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Artificial Intelligence in Mathematics Education: A Systematic Review

Inteligencia Artificial en educación matemática: Una revisión sistemática

Inteligência artificial na educação matemática: Uma revisão sistemática

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Abstract

[Objective] This study aims to analyze the current state of research on artificial intelligence (AI) in mathematics education, its applications, and its role in teaching and learning processes. [**Methodology]** A systematic review of the literature was conducted in three stages: identification, selection, and inclusion of articles from three recognized databases, resulting in 29 articles. These articles were thoroughly analyzed to identify participants, instruments used, the country of the authors' affiliation, year of publication, type of research, methodological approach, and the role of AI in these studies. **[Results]** There is a noticeable increase in research related to AI in mathematics education, with most studies being empirical and quantitative. The most frequently used instruments are questionnaires and interviews, with half of the studies employing at least two data collection instruments. Additionally, most studies focused on intelligent learning systems to enhance learning and support teaching, particularly for online assessment. **[Conclusions]** The reviewed articles show no evidence of research at the early childhood education level and very little related to teacher training. Few studies demonstrate the use of theoretical frameworks or approaches from the Didactics of Mathematics.

Keywords: AI, artificial intelligence, intelligent tutoring systems, mathematics, mathematics education, systematic review

Resumen

[Objetivo] El objetivo de este estudio es analizar el estado actual de la investigación en inteligencia artificial en el ámbito de la educación matemática, su aplicación y rol en los procesos de enseñanza y aprendizaje. **[Metodología]** Se realizó una revisión sistemática a la literatura que sigue las siguientes etapas: identificación, selección e inclusión de artículos de tres bases de datos reconocidas, resultando 29 artículos, que fueron sometidos a un análisis minucioso para la detección de participantes, instrumentos utilizados, país de la filiación de los autores, año de publicación, tipo de investigación, enfoque metodológico y el rol de la inteligencia artificial en estos estudios. **[Resultados]** Se identifica un claro aumento de la investigación

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vinculada a la inteligencia artificial en educación matemática, la mayoría de carácter empírico y de tipo cuantitativa, los instrumentos más frecuentes son el cuestionario y la entrevista, la mitad de los estudios utilizan, al menos, dos instrumentos de recolección de los datos. También, la mayoría de los estudios se centró en sistemas de aprendizaje inteligente para mejorar el aprendizaje y apoyo a la enseñanza, para la evaluación en línea. **[Conclusiones]** En los artículos estudiados no se evidencia investigaciones en el nivel de educación infantil y muy poco relacionadas a la formación de profesores. En pocas investigaciones se evidencia la utilización de marco o enfoque teóricos de la Didáctica de la Matemática.

Palabras claves: educación matemática; IA; inteligencia artificial; matemática; revisión sistemática; sistemas de tutoría inteligente

Resumo

[Objetivo] O objetivo deste estudo é analisar o estado atual da pesquisa em inteligência artificial no campo da educação matemática, sua aplicação e seu papel nos processos de ensino e aprendizagem. **[Metodologia]** Realizou-se uma revisão sistemática da literatura nas seguintes etapas: identificação, seleção e inclusão de artigos de três base de dados reconhecidas, resultando em 29 artigos, que foram submetidos a uma análise minuciosa para a detecção de participantes, instrumentos utilizados, país de afiliação dos autores, ano de publicação, tipo de pesquisa, abordagem metodológica e o papel da inteligência artificial nesses estudos. **[Resultados]** Identifica-se um claro aumento de pesquisas relacionadas à inteligência artificial na educação matemática, a maioria delas empírica e quantitativa, os instrumentos mais frequentes são o questionário e a entrevista, sendo que metade dos estudos utiliza pelo menos dois instrumentos para a coleta de dados. Além disso, a maioria dos estudos se concentrou em sistemas inteligentes de aprendizagem para aprimorar a aprendizagem e o suporte ao ensino para avaliação on-line. **[Conclusões]** Nos artigos estudados, não há evidências de pesquisas no âmbito da educação infantil e muito pouco relacionado à formação de professores. Em poucos estudos de pesquisa há evidências do uso de uma estrutura ou abordagem teórica para a Didática da Matemática.

Palavras-chave: educação matemática; IA; inteligência artificial; matemática; revisão sistemática; sistemas de tutoria inteligente

Introduction

The integration of Artificial Intelligence (AI) in mathematics education has spurred numerous research initiatives at the international level (Shin, 2022; Hsu *et al*., 2021; Zhou, 2023). These initiatives primarily focus on analyzing the impact of AI on teaching and learning mathematics (Hwang & Tu, 2021; Zhang & Aslan, 2021), driven by the increasing and progressive use of AI by students to tackle school challenges. Consequently, it is essential to identify how educational research can provide guidelines that positively impact teaching and learning.

Initially, AI concentrated on various problem-solving tasks, such as theorem proving or playing chess, which are linked to decision-making and traditionally modeled by decision trees to devise problem-solving strategies (Abeliuk & Gutiérrez, 2021). Currently, AI has been integrated into various domains and use cases, including facial recognition technology, language learning, image processing, and natural language processing. Education, particularly

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mathematics, has emerged as an area of interest for AI applications in teaching and learning processes (Zhang & Aslan, 2021). In this regard, Jara and Ochoa (2020) highlight AI's role in personalizing learning, fostering student collaboration, and using games as learning experiences. Additionally, AI has significantly collaborated with Information and Communication Technologies (ICT), which, in educational settings, have been mediated by public policies and various technological waves leading to the implementation of digital whiteboards, tablets, computers, Internet access, and other technological resources with AI integration (Jara and Ochoa, 2020).

These technological waves also influence the teaching and learning of mathematics. According to Bakker *et al*. (2021), mathematics education faces challenges such as incorporating new teaching approaches, conducting research in diverse domains, utilizing low-technology resources, maintaining online presence, and conducting online assessments. AI is recognized as a driver that can contribute to the solution of some of these problems (Chen *et al*., 2020; Hwang & Tu, 2021). For instance, Zhou (2023) developed a program based on computer-assisted personalized learning, which demonstrated improvements in students' academic performance and motivation across five different subjects.

In this context, and based on the literature reviewed, efforts to systematize the state of the art on AI in mathematics education are evident when analyzing systematic reviews in the English language (e.g., Zhang & Aslan, 2021; Mohamed *et al*., 2022). However, in the context of Latin American research, there are still no comprehensive reviews of the literature on how different technologies can be utilized in education. Therefore, this systematic review aims to analyze the current state of research in AI in mathematics education, its applications, and its role in teaching and learning processes, as well as the purposes and methods used. This analysis is expected to enhance the understanding of the concepts underpinning AI research, with implications for mathematics education, and to encourage further research.

Conceptual Framework

Artificial Intelligence

The International Conference on Artificial Intelligence and Education, held in Beijing in 2019, reached a consensus on the implementation of AI in education. The conference identified integrating AI planning in educational policies as a key area for several tasks: management and participation in education, support for teaching and teachers, learning and assessment of learning, monitoring, evaluation, and research (UNESCO, 2019). This underscores the growing significance of AI in the educational sector and the various aspects of teaching that can benefit from it. Therefore, it is necessary to clarify certain terms or concepts used in the AI field to refer to specific technologies used in education, including intelligent tutoring systems, machine learning, chatbots, and robotics.

Intelligent Tutoring Systems

Intelligent Tutoring Systems (ITS) are computerized learning environments that mimic a teacher's teaching style to provide student support in a way that adapts to their learning needs and profiles (Erümit & Çetin, 2020; Lippert *et al*., 2020; Sharma & Harkishan, 2022). In other words, ITS

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adapt to the content or concepts, teaching methods, and needs of individual students (Lippert *et al*., 2020). From this perspective, one of its primary functions is "to assess students' knowledge acquisition during the educational process" (Erümit & Çetin, 2020, p. 4478).

Machine Learning

Machine Learning is a type of AI that automates data analysis methods. This automation develops algorithms that enable learning from data and making predictions (Alenezi & Faisal, 2020; Chen *et al*., 2020; Webb *et al*., 2021). Machine learning can build intelligent applications whose behavioral systems can mimic the human brain; these applications can be controlled through human-computer interaction (Chen *et al*., 2020).

Chatbots

Chatbots are conversational agents, i.e., computer software capable of engaging in conversations or simulating communication to provide information and services through interaction in common or everyday language (Følstad *et al*., 2021; Liu *et al*., 2020). In the educational environment, chatbots can help personalize and enrich the learning environment (Liu *et al*., 2020). Additionally, they can support students with course content, assignments, study resources, individual interaction, or collaborative activities (Kuhail *et al*., 2023).

Robotics

Educational robotics is defined by Mendoza-Hernández *et al*. (2020) as "a pedagogical approach that becomes a teaching strategy for different areas such as mathematics, science, and computer science. This approach creates a learning environment where the student plays a key role" (p. 7). Robotics practices in education can promote mental representations of abstract concepts, increase motivation, enhance teamwork, and foster persistence when students face complex and challenging scenarios (Kopcha *et al*., 2017).

Based on the aforementioned concepts, this systematic review of the literature on artificial intelligence in the field of mathematics education aims to show the progress of research in this area over the last five years. We pose the following research questions:

1. How are artificial intelligence studies characterized according to the country of research conduct, the year of publication, the type of research, the use of research methods, and the educational level?
2. What are the uses or roles of artificial intelligence in mathematics education in the studies analyzed?

Methodology of the Systematic Literature Review

Search Strategies and Article Selection Procedures

To determine the scope of artificial intelligence research in mathematics education, a systematic literature review was conducted, defined as "a review of existing studies that use rigorous, explicit, and accountable research methods" (Gough *et al*., 2012, p. 6). The systematic review followed the guidelines of the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement

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(Page *et al*., 2021). The search was conducted up to June 20, 2023, in the following databases: Web of Science (WoS), Scopus, and SciELO.

The terms or words used in the search string or equation were consistent with the UNESCO thesaurus: artificial intelligence, education, and mathematics. Boolean and asterisk operators were employed to refine the search. The search strings used to retrieve the items are shown in Table 1 below.

The search focused on articles published in English and Spanish as of June 20, 2023, that relate artificial intelligence to various areas of mathematics education, including teaching, learning, assessment, and other topics. The search yielded 9,144 studies addressing AI at different educational levels in mathematics. After applying the inclusion and exclusion criteria outlined in Table 2, 32 articles were selected.

The article selection process was conducted using the steps proposed by Page *et al*. (2021): identification, selection, and inclusion. During the identification phase, the search strings shown in Table 1 were implemented. The search across three databases yielded 9,144 articles based on titles, abstracts, and keywords. In the initial selection phase, we used the refine function of the electronic databases to exclude 8,958 articles. These exclusions were based on the type of publication (e.g., book chapters, conference proceedings, or books), language (other than Spanish or English), subject areas (other than social sciences or educational research), and publication years (prior to 2019). In the final selection phase, we reviewed the abstracts of 173 articles that were potentially relevant to this manuscript. In the last inclusion stage, we included 29 articles in the

Table 1. *Search strings used*

Database	Search terms
Scopus	TITLE-ABS-KEY (“artificial intelligence” OR “AI”) AND TITLE-ABS-KEY (education) AND TITLE-ABS-KEY (math*)
WoS	ALL= (((“AI” OR “artificial intelligence”) AND (“education”) AND (math*)))
SciELO	(“AI” OR “artificial intelligence”) AND (“education”) AND (math*)

Note: Own research source.

Table 2. *Inclusion and exclusion criteria*

Inclusion criteria	Exclusion criteria
I1: Studies at all school levels of mathematics education.	E1: Studies in disciplines other than mathematics.
I2: Studies focused on artificial intelligence in future teachers, students of school education or tertiary education related to mathematics.	E2.1: Studies that do not focus on the incorporation of artificial intelligence in mathematics education. E2.2: Studies that mention artificial intelligence, but do not focus on it.
I3: Studies published in English or Spanish	E3: Studies not published in English or Spanish.
I4: Articles	E4: Conference proceedings, books, articles in press, and book chapters.
I5: Articles in the final stage of publication	E5: Articles in press.
I6: Studies indexed in WoS, Scopus and SciELO databases.	E6: Studies not indexed in any of the databases included in the study.
I7: Studies conducted between 2019-2023	E7: Studies conducted before 2019.

Note: Own research source.

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systematic review. Figure 1 presents the flow chart of the article selection process.

Data Analysis

This analysis included 29 articles. Initially, a content analysis of the eligible studies was performed, which were reviewed in depth. Subsequently, a coding scheme was developed to relate them to the research questions according to the following categories:

- Bibliometric indicators for the selected studies
- Research methodologies implemented
- Role of artificial intelligence in studies
- Concepts addressed in studies related to mathematics education.

Regarding the coding of the bibliometric and methodological characteristics of the studies, we followed the guidelines proposed by Cevikbas *et al*. (2022). The analysis continued with content analysis techniques (Cáceres, 2003), focusing on the proposed categories of analysis (deductive). For the first research question, the bibliometric and methodological characteristics identified in each study were subcategorized using the following criteria: year of publication, geographic distribution, research method, sample/participants, level of education, sample size, data collection methods, and role of AI.

Results of the Systematic Review of the Literature on Mathematics Education and Artificial Intelligence

Characteristics of the Studies and Research Methodologies of the Articles

Types of Documents and Years of Publication

The 29 articles included in the analyses were published in 21 different scientific journals: 8 technology and education journals, 4 mathematics education journals, 3 education journals, 3 interdisciplinary journals, 2 distance education journals, and 1 education journal. Articles published in mathematics education journals represent 14% of the total, while those published in technology and

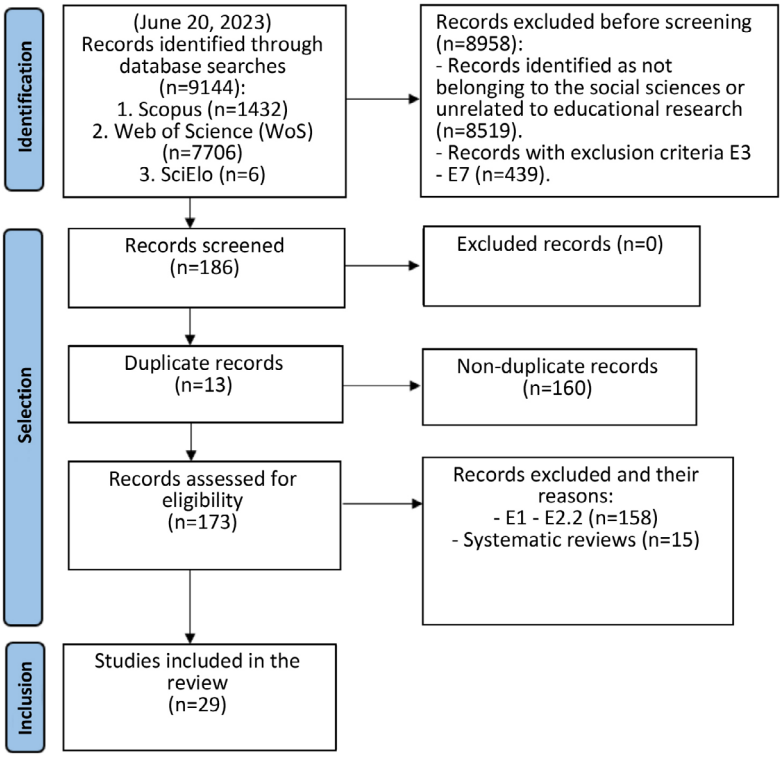

Figure 1. *Flowchart of the selection process of articles*
Note: Own elaboration of the research.

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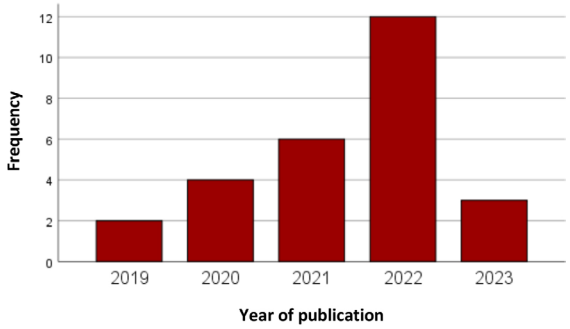
education journals account for 25%. Regarding the years of publication, there has been an increasing trend in the production of scientific articles over the past five years, as illustrated in Graph 1. Few articles were published in 2023, possibly because the year has not yet concluded and several journals are published semi-annually.

Graph 1. *Distribution of the number of studies published per year*



Note: Own research source.

Geographic Distribution

The geographic distribution of authors was determined based on the affiliations reported in the articles. An analysis revealed that 80% of the articles have between one and five authors. Table 3 shows the distribution of authors across 19 countries, with the United States (30%) and China (16.3%) being the most represented. However, when analyzed by continent, most authors are from Europe and Asia, followed by the Americas.

Research Designs and Data Collection Methods

The articles included in the analyses are subdivided into 20 empirical studies, 3 theoretical studies, and 6 studies present the implementation of AI in the field of education. As a general trend, they demonstrate

Table 3. *Geographical distribution of authors according to their affiliation*

Countries	Frequency	Percentage
Germany	13	12.5
Canada	3	2.9
China	17	16.3
Colombia	2	1.9
South Korea	2	1.9
United Arab Emirates	2	1.9
Fiji	2	1.9
Indonesia	3	2.9
Italy	5	4.8
Jordan	1	1.0
Kazakhstan	7	6.7
Norway	3	2.9
Oman	1	1.0
Portugal	4	3.8
United Kingdom	1	1.0
Russia	1	1.0
Sweden	4	3.8
Taiwan	2	1.9
United States	31	29.8
Total	104	100

Note: Own research source.

successful applications of AI in educational environments. The analysis revealed that 27.6 % of the articles used quantitative methods, 24.1 % were qualitative methods, and 10.3% used a combination of both qualitative and quantitative methodologies (see Graph 2). This relates to the fact that 9 articles discussed online programs based on artificial intelligence applied to mathematics education, though these were not empirically tested. The approaches reported in the qualitative and quantitative articles include design-based studies, phenomenological and ethnographic approaches, case studies, and experimental designs.

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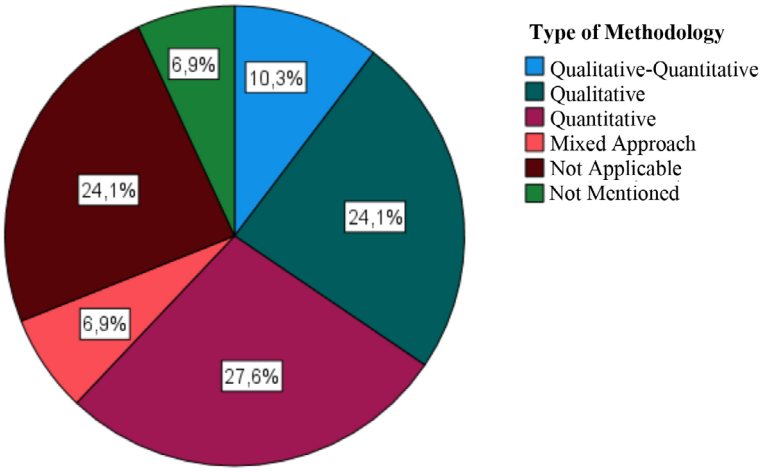
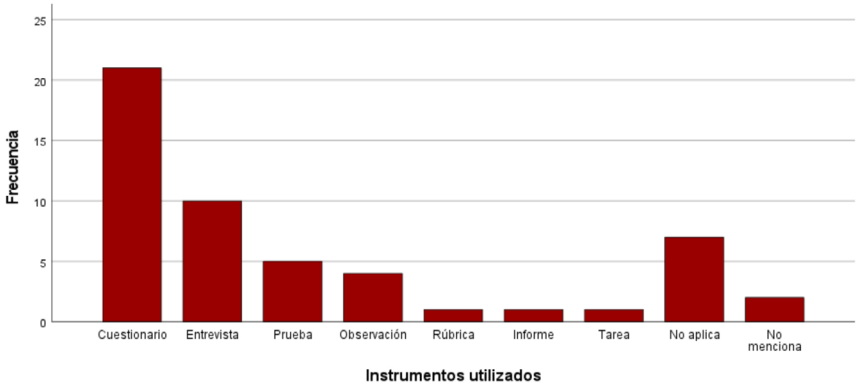
Graph 2. *Type of Research Methodologies Used in the Studies*



Note: Own research source.

Graph 3. *Data collection instruments used in the studies*



Note: Own research source.

In the 29 articles reviewed, data collection methods were analyzed to identify the number and types of instruments used in the research. A total of 43 instruments were employed, including questionnaires, interviews, tests, and various observation tools (see Graph 3). The most frequently used instruments were questionnaires (40.4%) and interviews (19.2%). Regarding the number of instruments per article, it was found that 4 instruments were used in one study, while 1 and 2 data collection instruments were most commonly used, at 47% and 32% (n=20), respectively.

Sample, Sizes and Education Levels of Survey Participants

In the 29 studies analyzed, the sample, its size, and the educational levels of the participants were examined and categorized based on the information provided by the authors in each article. Twenty-four percent of the studies had a sample size of fewer than 50 participants, and the same percentage applied to studies with sample sizes between 101 and 200 participants. Studies that did not mention or did not apply sample sizes (theoretical articles) represented 20% of articles reviewed (see Table 4).

Regarding the educational levels of the study participants, Graph 4 shows that most of them were primary and secondary school students, at 13.8% and 34.5%, respectively. Only one article considered both students and teachers as participants. Three articles reported studies with teachers as participants, while 2 articles focused on future teachers. In addition, we subcategorized the higher education level into university students and future teachers.

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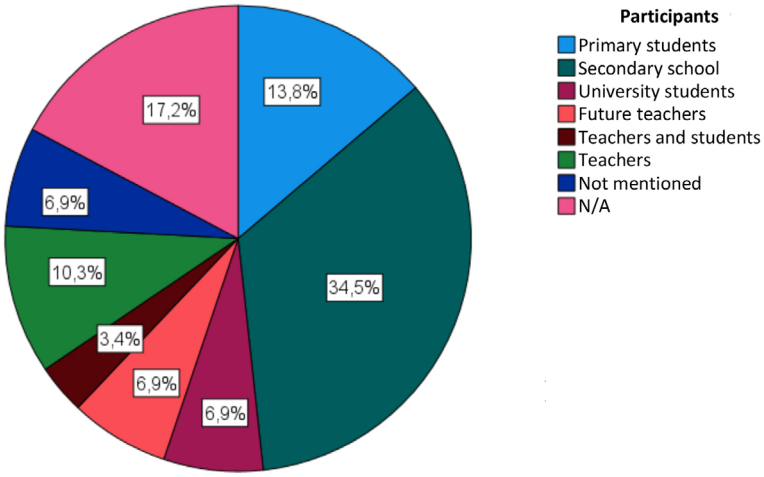
Table 4. *Sample size used in the studies*

Sample size	Frequency	Percentage
0-50	7	24.1
51-100	2	6.9
101-200	7	24.1
201-500	4	13.8
>500)	3	10.3
Not mentioned	1	3.4
Not Applicable	5	17.2
Total	29	100.0

Note: Own research source.

Graph 4. *Participants of the analyzed studies*



Note: Own research source.

Table 5. *Concepts of artificial intelligence found in the articles*

Concepts	Frequency	Percentage
Automatic learning	6	20.7
Chatbot	2	6.9
Robotics	2	6.9
Intelligent tutoring systems	14	48.3
Not mentioned	1	3.4
Not Applicable	1	3.4
Another	3	10.3

Note: Own research source.

Analysis of Artificial Intelligence Concepts

Given that the studies link some AI concepts in the articles, this information was inductively analyzed and categorized using the proposed conceptual framework, prioritizing the significance of the AI resource in the analysis. These concepts include machine learning, adaptive learning, chatbot, robotics and intelligent tutoring systems. The results indicate that most of the articles refer to artificial intelligence systems (48%, n=19), followed by machine learning (20.7%, n=6). The complete description can be found in Table 5.

Some Results of the Reviewed Articles

Table 6 presents some empirical results from the reviewed articles.

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Table 6. *Some empirical results of the reviewed articles*

Authors/year	Diploma	Some results
Kong *et al.* (2023)	Evaluating an artificial intelligence literacy programme for empowering and developing concepts, literacy and ethical awareness in senior secondary students	Knowledge of programming provide advantages for the deep learning course but not for other courses, such as AI application projects. In addition, some ethical principles may be too complex for upper secondary school students to understand.
Huang and Qiao (2022)	Enhancing Computational Thinking Skills Through Artificial Intelligence Education at a STEAM High School	AI education integrated with STEM is beneficial in promoting students' creativity, cooperation, critical thinking, and problem-solving skills in computational thinking. Also, it improves learning motivation and self-efficacy of students in the experimental group.
Lee and Yeo (2022)	Developing an AI-based chatbot for practicing responsive teaching in mathematics	They developed a chatbot with knowledge of concepts and operations between fractions. They show that this chatbot reasonably and adequately addressed future teachers' questions and provided answers that seemed realistic.
Zhai *et al.* (2022)	Applying machine learning to automatically assess scientific models	Using assessments incorporating drawn and textual models, they achieved excellent scoring accuracy through machine learning. They also identified five characteristics of the drawn models that can significantly affect the accuracy of the machine score.
Bekmanova *et al.* (2021)	Personalized training model for organizing blended and lifelong distance learning courses and its effectiveness in Higher Education	The results of a distance learning course, based on personalized learning, indicate that the course meets expectations and is innovative. In addition, they found that 100% of students were successfully certified compared to a traditional classroom course.
Shin (2022)	Teaching Mathematics Integrating Intelligent Tutoring Systems: Investigating Prospective Teachers' Concerns and TPACK	Future teachers recognize that they have solid pedagogical knowledge (PK) and pedagogical content knowledge (PCK) they need to teach mathematics. However, when PK and PCK were integrated with technological knowledge, they were less likely to recognize that they had sound knowledge for effective teaching with technology.
Azevedo *et al.* (2022)	Mathematics learning and assessment using MathE platform: A case study	When asking students about the extent to which the MathE platform is a valuable aid to their studies, they found that 40.6% of students considered it useful, while 9.4% said it was not useful, and 9.4% thought the platform was helpful. The main difficulties experienced with the platform were organization and language.
Moltudal *et al.* (2022)	Adaptive Learning Technology in Primary Education: Implications for Professional Teacher Knowledge and Classroom Management	Teachers describe the technology as promising but feel that, to use it fully, their students must spend more time solving tasks in the program than teachers are willing to allocate.
Zhou (2023)	Integration of modern technologies in higher education on the example of artificial intelligence use	There is a significant difference in student performance in five subjects before and after the introduction of the Raptivity personalized learning platform.

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Authors/year	Diploma	Some results
Wang *et al.* (2023)	When adaptive learning is effective learning: comparison of an adaptive learning system to teacher-led instruction	Students using Aquirrel AI learning independently outperformed students enrolled in a course taught by expert teachers. They also outperformed students who received both whole-class and small-group instruction.
Sperling *et al.* (2022)	Still w(AI)ting for the automation of teaching: An exploration of machine learning in Swedish primary education using Actor-Network Theory	The study shows that AI technologies designed to personalize and automate require mutual adaptation of human and non-human actors in the network.
Wang *et al.* (2022)	Development and Application of an Intelligent Assessment System for Mathematics Learning Strategy among High School StudentsTake Jianzha County as an Example	They found that assessment and implementation systems are effective in providing teachers with techniques to help assess and improve mathematics learning strategies.
Shin *et al.* (2021)	Analyzing students' performance in computerized formative assessments to optimize teachers' test administration decisions using deep learning frameworks	The model created helps predict whether the next test will be significant based on the performance scores of two previous high-pressure tests.
Ferro *et al.* (2021)	Gea2: A Serious Game for Technology-Enhanced Learning in STEM	They found that the effectiveness of the game, as a learning tool, did not yield good overall results. The game was expected to improve understanding of topics explained in class but ended up being a replacement for face-to-face lectures.
Hsu *et al.* (2021)	Is it possible for young students to learn the Ai-STEAM application with experiential learning?	They showed that the use of experiential learning integrated into an AI-STEM course improves learning effectiveness.
Robles and Quintero (2020)	Intelligent system for interactive teaching through videogames	For each video game it is shown that the implementation of the intelligent system, with two computational techniques implemented, enables the user to obtain a better performance in the subjects addressed.
Yannier *et al.* (2020)	Active Learning is About More Than Hands-On: A Mixed-Reality AI System to Support STEM Education	AI agent-guided inquiry helped students formulate better and more scientific theories of the phenomena they experience. Additionally, children who receive guidance during inquiry can learn to apply science in engineering tasks better.
Büscher (2020)	Scaling up qualitative mathematics education research through artificial intelligence methods	They report that the model performed with 76% accuracy on the test set, meaning that it labeled 76% of the data in the same way as a research team would have done.
Cung *et al.* (2019)	Getting Academically Underprepared Students Ready through College Developmental Education: Does the Course Delivery Format Matter?	When using a well-developed intelligent tutoring system, the learning gains are even more significant when combined with in-person lectures.

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Authors/year	Diploma	Some results
So and Lee (2023)	Pedagogical exploration and technological development of a humanoid robotic system for teaching to and learning in young children	They found that the NAO Robot can build a positive and friendly relationship with children while achieving math learning outcomes.
Denes (2023)	A case study of using AI for General Certificate of Secondary Education (GCSE) grade prediction in a selective independent school in England	They showed that predictions are more accurate for STEM subjects and those with more students. In addition, they found that STEM and non-STEM teachers have different perceptions when awarding grades.
Soesanto *et al*. (2022)	Indonesian students' perceptions towards AI-based learning in mathematics	Some of the students' perceptions are the following: they see AI robots as intelligent machines that can detect something; they understand AI as a robot created to do something; and AI is seen as a simulation of intelligence modeled on a machine.
Yang *et al*. (2021)	Can Crowds Customize Instructional Materials with Minimal Expert Guidance? Exploring Teacher-guided Crowdsourcing for Improving Hints in an AI-based Tutor	In one of the studies conducted (2), they report that teachers perceive self-written suggestions as better and more satisfactory than existing AI tutor suggestions. However, they did not perceive personalized, crowd-produced suggestions as an improvement on the original suggestions.
Walkington and Bernacki (2019)	Personalizing Algebra to Students' Individual Interests in an Intelligent Tutoring System: Moderators of Impact	Deeper personalization tended to result in lower efficiency, but more positive affective states, whereas situational interest and play were unaffected. Additionally, students who were more deeply engaged with their interests performed better on measures of efficiency.
Wardat *et al*. (2023)	ChatGPT: A revolutionary tool for teaching and learning mathematics	They found that ChatGPT is a useful tool, but caution is needed when using it and guidelines for its safe use should be developed.

Discussion

The above results show a notable lack of papers from Latin America focused on AI and education. This gap invites further development of such topics, placing issues related to teaching and learning in different educational environments. Given the small number of works identified, research efforts should be implemented at all educational levels. Regarding the methods used, although there is no great imbalance in what has been done, there are insufficient studies using mixed methods and involving a high number of participants. Progress in this area is crucial, as AI implementation is already widespread in everyday life, being used as a support to collaborate in mathematical problems, at the student's fingertips.

On the other hand, the results consider, for the most part, the integration of AI to enhance learning, mainly through autonomous work. The articles identify exploratory-descriptive scopes regarding its implementation, either by integrating this type of technology into their teaching processes (e.g., chatbots in initial teacher training), or by identifying the types of knowledge that optimize technology use, such as prior programming knowledge at intermediate levels as reported in Kong *et al*. (2023). This also calls for a deeper understanding

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of the complexities involved in adequately integrating AI into educational processes. Consequently, creation and proper functioning are not sufficient: correct integration is required in both pedagogical practice and gradual adaptation with students (Sperling *et al*., 2022).

This review highlights papers in which AI is directly linked to evaluation processes. The results indicate a higher degree of effectiveness when AI plays a significant role in feedback processes. However, several reviewed studies emphasize the importance of continuously monitoring technological tools to ensure that responses are closely aligned with students' needs, encompassing language aspects and developing a response typology consistent with in-person practices. From this perspective, it is highly important that when educational activities are conducted concurrently—that is, when involving work with a teacher and work with an AI system—there is synchrony that not only facilitates discussions about them, and that the feedback processes are consistent with the classroom work, but also enables assessment beyond each task individually. In this regard, a projection of research development is proposed. Although some studies focus on synergistic assessment, the results are still in their early stages in the evaluation field.

Conclusions

This study systematically analyzed current research on AI in mathematics education across 29 articles. Our main focus was to examine the characteristics of these studies, the AI technologies used, and their linkage to theories or theoretical perspectives in mathematics education.

Concerning the first research question, the examined studies indicate a growing presence of AI in mathematics education, especially notable in 2022, with a similar trend expected for 2023. Additionally, the vast majority of the reviewed material was empirical, with only a few theoretical studies. Articles published in journals with a tradition in mathematics education constituted less than 20% of the analyzed articles; most of these come from the United States and China. Moreover, Asia is the continent with the largest number of countries addressing AI in mathematics education, while only a small number of authors come from Latin America.

The examined studies primarily used quantitative (26%) and qualitative (24.14%) methods, with few and insufficient mixed-method studies (6.90%) for research development in the area. Furthermore, approximately one-third of the studies focused on high school students as subjects of study, followed by primary students and teachers. Few research studies analyzed university students, particularly future teachers. According to the results, most studies were conducted in secondary and primary education. However, no study was found investigating participants in early childhood education.

The strategies used to collect data from AI interventions were mostly questionnaires, interviews, and tests. Approximately half of these studies used at least two instruments to obtain their data. However, few investigations approached AI from a theory or a theoretical perspective of the didactics of mathematics (n=6).

Regarding the role of AI in mathematics education, the results reveal that it is most commonly used as a computerized learning environment, i.e., intelligent learning systems for assessment, learning effectiveness, distance education, learning, and

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teaching. This finding encourages further development in already initiated research fields or the identification of new areas to explore, starting from those mentioned.

The limitations of this study are influenced by the selected databases and the exclusion of conference proceedings, book chapters, books, and other materials, as well as journals not included in the Scopus, WoS, and Scielo databases. In addition, the exclusion of written languages other than English and Spanish limits the scope of the results. Another limitation may be connected to the automated exclusion process conducted in each database and the search strings utilized. "Artificial intelligence," "education," and "math" were the terms employed in this review, although some identified studies did not use the term "artificial intelligence" but instead referred directly to the AI technology used in the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contribution Statement

All authors acknowledge that they have read and approved the final version of this article.

Data Availability Statement

Data supporting the results of this study will be made available by the corresponding author, DP, upon reasonable request.

The percentages of contribution for the conceptualization, preparation, and correction of this paper were as follows: D.P.G 70 % and J.H.A. 30 %

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