2023).

On the other hand, AI systems designed for mathematics education can present students with complex problems that require deep analysis and a methodical approach to solve them. This helps them develop critical skills for breaking down problems into more manageable parts, identifying patterns, and applying different problem-solving strategies. Also, AI can simulate real-world scenarios, ranging from modeling natural phenomena to solving financial or engineering problems, providing an authentic context for mathematical learning, and encouraging the application of mathematical skills in practical situations (Hwang & Tu, 2021). This approach promotes more relevant and meaningful learning, increasing students' motivation, engagement, and participation by using gamified learning environments. Additionally, AI can create more immersive learning experiences through technologies like augmented reality and virtual reality, allowing students to explore mathematical concepts in three-dimensional environments or interact with mathematical objects in a tangible way (Van Vaerenbergh & Perez-Suay, 2022). Simultaneously, AI offers significant improvements in assessing student performance and monitoring their progress. AI-based learning platforms can collect and analyze large amounts of data on students' interactions with mathematical content, providing detailed insights into their performance. These tools can be used to create adaptive assessments that adjust their level of difficulty based on the student's performance, offering a more accurate evaluation of their math skills (Qiu, 2023).

Despite its many benefits, the integration of AI in mathematics education also presents several challenges. Ethical concerns (Porayska-Pomsta et al., 2023), such as student data privacy, biases in AI algorithms (Cecere et al., 2024), the potential for misuse, and equitable access to advanced technologies (Yang et al., 2024), must be addressed to ensure a fair and effective implementation. Furthermore, it is necessary to train teachers in the use of these tools and ensure that the required technological infrastructure is available in all educational institutions (Copur-Gencturk et al., 2024; Lee & Yeo, 2022). The objective of this bibliometric review is to describe the scientific production related to mathematics education and AI over the past 5 years.

METHOD

For this quantitative-bibliometric study, the Web of Science (WoS) database was used, with searches conducted through titles, keywords, and abstracts. To extract bibliographic references related to AI and mathematics education, the search function was refined cyclically. Initially, the search included the term

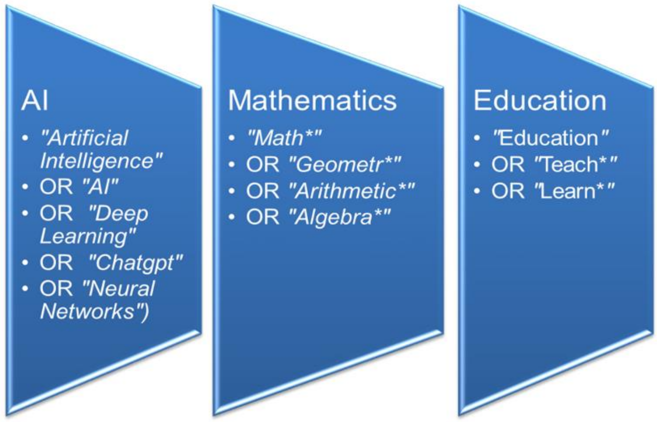

Figure 1. Search function to extract data from the database WoS (Source: Authors' own elaboration)

"artificial intelligence" along with terms related to mathematics education. The need to refine the search function arose due to the inclusion of studies from the healthcare field in the initial sample of 1055 records.

To broaden the inclusion of studies related to AI, various terms related to AI were incorporated, while excluding healthcare-related studies was achieved by including terms associated with different branches of mathematics as well as terms related to the teaching and learning process. The final search function used (**Figure 1**) was: ("artificial intelligence" or "ai" or "deep learning" or "chatgpt" or "neural networks") AND ("math*" or "Geometr*" or "Arithmetic*" or "Algebra*") AND ("Education" or "Teach*" or "learn*").

The term "statistical*" was deliberately excluded to minimize the risk of bias, and tests were conducted to include the term "Estocastic*"–which is more related to the educational field–without yielding new records for the sample. Additionally, the search was refined by restricting it to records categorized as "articles," and further limited to the SSCI and ESCI indexes, as publications specific to mathematics education are included in these two indexes. The search was also refined to categories related to education (education educational research, education scientific disciplines, special education, and psychology educational) and limited to the last 5 years (2020-2025). The final sample consisted of 384 records, with the search conducted on 9 September 2024. Subsequently, the Biblioshiny program in RStudio v.4.0.4 (Aria & Cuccurullo, 2017) was used to generate various bibliometric analyses with the obtained sample, including thematic map visualizations and network analyses.

RESULTS

Data Analysis

For the data analysis process, two main categories of keywords extracted from the scientific articles were used: the keywords provided by the authors (author's

Table 1. Main sample information

Time period	2020:2024
Sources (journals, books, etc.)	155
Documents	384
Average years from publication	1.26
Average citations per document	4.53
Average citations per year per document	1.74
References	1
Document types	
Articles	324
Articles: early access	60
Document content	
Keywords plus (ID)	594
Author's keywords (DE)	1440
Authors	
Authors	1251
Author appearances	1468
Single-author documents	30
Multi-author documents	1221
Authors collaboration	
Single-author documents	30
Documents per author	0.31
Authors per document	3.26
Co-authors per document	3.82
Collaboration index	3.45

keywords) and the keywords plus, which are generated from the references cited in the articles.

The Biblioshiny platform integrated into RStudio, version 4.0.4, developed by Aria and Cuccurullo (2017), was employed for the construction and visualization of figures, network maps, and thematic maps. This tool allowed for the effective analysis of the relationships between keywords and the identification of key trends within the sample of articles analyzed.

Sample Information Table

Of the 384 documents that make up the sample, **Table 1** presents key information, including the number of keywords retrieved in its two categories: keywords plus and author's keywords. Additionally, detailed information is provided about the sources and authors, considered the main variables in this analysis. The time period for the present study spans from January 2020 to September 2024, during which data was collected from 155 sources, including journals, books, and other academic publications. The selection of this relatively brief period is justified by the incorporation of generative AI into education, both in general and in the field of mathematics education (see **Table 1**).

Table 1 presents the results of the search conducted. A total of 384 documents were analyzed, with an average publication age of 1.26 years, highlighting the recent inclusion of scientific literature in the studied field. Additionally, the average number of citations per document is 4.53, and the average citation rate per year per document is 1.74, reflecting sustained influence over time. Furthermore, 324 of the published works (84.38%) are classified as scientific articles. Among these, 60 documents were categorized as early access articles. In the analysis of keywords, 594 terms were identified through keywords plus (ID) and 1440 keywords provided by the authors (author's keywords or DE). This difference underscores a greater specificity in the terms provided by the authors themselves.

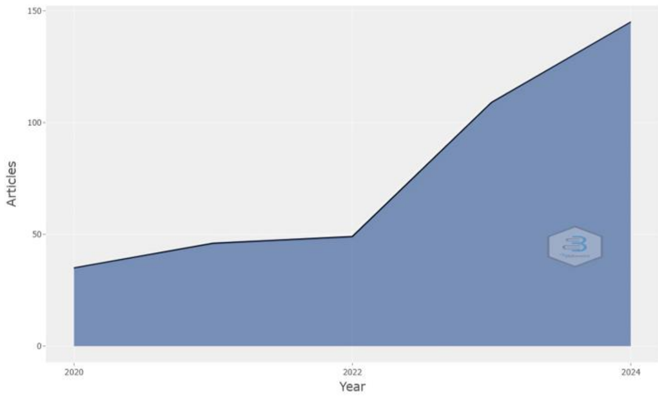

Figure 2. Annual production of scientific articles on mathematics education and AI (2020-2024) (Source: Authors' own elaboration)

Regarding the authors, the total number of researchers involved in producing the 384 documents amounts to 1251. However, there were 1468 author appearances, suggesting that some researchers participated in multiple studies. In contrast, it is noteworthy that out of the 1251 authors, only 30 worked on single-authorship documents, while 1221 participated in multi-authored publications. Additionally, the average number of documents per author is 0.31, with an average of 3.26 authors per document and 3.82 co-authors per work, resulting in a collaboration index of 3.45. This confirms the current trend toward collaboration in contemporary scientific production.

Figure 2 shows a clear upward trend in scientific production on mathematics education and AI during the study period. Starting in 2020, the number of published articles was relatively low, with fewer than 50 articles. However, there was a steady increase, leading to a doubling of scientific output by 2024. During the first three years (2020-2022), production grew at a moderate pace, reaching approximately 50-60 articles per year, reflecting the emerging interest in research on the application of AI in mathematics education, which was still in an exploratory phase.

In 2023, a significant jump in the number of published articles is evident, suggesting a growing academic interest in the topic, likely driven by technological advancements and their implementation in the educational field. Production reaches its peak in 2024, with annual publications exceeding 140 articles. This suggests the consolidation of AI as a tool for studying

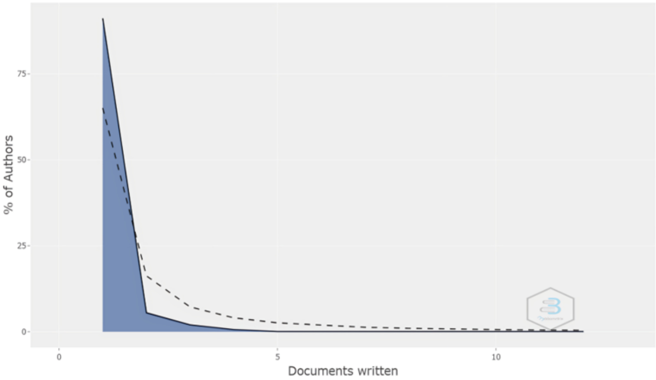

Figure 3. Distribution of scientific productivity (Lotka's law) (Source: Authors' own elaboration)

educational processes and an increased investment in projects and studies in this area.

Next, the graph titled "the frequency distribution of scientific productivity" corresponding to the frequency of scientific productivity is analyzed. The x-axis represents the number of documents written by the authors. The y-axis shows the percentage of authors who have written that number of documents.

In **Figure 3**, a pronounced downward trend is observed, where a significant majority of authors have written only one document. As seen in **Figure 3**, more than 75.0% of the authors have contributed just one paper, indicating a predominance of researchers making sporadic contributions. From this point, the curve drops sharply and follows a quasi-exponential downward trajectory as the number of articles per author increases.

This behavior follows a typical pattern known as Lotka's law in scientific studies, an adjustment based on the Pareto distribution, which posits that a small number of authors generate a large proportion of the total scientific output, while the majority contribute with a limited number of publications. In this case, we can observe that very few authors have written five or more documents, and the values approach zero for those who have produced ten or more articles. This confirms that only a minority of researchers are responsible for the majority of scientific output in this field.

This productivity pattern has clear implications in terms of scientific impact: the most prolific authors tend to accumulate a higher number of citations and, therefore, gain greater visibility and recognition within the academic community. Additionally, the low proportion of authors with multiple documents could be related to the collaborative nature of contemporary scientific research, where advances are often the result of teamwork and interdisciplinarity.

Figure 4, in a TreeMap format, visually organizes the most frequent topics in scientific production related to AI and mathematics in education. The largest block is "education," which aligns with how the records were extracted from the database. The second largest block is "students" (35 mentions), focusing on AI and mathematics to improve student learning. In this context, the relevance of terms such as "mathematics" (32 mentions), "achievement" (30 mentions), and "science" (29 mentions) highlights the connection between AI and mathematics education with broader scientific education. The use of AI to measure and

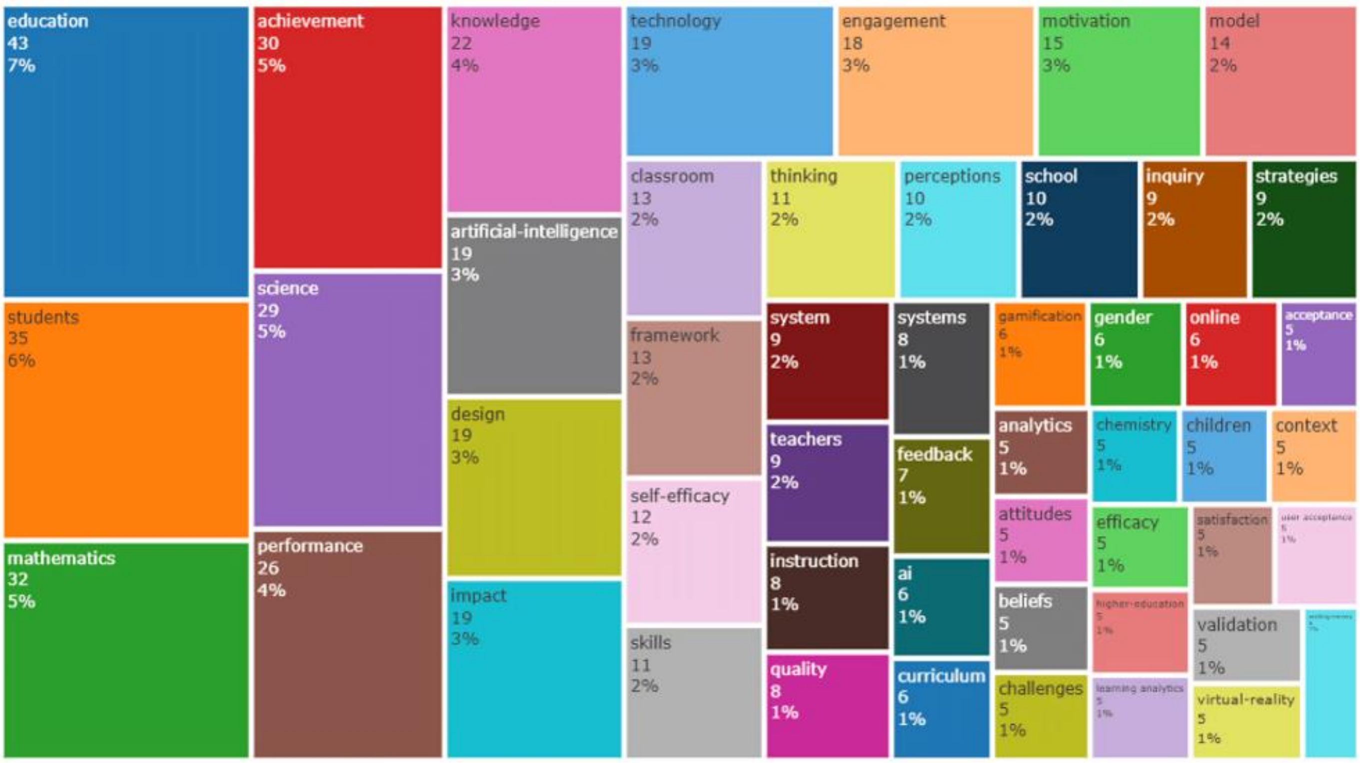

Figure 4. Keywords TreeMap: Number of keywords (Source: Authors' own elaboration)

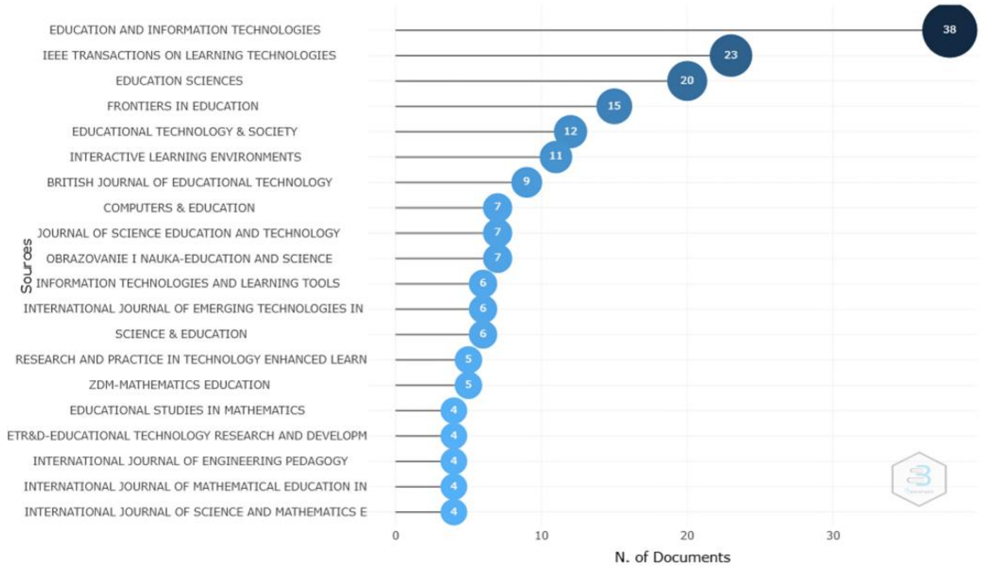

Figure 5. Distribution of the most relevant journals (Source: Authors' own elaboration)

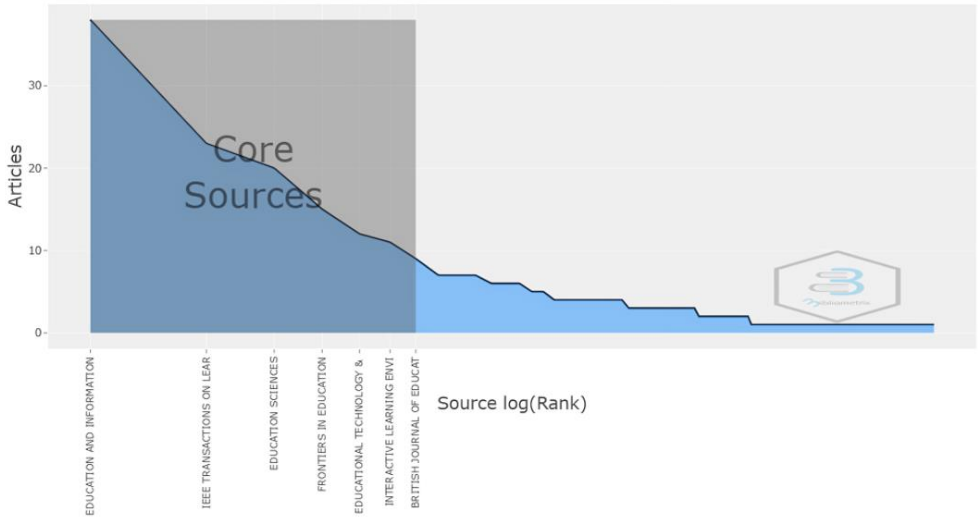

Figure 6. Distribution of the most relevant journals (Bradford's law) (Source: Authors' own elaboration)

improve academic performance in mathematics appears to be a central focus of the academic output, as also indicated by the presence of related terms such as "performance" (26 mentions) and "knowledge" (22 mentions). Another significant term is "artificial-intelligence" (19 mentions). Additionally, the mention of "impact" (19 mentions) suggests that studies are evaluating the actual effect these technologies are having on educational outcomes, which is crucial for validating the effectiveness of AI-based tools.

The following analysis presents the most relevant sources in terms of the number of documents published on mathematics education and AI during the study period.

Figure 5 shows that the journal "Education and Information Technologies" stands out as the leading source, with 38 documents (18.6%). It is followed by "IEEE Transactions on Learning Technologies" with 23 documents (11.2%) and "Education Sciences" with 20 documents (9.8%). These three sources account for a significant portion of the total production, indicating they are the preferred journals for authors in this field. Starting with "Frontiers in Education" (15 documents, approximately 7.3% of the total), the productivity across other sources is more evenly distributed. Between the fourth and tenth sources, the number of documents ranges from 12 to 6, representing between 2.9% and 5.8% of the total for each source. The last sources on the list, such as "ETR&D-Educational Technology Research and Development", "International Journal of Engineering Pedagogy", and others, each contributed 4 documents, accounting for approximately 2.0% of the total production per journal.

It is also interesting to analyze **Figure 6** in terms of Bradford's law. This law states that, in any area of research, a small number of journals will publish a large proportion of the most relevant articles, while a greater number of journals will publish significantly fewer

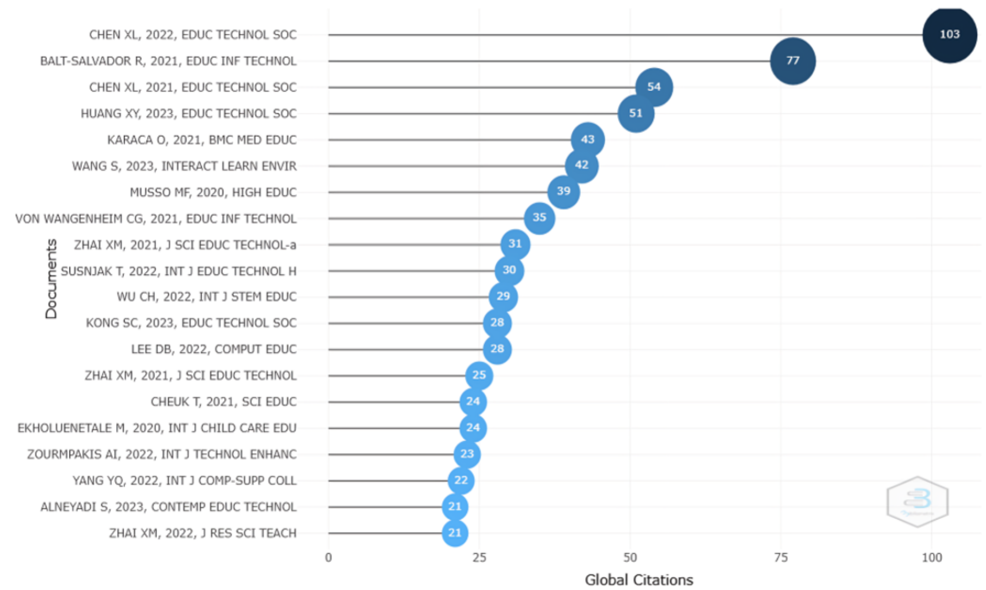

Figure 7. Globally most cited documents (Source: Authors' own elaboration)

articles on the same topic. It is a principle that allows journals to be categorized into zones of productivity (core, intermediate zone, and peripheral zone), based on their publication frequency in a specific field. Bradford's law suggests that the number of articles published follows a geometric progression.

According to this criterion, we could divide the journals into three zones: The first zone (core) is made up of the journals that together represent approximately one-third of the total publications. Given that there are a total of around 220 documents and the top three journals (Education and Information Technologies, IEEE Transactions on Learning Technologies, and Education Sciences) collectively publish 81 documents, these journals represent the core. The second zone, or intermediate zone, would include journals that together publish the next third of documents. In this case, journals like Frontiers in Education and Educational Technology & Society, which account for a total of around 50-60 documents, belong to the second zone according to Bradford's law.

Finally, the third zone (peripheral) would include the remaining journals, which publish between 4 and 9 documents. Next, a qualitative and quantitative analysis of the most cited documents globally in the field of mathematics education and AI is carried out.

In **Figure 7**, it can be observed that the article by Chen, X. Li (2022), published in Educational Technology & Society, leads the ranking with 103 global citations, positioning the author as a reference in terms of scientific impact. In second place is the work by Balt-Salvador, R. (2021), published in Education and Information Technologies, with 77 citations. This high number of citations could suggest the presence of emerging topics or new areas of interest that have quickly and expansively captured the attention of the scientific community. The third most cited article is another work by Chen, X. L. (2021), also in Educational Technology & Society, with 54 citations, underscoring the continued relevance of the author in the field and their significant contribution to educational technology. Other notable articles include studies by Huang, X. Y. (2022) with 51 citations and Karaca, O. (2021) with 43 citations.

At a qualitative level, the most cited articles were published in a wide range of scientific journals, including Educational Technology & Society, Education and Information Technologies, BMC Medical Education, and Interactive Learning Environments. This reflects thematic diversity in the areas of focus, encompassing educational technology, and interactive learning technologies, among others. This variety of sources demonstrates that the field of educational technology is multidisciplinary, with research applied in various educational and technological contexts.

Another interesting analysis includes the countries where scientific research related to the specific field of this study has been conducted.

In **Figure 8**, it is observed that China is the most cited country, with a total of 581 citations, positioning it as the most influential nation in terms of scientific impact in the field analyzed. In second place is the United States, with 314 citations, less than half of China's total. Spain ranks third with 119 citations, making it the most influential European country in this analysis. Turkey and the United Kingdom follow, with 74 and 58 citations, respectively. Countries such as Argentina, South Korea, Germany, Japan, and Brazil have citation counts ranging from 30 to 45. At the lower end, countries like Greece, Nigeria, Canada, and Sweden have between 15 and 30 citations.

Another relevant analysis in this study focuses on keywords plus and author's keywords.

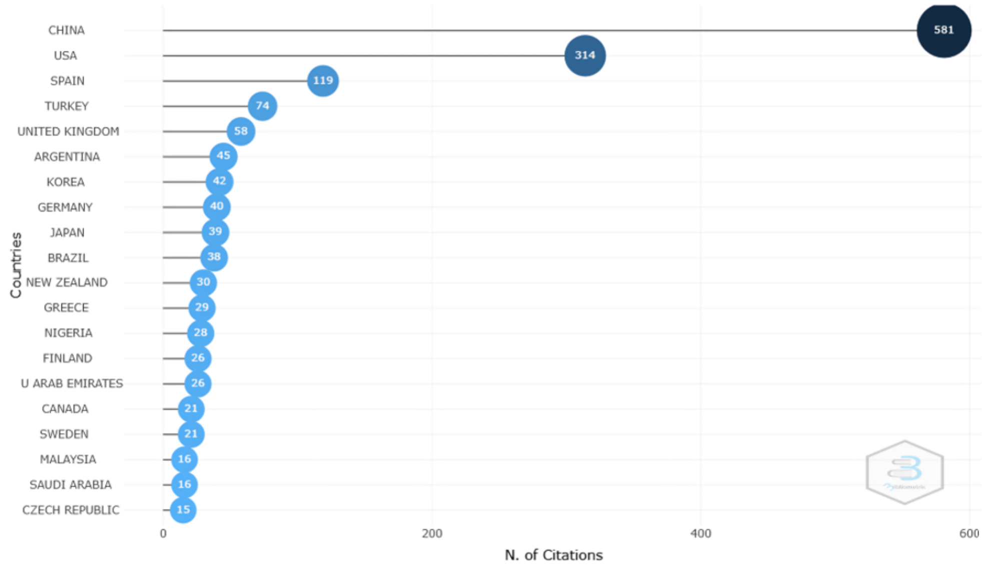

Figure 8. Number of citations by country (Source: Authors' own elaboration)

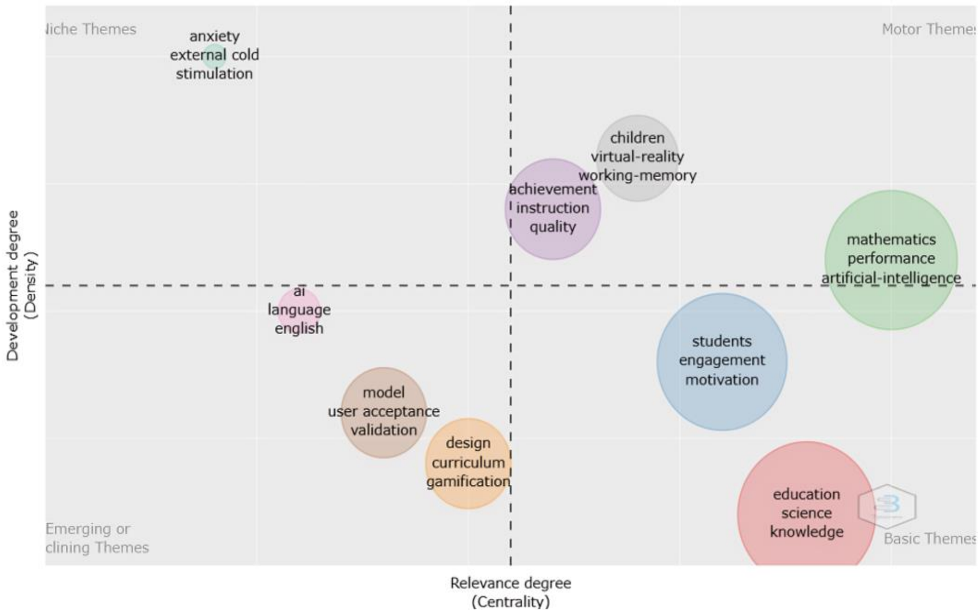

Figure 9. Thematic map of keywords according to conceptual structure (Source: Authors' own elaboration)

Figure 9 presents the distribution of keywords based on two parameters: degree of development (density) and degree of relevance (centrality). Among the most relevant and well-developed themes (located in the upper-right quadrant as "motor themes"), keywords such as "mathematics," "performance," and "artificial intelligence" stand out, reflecting the significance of AI and mathematics in educational research.

In contrast, terms like "AI," "language," and "English" appear in the lower-left quadrant, indicating they are emerging or declining themes, with lower centrality and density. The upper-left quadrant includes terms such as "anxiety" and "external cold stimulation", which represent niche topics in educational research, likely applied to very specific or interdisciplinary contexts.

As for the size of the bubbles, the largest and most prominent is for "mathematics, performance, artificial intelligence", indicating that it is a central and highly developed theme in the research. Other smaller topics, such as "design," "curriculum," and "gamification," are positioned with lower density, suggesting they are less developed but still relevant themes.

In **Figure 10**, the most central and developed author's keywords include terms such as "mathematics," "e-learning," and "task analysis," which are also found in the motor themes quadrant. This suggests consistency in the relevance and development of these topics in the educational field. Terms like "artificial intelligence," "higher education," and "machine learning" are represented by relatively large bubbles, indicating a significant focus on the application of these technologies in higher education.

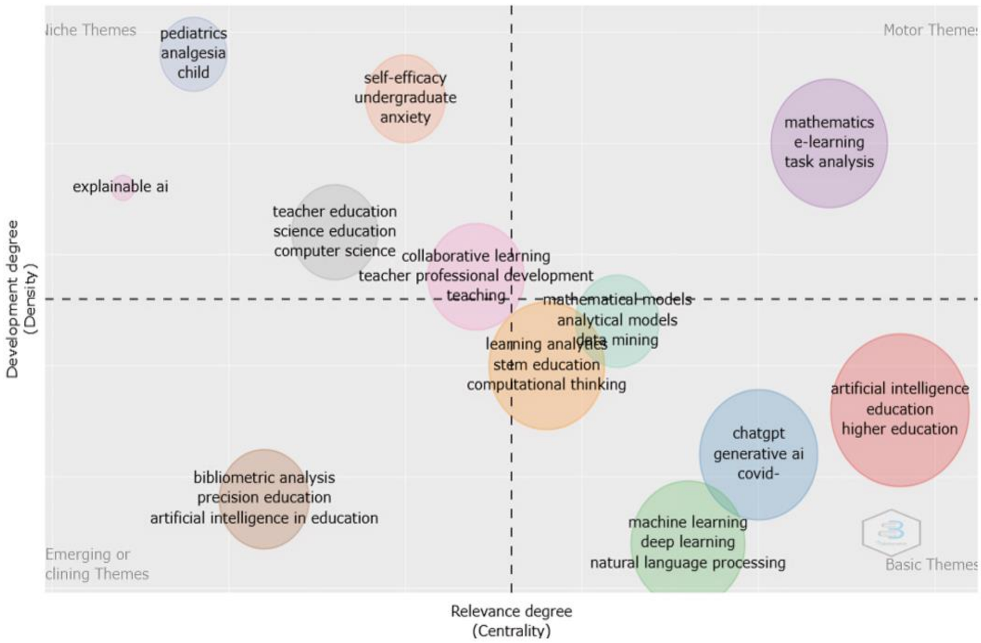

Figure 10. Thematic map of author's keywords according to conceptual structure (author's keywords) (Source: Authors' own elaboration)

Additionally, emerging terms such as "chatgpt," "generative AI," and "covid" are located in the lower-right quadrant. While their density is lower, these topics are highly relevant today and are likely to continue developing in the coming years.

The comparative analysis between keywords plus and author's keywords shows that in both maps (**Figure 9** and **Figure 10**), "mathematics" and "artificial intelligence" appear as highly central and developed themes, indicating a consistency in the importance of these topics for both authors and keyword analysis. However, in keywords plus, terms like "AI" and "language" appear as emerging, while in author's keywords, there is a focus on more specific topics such as "chatgpt" and "covid," reflecting recent interest in the direct application of AI in education. Additionally, the concept of "e-learning" has greater relevance and development in author's keywords, highlighting the importance of online education in recent years.

On the other hand, keywords plus graph shows greater thematic diversity, with topics such as "anxiety," suggesting an interdisciplinary approach to educational research. In contrast, in author's keywords, the focus is more technological and pedagogical, with terms like "deep learning" and "machine learning," indicating growing interest in the educational applications of these technologies.

Another analysis presented is the co-occurrence network of keywords plus and author's keywords, which allows for the visualization of the relationships and frequency between concepts or keywords in the scientific articles of this study. This network helps to identify how frequently certain terms are used together and how they are connected within the research.

In **Figure 11**, the largest nodes represent the most common and co-occurring terms within the conceptual structure, including "education," "students," "mathematics," and "performance," which are the most frequent and central themes in this study. Additionally, the number of lines (connections) extending from each node indicates the degree of co-occurrence with other terms. Nodes such as "education" and "students" have multiple connections to terms like "achievement," "knowledge," "skills," and "teachers," suggesting that these are integrative themes that connect with a broad range of subtopics within the educational field. The position of the nodes shows that "performance" and "mathematics" are more distant from the central nodes like "education" and "students," indicating they are less deeply connected to all other concepts compared to terms like "achievement" or "engagement." Furthermore, the clustering of terms into color-coded groups shows that the red group at the center is strongly related to education, including terms like "knowledge," "thinking," and "science," while the green group focuses more on mathematics, performance, and self-efficacy.

In the analysis of **Figure 12**, it is evident that the term "artificial intelligence" dominates the graph in size, indicating that it is the most frequently mentioned keyword by authors. Other prominent terms include "chatgpt," "machine learning," and "education," reflecting the prevalence of these technologies in educational research. The node for "artificial intelligence" shows a considerable number of connections, indicating strong links to terms such as "machine learning," "deep learning," and "natural language processing." The central position of nodes like "artificial intelligence" and "chatgpt" highlights their high interconnection with other concepts, while terms

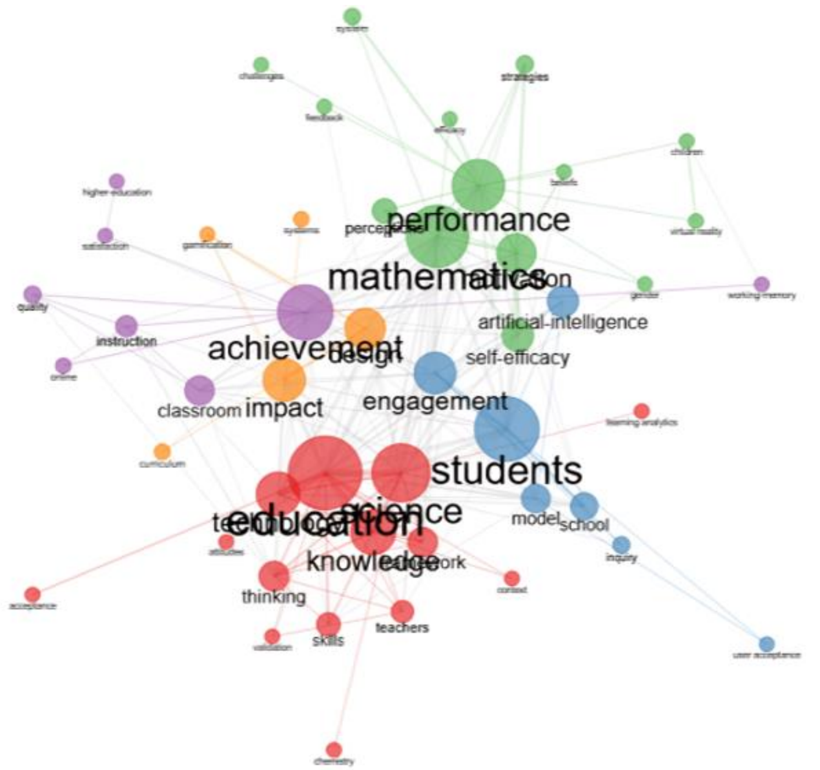

Figure 11. Co-occurrence network of conceptual structure (keywords plus) (Source: Authors' own elaboration)

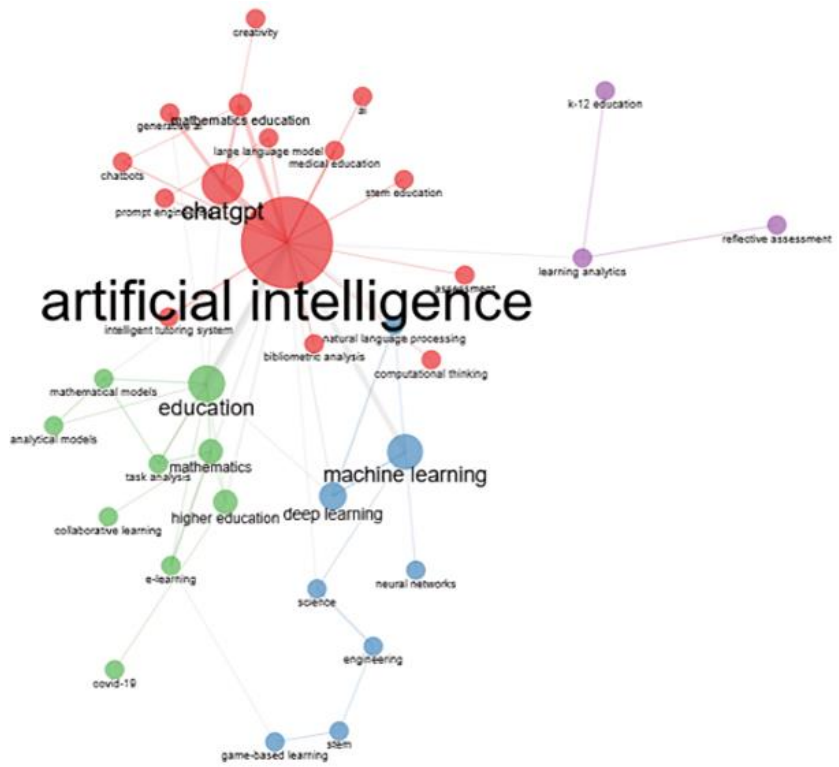

Figure 12. Co-occurrence network of author's conceptual structure (author's keyword) (Source: Authors' own elaboration)

like "covid-19" and "neural networks" appear on the periphery, suggesting they are less interconnected but still maintain relevance in specific niches.

Regarding the color-coded thematic clusters, the red cluster surrounding "chatgpt" includes terms related to "large language models," "prompt engineering," and "STEM education," due to the intersection between education and generative AI applications. In contrast, the green cluster focuses more on mathematics education and analytical models, highlighting the integration of AI technologies with mathematics learning and STEM education.

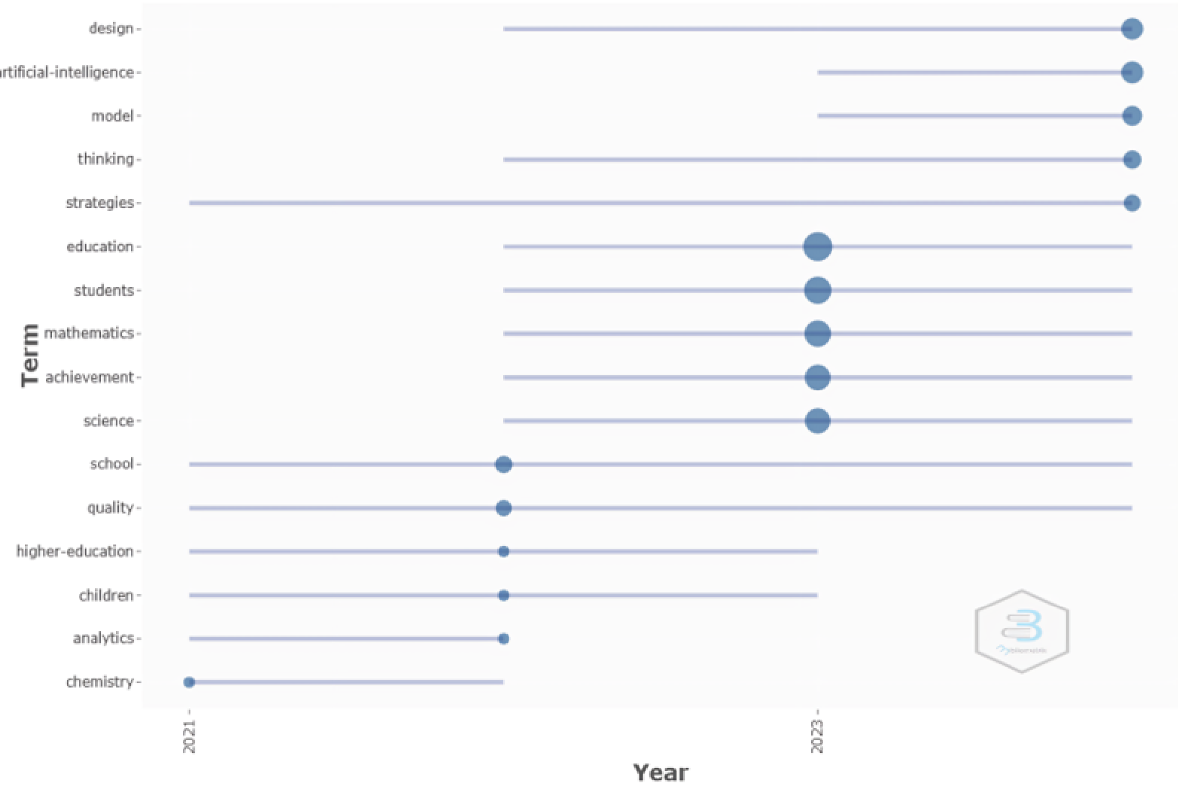

Figure 13. Trend topics (keywords plus) (Source: Authors' own elaboration)

At a comparative level, in the keywords plus graph, the most prominent and central terms are mainly related to education, students, and mathematics. In contrast, in the author's keywords graph, the dominant terms are associated with AI, especially "artificial intelligence," "machine learning," and "chatgpt." This indicates that authors are more focused on the use of advanced technologies within education. Furthermore, in the keywords plus graph, the terms tend to be more related to traditional pedagogical aspects of education, while in the author's keywords graph, the terms are more interconnected with emerging technologies and their implementation in the educational field. This suggests that the authors' perspective is more technology-centered than rooted in traditional learning structures.

Additionally, keywords plus graph shows broader thematic diversity, with nodes covering topics ranging from engagement and performance to science and skills. On the other hand, the author's keywords graph exhibits a greater concentration around specific technologies like AI, machine learning, and ChatGPT, focusing on the application of new technologies in education. Similarly, in keywords plus (**Figure 11**), the term "artificial intelligence" appears but is not central, meaning it does not dominate the conceptual structure in the general educational field. However, in author's keywords (**Figure 12**), AI is the central node, reflecting the authors' primary interest in AI applications in education.

Figure 13 shows the evolution of key terms in scientific literature from 2021 to 2023. Topics such as "artificial intelligence" and "design" became more prominent in 2023, reflecting a growing interest in the application of AI in education and the design of learning environments. Other terms like "model" and "thinking" also emerged in 2023, although their relevance in earlier years was limited or nonexistent. In contrast, terms such as "education" and "students" have had a continuous presence throughout the observed period (2021–2023). Similarly, "mathematics" maintains significant continuity over time. However, terms like "chemistry," "analytics," and "children" appeared in 2021 but became less prominent or less relevant in subsequent years.

In **Figure 14**, the authors' keywords cover a broader time range (2020 to 2024). The presence of terms such as "chatgpt," "artificial intelligence," and "machine learning" in the most recent period (2023–2024) prominently reflects their rise toward the end of the period. "chatgpt" is the most recent term to appear, specifically in 2023, associated with the immediate and growing impact of generative AI models in education. "Deep learning" and "machine learning" emerged in 2022 and continued to be relevant through 2023–2024. Additionally, keywords like "education," "higher education," and "mathematics" show notable consistency throughout the entire period. In contrast, terms such as "neural networks" and "e-learning" appeared early in 2020–2021 but seem to have lost relevance in recent years.

At a comparative level, in both keywords plus and author's keywords, AI and associated technologies play a significant role, especially towards 2023. In author's keywords, more specific terms such as "chatgpt" and

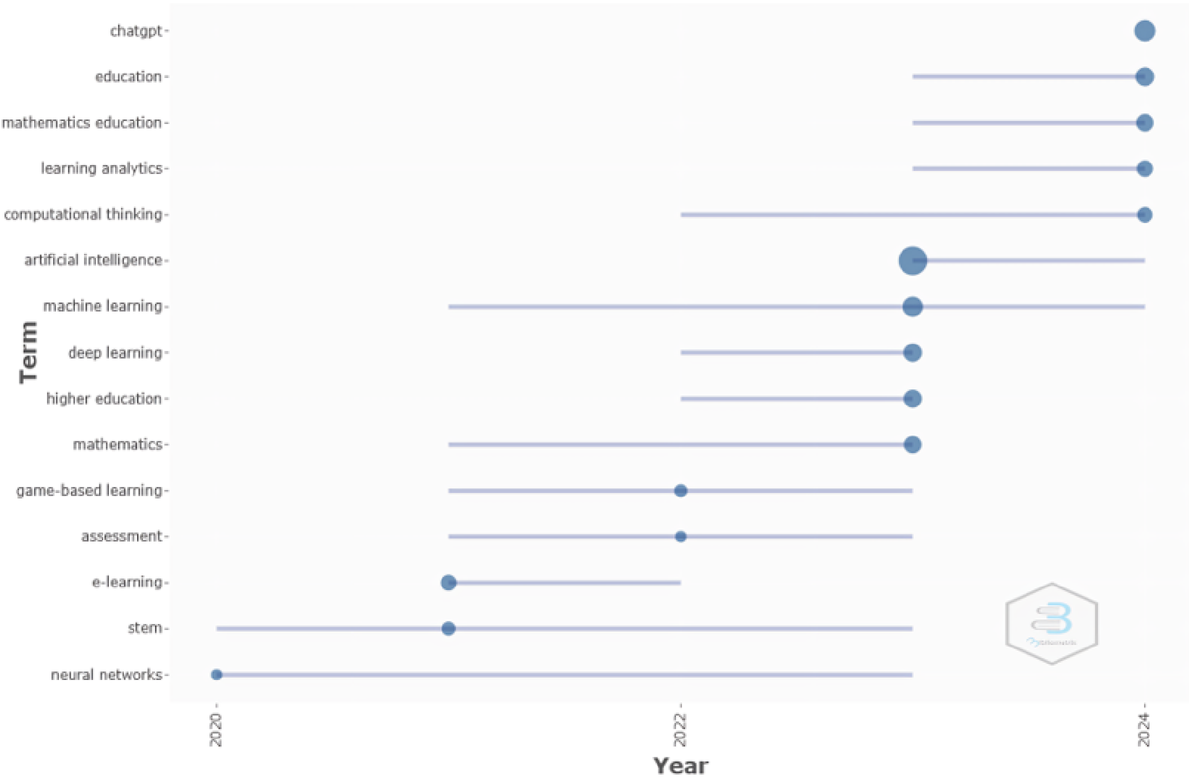

Figure 14. Trend topics (author's keywords) (Source: Authors' own elaboration)

"machine learning" emerge as recent trends. In keywords plus, the focus seems broader, with terms like "artificial intelligence" and "design" emerging without delving into specific technologies or methods. Terms like "education" and "mathematics" appear consistently over time. However, in the author's keywords graph, there is greater precision regarding advanced technologies, with terms such as "deep learning" and "chatgpt." This specificity is less evident in the keywords plus graph, where "artificial intelligence" appears as a more general term.

DISCUSSION

A comparison with a systematic review of 2021 (Hwang & Tu, 2021) highlights the continuity of the leadership of the USA, while the recent emergence of China's leadership in AI and mathematics education research is noted. Also, comparing with the same previous study, a certain difference is noted with respect to the means of dissemination used for publication, a difference perhaps partly due to the extraction of the sample, here only in the WoS database, while the Scopus database is also included in the 2021 sample.

Regarding the thematic trends, the focus of interest in student learning and in the assessment of their achievement and performance, as well as a certain interest in affective aspects is a result consistent with previous reviews (Hwang & Tu, 2021; Opesemowo & Adewuyi, 2024) and demonstrates the interest in assessing the usefulness of the use of these tools and their impact on motivation.

Moreover, the majority presence of studies in high school is a trend confirmed with respect to previous studies (Hwang & Tu, 2021), possibly due to the more challenging nature of mathematics at those levels.

Furthermore, the emergence of more specific terms regarding the AI tools used (such as ChatGPT) is a result in line with those found in other recent reviews (Opesemowo & Adewuyi, 2024) but in contrast to more dated reviews that referred to a more generic "intelligent tutoring system" (Hwang & Tu, 2021).

On the other hand, while personalization of learning has emerged as a central element in the use of AI in other narrative reviews (Engelbrecht & Borba, 2024) as well as in the aforementioned systematic review (Hwang & Tu, 2021), the above analysis does not explicitly highlight personalization of the learning process as a central focus of recent research interest in AI and mathematics education.

CONCLUSIONS

The following are the main conclusions derived from this bibliometric analysis on the scientific production related to mathematics education and the use of AI over the past five years (2020-2024).

In terms of scientific productivity, the results largely follow Lotka's law, with a vast majority of authors contributing only one article, while a small group of authors produce a disproportionately large number of publications. This finding is consistent with trends observed in most scientific fields. However, there has also been an increase in collaborations between authors from different countries in research on AI in mathematics education. On the other hand, Bradford's law, applied to the analysis of journals, reveals that a small number of sources concentrate a large proportion of the scientific output. The journals "Education and Information Technologies," "IEEE Transactions on Learning Technologies," and "Education Sciences" stand out as the primary publication channels in this field.

Regarding keywords, the analysis of keywords plus and author's keywords shows convergence around themes such as AI, mathematics, and academic performance, with research focusing on how AI can improve educational outcomes, particularly in STEM disciplines. However, it was observed that keywords plus tend to exhibit greater thematic diversity, while author's keywords are more focused on topics such as ChatGPT and deep learning, highlighting specific applications of generative AI in education.

Recent thematic trends underline the interest in the effectiveness of the use of AI in mathematics education in terms of student achievement and motivation. Personalization of learning has not been detected as a central theme, being a potential of AI that apparently remains to be further investigated. This may be due to the difficulty of assessing a personalized process and then generalizing the results to large samples.

Finally, international collaboration is a significant factor in scientific production in this field, with countries like China and the United States leading both in the number of publications and citation impact. However, it is noted that China tends to engage more in intranational collaborations, while the United States has a more internationally collaborative profile.

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