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Current practices and future direction of artificial intelligence in mathematics education: A systematic review

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ABSTRACT

Mastering mathematics is often challenging for many students; however, the rise of artificial intelligence (AI) offers numerous advantages, including enhanced data analysis, automated feedback, and the potential for creating more interactive and engaging learning environments. Despite these benefits, there is a need for comprehensive reviews that provide an overview of AI's role in mathematics education to help educators identify the best AI tools, and to inform researchers about current trends and future directions. This study conducts a systematic literature review (SLR) to investigate the applications and trends of AI in mathematics education by examining articles published in reputable journals indexed in Web of Science and Scopus. The review categorizes AI tools into those narrowly addressing mathematical problems, such as solving equations and visualizing geometry, and those offering broader pedagogical support, including adaptive learning systems and generative AI platforms. Key aspects analyzed include the distribution of AI in Mathematics Education (AIME) studies across different educational levels, the types and categories of AI tools used, the functionality of commercialized AIME tools available on the internet, and the emerging trends and future directions in AIME based on recent literature. The insights from this SLR are crucial for educators, policymakers, and researchers, enabling them to integrate AI effectively into mathematics education and tailor tools to specific teaching strategies and learning needs.

Keywords: artificial intelligence in education, AIED, artificial intelligence in mathematics education, AIME, AI tools, mathematics education

INTRODUCTION

Artificial intelligence (AI) refers to the capability of a machine to imitate intelligent human behavior. It's a broad field of science encompassing not just machine learning and data processing, but also complex problem-solving and decision-making capabilities (Zawacki-Richter et al., 2019). AI technologies are increasingly becoming integral to our daily lives, influencing industries from healthcare to finance with their ability to process large volumes of data quickly and efficiently.

In the context of education, AI has had a transformative impact. AI technologies have revolutionized how educational content is delivered, accessed, and interacted with. This includes the development of personalized learning platforms that adapt to individual learning speeds and styles, intelligent tutoring systems that provide customized feedback and guidance to students without the need for a human tutor, and automated grading systems that can assess student work promptly and objectively (Aggarwal et al., 2023; Jian, 2023). AI also enables the analysis of educational data on a large scale, providing insights that can improve teaching strategies and learning outcomes (Sangarsu, 2023). Furthermore, AI-driven simulations and virtual reality environments create interactive and immersive learning experiences that engage students in novel ways (Sharki et al., 2024). Overall, AI's integration into education has facilitated more adaptive, efficient, and engaging educational practices that cater to diverse learner needs and preferences (Tahiru, 2021; Zhang & Aslan, 2021).

Artificial Intelligence in Education (AIEd) plays a multitude of roles that substantially enhance educational experience by leveraging advanced technologies to cater to diverse learning needs. To be more specific, AIEd technologies encompass a broad range of applications including chatbots, expert systems, intelligent tutors or agents, machine learning algorithms, personalized learning systems, and virtual reality (Zhang & Aslan, 2021). Chatbots facilitate real-time interaction and immediate feedback, mimicking human conversation and aiding in language learning or problem-solving tasks (Bayounes et al., 2023). Expert systems utilize a vast knowledge base to provide expert advice and guidance in specific subject areas (Koivisto, 2023). Intelligent tutors or agents offer personalized instruction and adaptive feedback, adjusting the complexity and pacing of material to match the student's progress (Nguyen et al., 2019). Machine learning algorithms analyze educational data to uncover patterns and insights, which can inform personalized learning paths and improve educational outcomes (Kaiss et al., 2023). Personalized learning systems adapt content and assessments to the learner's individual needs, optimizing their engagement and retention (Belda-Medina & Calvo-Ferrer, 2022). Lastly, virtual reality creates immersive environments that simulate real-world scenarios, making learning more engaging and practical (Mills, 2022). Collectively, these AIEd tools revolutionize traditional educational methods by providing customized and interactive learning experiences.

In mathematics education, AI is fundamentally reshaping how students engage with and comprehend mathematical concepts. By providing customized learning experiences, AI facilitates deeper understanding and retention of mathematical principles (Tahiru, 2021). It enhances the learning process through personalized instruction, adaptive feedback, and interactive problem-solving scenarios, which are all tailored to the individual learning styles and pace of students (Ojeda-Bazaran et al., 2021). This targeted approach not only improves educational outcomes but also makes the learning of complex mathematical theories more accessible and engaging (Zhai et al., 2021).

Globally, countries such as China, Korea, India, and various European nations have recognized the transformative potential of AI in education and have begun integrating these technologies into their school curricula (Han et al., 2018; Karan & Angadi, 2023; Lee et al., 2022a, 2022b; Park & Lim, 2023). This growing global interest highlights the urgency for educators in the field to be equipped with the knowledge, skills, and resources necessary to effectively integrate AI tools into their teaching practices. Without adequate training and support, educators may struggle to harness the full potential of AI technologies, limiting their impact on improving teaching strategies and enhancing learning outcomes.

Despite the growing body of research on Artificial Intelligence in Education (AIEd), much of the existing work focuses on identifying current trends in terms of the categories or types of AI technologies, such as intelligent tutoring systems, virtual reality, and adaptive learning platforms. While these studies provide valuable insights into the capabilities and potential of these technologies, they often lack emphasis on ready-to-use AI tools that are commercially available for immediate implementation in educational settings. Furthermore, a significant portion of this research highlights AI tools still in the research and development (R&D) stage, limiting their relevance and practicality for educators seeking solutions from the existing applications. As a result, there is a noticeable gap in the literature regarding the synthesis of accessible AI tools that educators can readily adopt to enhance classroom teaching and learning experiences.

This study aims to address these limitations by conducting a systematic review with a targeted focus on commercialized AI tools that have demonstrated applicability in mathematics education. By analyzing tools that are already market-ready, this review bridges the gap between theoretical research and practical implementation, offering actionable insights for educators and policymakers. The findings from this study will play a pivotal role in informing educators, policymakers, and developers about the most effective AI-driven strategies for implementation. By bridging the gap between research and practice, this review ensures that AI integration into mathematics education not only maximizes learning outcomes but also addresses the needs of all students equitably, guiding future investments and innovations in educational technology.

REVIEW OF LITERATURE

A systematic review is a study of specifically formulated questions that use systematic and explicit procedures to identify, select, and critically evaluate relevant research as well as collect and analyze data from studies included in the review. A systematic review justified the rigorousness of research besides allowing for the identification of gaps and required direction for future research.

Systematic reviews on AI in education have been conducted with various aspects of investigation. Some researchers emphasized the research-related aspects by reviewing the trends and recent developments in the field. For example, a review by Tahiru (2021) analyzed the opportunities, benefits, and challenges of AI in education, providing a comprehensive overview of the current research focus and future directions. Another review by Bhatt and Muduli (2023) explored AI applications in learning and development, highlighting AI innovations and their impact on learning processes. Additionally, Zafari et al. (2022) conducted a systematic review focusing on AI applications in K-12 education, categorizing AI uses in various educational tasks and analyzing their impact on student performance and teaching effectiveness.

Moreover, Zawacki-Richter et al. (2019) provided an extensive review of AI applications in higher education, identifying four main areas of application: profiling and prediction, assessment and evaluation, adaptive systems and personalization, and intelligent tutoring systems. On the other hand, Chen et al. (2020) focused on the broad impact of AI in education, particularly in administration, instruction, and learning, detailing the transition from traditional technologies to advanced AI-driven systems like humanoid robots and web-based chatbots. Similarly, Bozkurt et al. (2021) examined AI studies in education over half a century, identifying key research clusters and themes such as adaptive learning, deep learning, and the ethical implications of AI in education.

However, this study aims to narrow the scope of AIED and provide a more in-depth exploration of AI in mathematics education. Several recent studies have conducted reviews on AI in mathematics education over the past five years. Notably, Hwang and Tu (2021) provided a bibliometric mapping analysis and systematic review of the roles and research trends of AI in mathematics education. Their findings emphasize the diverse roles of AI in mathematics education, mostly as intelligent tutoring systems, profiling and prediction, adaptive system and personalization and as an assessment and evaluation tool.

Similarly, Mohamed et al. (2022) conducted a systematic literature review focusing on various AI approaches used in mathematics education. The primary approaches identified were robotics, systems, tools, teachable agents, autonomous agents, and comprehensive methods. The study also explored the themes addressed in previous studies on AI in mathematics education.

These themes were categorized into advantages and disadvantages, conceptual understanding, factors, roles, idea suggestions, strategies, and effectiveness.

Additionally, Hwang (2022) conducted a meta-analysis specifically examined the impact of different types of AI, including Adaptive Learning Systems (ALS), Intelligent Tutoring Systems (ITS), and robotics, on elementary students' mathematics performance. The findings revealed that these AI tools significantly enhance students' mathematics achievement. Adaptive Learning Systems and Intelligent Tutoring Systems were particularly effective in providing personalized learning experiences and adaptive feedback, while robotics engaged students through interactive and hands-on learning activities. These results highlight the potential of AI to improve educational outcomes in mathematics by leveraging various AI technologies.

On the other hand, Niño-Rojas et al. (2024) conducted a systematic review that specifically focused on the use of Intelligent Tutoring Systems (ITS) in mathematics learning. Their study highlighted several widely used ITS, including ALEKS, PAT2Math, GeoGebra Tutor, and MATHia. These systems have been instrumental in enhancing mathematics education by providing personalized and adaptive learning experiences. The review identified that the most employed AI techniques in the adaptation process of these ITS are expert systems, predictive models, and neural networks.

In summary, the recent systematic review studies provide a comprehensive understanding of the diverse roles and impacts of AI in mathematics education. From the broad applications and trends identified by Hwang and Tu (2021), the varied AI approaches detailed by Mohamed et al. (2022), to the specific impacts of AI tools like ALS, ITS, and robotics on student achievement as highlighted by Hwang (2022), and the focused review of ITS by Niño-Rojas et al. (2024), it is evident that AI is reshaping mathematics education. These studies collectively highlight the potential of AI to create more personalized, adaptive, and effective educational experiences, thereby enhancing student engagement and achievement in mathematics.

Nonetheless, there is still ample potential to expand research on AI in mathematics education, particularly to identify the specific AI tools used and their impact on mathematics learning at all levels. Since Hwang's (2022) study only identified ITS, ALS, and robotics as AI types, further research is needed to identify a broader range of AI types. Although Mohamed et al. (2022) found a wider range of AI approaches, such as teachable agents, mathematical tools, and autonomous agents, the study did not clearly specify the names of the AI tools or applications used. The lack of clarity makes it challenging for practitioners in the field to identify which AI tools are most effective in enhancing mathematics learning outcomes. The study by Niño-Rojas et al. (2024), while specifically mentioning the systems like ALEKS, PAT2Math, GeoGebra, and MATHia, is limited to ITS only.

While existing systematic reviews on AIEd and AIME provide valuable insights into the diverse roles, technologies, and applications of AI, there is a lack of clarity and focus on identifying specific commercialized tools and their direct applicability in mathematics education. Most of the reviewed studies, such as those by Hwang (2022), Mohamed et al. (2022), and Niño-Rojas et al. (2024), explore general categories or types of AI (e.g., ITS, ALS, robotics) without sufficiently detailing specific, ready-to-use tools or their functionalities. This leaves a critical gap for educators and practitioners who need guidance on the tools they can immediately implement to enhance their teaching practices and improve student outcomes in mathematics.

Moreover, although previous reviews have highlighted the theoretical benefits and potential impacts of AI technologies, there has been limited effort to systematically map the distribution of AIME studies across different educational levels or to examine trends in the commercialization of AIME tools. Educators often struggle to navigate the rapidly evolving landscape of AI technologies, making it essential to provide a practical synthesis of tools that are accessible and effective in real-world educational settings.

This systematic review is particularly needed to address the specific problem of bridging the gap between research innovations and practical applications in mathematics education. By focusing on commercialized AI tools and their functionalities, this study aims to fill a critical void in the literature. The emphasis on identifying readily available tools will not only benefit educators in selecting and adapting these tools for their classrooms but also inform researchers and policymakers about trends and gaps in the adoption of AI in mathematics education.

By extending previous review research, this study aims to analyze the articles published in referred journals from the years 2019 to 2024, in the field of AIME. The authors selected a five-year timeframe to identify the latest AI tools and technologies adopted in recent studies. This study aims to identify a wide range of AI technologies and specific tools or applications used in mathematics education at all levels. The findings will provide educators with valuable insights, enabling them to facilitate better adaptation of AI in learning mathematics. Additionally, this study also analyzes the benefits, challenges, and limitations of using these AI tools specifically in mathematics learning, offering educators insights on effective integration and guiding researchers on areas needing further exploration. In this regard, the study aims to provide answers to the following questions:

RQ1 How are AIME studies distributed across different educational levels?

RQ2 What AI tools are currently being used in mathematics education, and how are they categorized?

RQ3 What commercialized AIME tools can be found on the internet and their functionality?

RQ4 What are the emerging trends and future directions in AIME based on recent literature?

The questions are designed to address critical gaps in the current understanding of AIME and provide significant contributions to the field. The first question, focusing on the distribution of AIME studies across educational levels, seeks to uncover trends in research emphasis across primary, secondary, and higher education. This analysis is essential for identifying underrepresented educational levels and highlighting areas where more research is needed to ensure the equitable adoption of AI tools across all stages of education.

The second question, which categorizes AI tools currently used in mathematics education, aims to provide a comprehensive understanding of the technologies driving advancements in the field. By classifying these tools into types, such as intelligent

Table 1. Keyword and searching information strategy

Database	Query	Result
Scopus	TITLE-ABS-KEY ((“artificial intelligence” OR “AI” OR “AI TOOL” OR “AI APP” OR “AI Application”) AND (“mathematics education” OR “math education” OR “mathematics learning” OR “Math learning” OR “Math teaching” OR “Math teaching and learning”)	49
WoS	(“artificial intelligence” OR “AI” OR “AI TOOL” OR “AI APP” OR “AI Application”) AND (“mathematics education” OR “math education” OR “mathematics learning” OR “Math learning” OR “Math teaching” OR “Math teaching and learning”)	68
Total articles collected		117

Table 2. The inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Journal (research articles)	Journals (systematic review), book series, book, chapter in book, conference proceeding
Language	English	Non-English publications
Timeline	Between 2019-2024	Before 2019
Focus of study	AI in Mathematics Education, Virtual Reality, Augmented Reality, Mixed Reality	AI in Science, Engineering and Technology Education

tutoring systems, adaptive learning platforms, and AR/VR technologies, this question reveals trends in AI tool adoption and development, offering direction for future research to explore emerging or underutilized technologies.

The third question addresses the practical side of AIME by identifying commercialized AI tools and their functionalities. This question bridges the gap between theoretical research and real-world application, offering educators insights into market-ready tools that they can immediately adopt to enhance teaching and learning. Additionally, it emphasizes trends in the commercialization of AI technologies, which is critical for guiding future development and refinement of these tools to better meet the needs of educators and students.

The fourth research question, which focuses on emerging trends and future directions in AIME, is essential for understanding how advancements in AI can shape the future of mathematics education. To address research question 4, the study conducts a thematic analysis of previous studies to identify and analyze emerging trends and future directions in AIME. By systematically examining the themes highlighted in recent literature, the study uncovers advancements and potential pathways that AI tools and technologies are expected to follow. This approach provides a comprehensive understanding of how AIME is evolving and offers valuable insights into the innovations and challenges shaping its future.

METHODOLOGY

This section discusses the employed method to retrieve the related articles, including the resources used to run the systematic review, eligibility and exclusion criteria, the steps of the review process, and data abstraction and analysis.

Resources

This study reviewed articles from two main journal databases, namely Web of Science (WoS) and Scopus. Both databases were selected based on their high reliability in searching for high-quality journals. WoS contains nearly 21,000 peer-reviewed, high-quality scholarly publications covering over 254 fields, including environmental studies, interdisciplinary social sciences, social concerns, and development and planning. Meanwhile, Scopus is one of the largest peer-reviewed abstract and citation databases, with 22,800 journals from 5000 publishers. It consists of diverse subject areas such as environmental sciences, social science and agriculture, and biological sciences.

Systematic Review Process

The review process involved four stages*: identification, screening, data abstraction and analysis*, and *thematic analysis*.

Stage 1: Identification

Table 1 lists the employed keywords and queries for the search. The publication period was set from 2019 to 2024 to ensure that the articles obtained are up to date and provide sufficient data to observe the research trend. The search category was set to "education/educational research" to keep the articles in educational settings.

Stage 2: Screening

Table 2 shows the eligibility and exclusion criteria of the screening process. The first criterion is the literature type, which has been limited to only journal articles. Therefore, review articles, book series, books, book chapters, and conference papers were eliminated. Second, the screening process excluded non-English publications to ensure consistency and reliability in the interpretation of data. While acknowledging the value of multilingual research, this study focused on English-language articles due to practical constraints, such as the availability of standardized search terms and the need for accurate analysis without the potential for translation inaccuracies. Limiting the scope to English-language publications ensures that all reviewed studies are evaluated using a consistent linguistic framework, which is critical for maintaining methodological rigor in a systematic review.

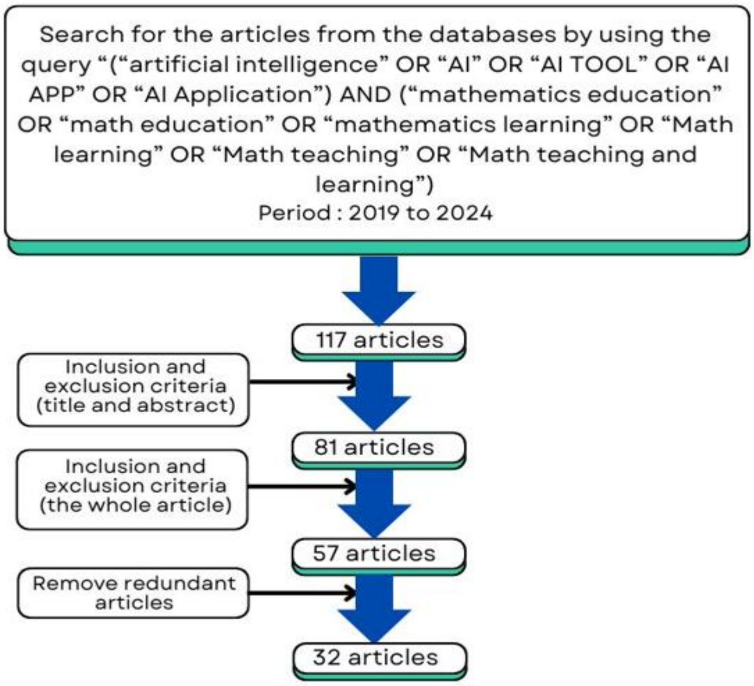

Figure 1. The process of identification and screening (Source: Authors' own elaboration)

The five-year timeline (2019-2024) was selected to focus on the most recent advancements and trends in Artificial Intelligence in Mathematics Education (AIME). AI technologies evolve rapidly, and analyzing recent publications ensures the study reflects current tools, practices, and innovations relevant to educators and policymakers. While this timeframe may not capture long-term developments, the emphasis on recent research provides actionable insights aligned with contemporary educational needs and technological capabilities.

The eligibility of the articles includes Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). There are also articles that use AI in STEM education but do not focus on mathematics. These articles were excluded because this study does not examine STEM in general but specifically focuses on learning mathematics subject.

In the screening process, the authors first reviewed the title and abstract of the included articles. Some 36 out of 117 articles were eliminated for being irrelevant to the study. The remaining 81 articles were screened by reviewing the complete article, and 24 articles were deleted using exclusion criteria. Before the data abstraction and analysis stage, the reviewer removed 25 redundant articles, resulting in an overall 32 articles to be included in this study. **Figure 1** illustrates the identification and screening process.

Stage 3: Data abstraction and analysis

This stage extracts and analyses data from 32 articles. The author extracted data by reading abstracts first, followed by an in-depth read of the full articles to identify the themes and sub-themes.

Stage 4: Thematic analysis

The thematic analysis was conducted systematically to ensure that the themes identified were aligned with the research objectives and provided meaningful insights into the field of AIME. The process began with a thorough review of the research objectives, which focused on understanding the distribution of AIME studies across educational levels, categorizing and identifying AI tools, and exploring emerging trends and future directions. Data extracted from the articles, such as descriptions of AI tools, their applications, and the educational levels they addressed, were coded systematically. These codes represented recurring patterns and insights, such as specific AI tools (e.g., GeoGebra, MATHia), functionalities (e.g., adaptive feedback, interactive problem-solving), or educational levels (e.g., primary, secondary, tertiary).

Once the coding process was completed, similar codes were grouped into broader categories, including level of studies/educational levels, name and category of AI tools, identified AI tools, and trends and future directions. These categories were then synthesized into themes that addressed key aspects of the research objectives. For instance, the theme level of studies/educational levels included sub-themes representing primary, secondary, and tertiary education, highlighting the scope of AIME across different educational stages. Similarly, the theme name and category of AI tools included sub-themes such as the names of specific AI tools, their categories, the educational levels where they were applied, the countries of their use, and their commercialization status.

Table 3. The themes and sub-themes emerged from the content analysis

Themes	Sub-Themes
1. Level of studies/Educational level	1. Primary/Elementary School
	2. High School/Middle School
	3. Tertier Education
2. Name and category of AI tools	1. Name of AI tools
	2. Category of AI tools
	3. Educational level
	4. Country
	5. Commercialization
3. Identified AI tools	1. Commercialized tools
	2. Functionality
4. Trends and future directions of AIME	1. Emerging trends
	2. Future directions

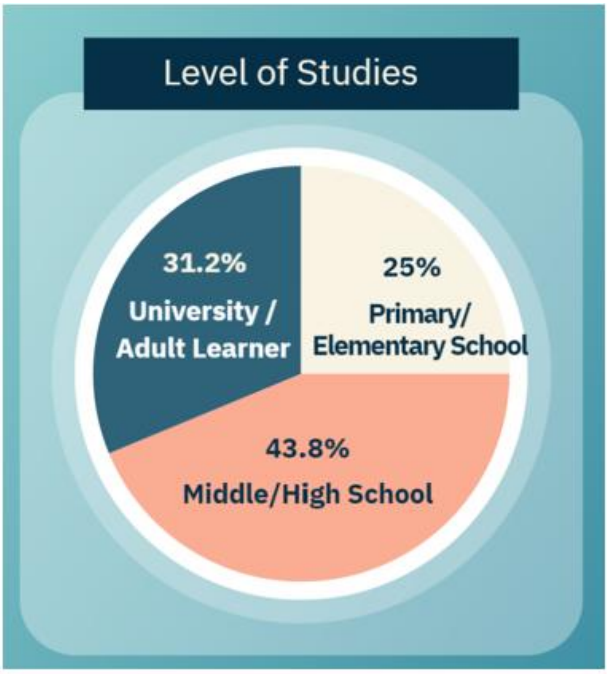

Figure 2. The distribution of level of studies related to AI in mathematics education (Source: Authors' own elaboration)

The final synthesis of these categories and themes was carefully refined to ensure they directly addressed the study's objectives, such as identifying commercially available AI tools and exploring trends in their application. **Table 3** presents the resulting themes and sub-themes, providing a structured overview of the focus areas in the reviewed studies and illustrating how the data was systematically analyzed and categorized to draw meaningful conclusions.

RESULTS

32 studies were analysed for this analysis (N = 32). Hoewever, the total frequency was not neccssarily 32 as some research provides more than one parameter and some research does not provide the information. Thus, the total frequency was adjusted accordingly.

Level of Sudies/Educational Levels

The educational levels in this study indicate the stages of education where the research was conducted to determine the distribution of AI research in mathematics education. Three categories have been identified in the levels of research involving AI in mathematics education, namely the elementary/primary school level, the middle/high school level, and the university/adult learner level. The distribution of research levels involving AI in education is illustrated through a pie chart in **Figure 2**.

The results show that most studies related to AI in mathematics education were conducted at the middle/high school level (43.8%, N=14), followed by university/adult learner level (31.2%, N=10) and lastly primary/elementary school (25%, N=8).

Name and Category of AI Tools

This study focusses on the identification of AI tools employed in the studies related to AIME and subsequently identifying the categories of the employed AI tools. The data analysis from 32 studies indicates that AIME tools used over the past five years can be classified into seven categories. These categories, listed in order of frequency from highest to lowest, are Chatbots (N=9), Virtual

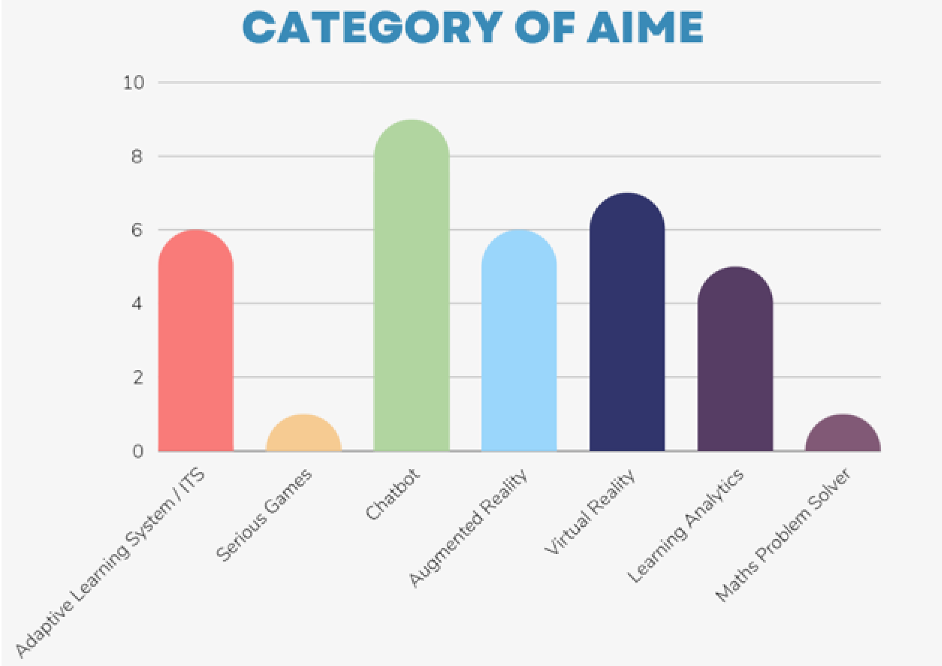

Figure 3. The categories of AI tools emerged in AIME (Source: Authors' own elaboration)

reality (N=7), Augmented reality (N=6), Adaptive learning systems/ITS (N=6), Learning analytics (N=5), Serious games (N=1) and Mathematics problem solver (N=1). The emergence of AIME categories is illustrated in **Figure 3**. It's notable that the frequency count, N=35, exceeds the number of studies involved, which was 32. This is due to one study utilizing both Augmented Reality and Virtual Reality tools, one study employing both Chatbot and Virtual reality tool and the other one employing Adaptive learning system/ITS and Chatbot.

Meanwhile, specific tools have been identified under each category. **Table 4** shows the category of AIME and name of the respective tools.

Table 4 includes a diverse range of technologies, such as adaptive learning systems/ITS, serious games, chatbots, Augmented Reality (AR), Virtual Reality (VR), learning analytics and AI-based mathematics problem solver. Twenty-eight educational AI tools/apps have been identified across 32 studies. However, three studies (Hershkovitz et al., 2022; Jancarik et al., 2023; Lee et al., 2022b) did not disclose the names of the tools/apps. Some tools/apps, such as ChatGPT and Geogebra, were used in more than one study. Additionally, the ENTiTi application can be categorized as both AR and VR technology.

Table 4. The list of identified AI educational tools

Category	Tools/app	Educational Level	Country	Commercialized
Adaptive Learning/ITS	MathE	University	Portugal, Lithuania, Italy, Ireland, Romania, Russia, Spain, and Slovenia	✓
	Mathematics Auxiliary Teaching System	University	China	X
	STEAM Graded Teaching System	Primary School	China	X
	Squirrel AI	Middle School	China	✓
	e-Mathematics Learning Strategies Intelligent Assessment	High School	China	X
	Khan Academy	Adult learner	United States	X
Serious Games	Game Gea2	High School	Spain	X
Chatbot	MathBot	Adult learner	United States	X
	SnatchBot (platform to create own chatbot)	University	Spain	✓
	ChatGPT	University & Adult Learner	United States	✓
	Bard	University	United States	✓
Augmented Reality	Mobile Math Trails App	Middle School	Indonesia	X
	Zappar	Middle School	Saudi Arabia	✓
	HP Reveal (Aurasma)	Middle School	Saudi Arabia	✓
	Vuforia	High School	Indonesia	✓
	Geogebra AR	High School	Spain	✓
	ENTiTi Creator	Primary School	Cyprus	✓
	cleARmaths	High School	Portugal	✓
Virtual Reality	Vlab (https://www.v-lab-education.com/)	Middle School	Jordan	✓

Table 4 (Continued). The list of identified AI educational tools

Category	Tools/app	Educational Level	Country	Commercialized
	3D Minigames - Multiplication board - Fractions Line Up - Declare a Fraction War - Fraction Hopscotch - Quadratic Function Analyzer - Linear Function Analyzer - Radians Conversion Code Colouring - Degrees Conversion Code Colouring - Polygon Party - Cartesian Battleship - The Scale factor - Fill'er Up (Liquid Measurement) - Connecting Europe	Middle School	Greek	✓
	CalcVR	University	United States	✓
	ENTiTi Creator	Primary School	Cyprus	✓
	Eclipse VR	Primary School	China	✓
	NeoTrie VR	Primary School	Spain	✓
Learning Analytics	Fidgety Speech Emotion Recognition	University	China	x
	Forum Graph (moodle)	High School	Italy	✓
	Geogebra	Primary School Middle School	Isreal Germany United States	✓
AI Math Problem Solver	Photomath	High School	Philippines	✓

There are nine tools/apps (N=9) used at university level, including MathE, Mathematics Auxiliary Teaching System, SnatchBot, ChatGPT, Bard, CalcVR, Fidgety Speech Emotion Recognition and Forum Graph (Moodle). Meanwhile, there are eight tools/apps (N=8) that were used at high school level, including e-Mathematics Learning Strategies Intelligent Assessment, Gea2, Geogebra AR, Vuforia, cleARmaths, Forum Graph (Moodle), Geogebra, and Photomath. Research conducted at the middle school level used nine tools/apps (N=9) such as Squirrel AI, Mobile Math Trails App, Zappar, HP Reveal, Vlab, 3D Minigames, Geogebra, Vuforia, and ENTiTi Creator. At the primary school level, seven tools/apps (N=7) include STEAM Graded Teaching System, HINTS, ENTiTi Creator, Eclipse VR, NeoTrie VR, and Geogebra. Lastly, research involving adult learners used MathBot, Khan Academy and ChatGPT (N=3).

Another aspect that can be observed in **Table 4** is the number of commercialized AIME tools that are available on the internet. This study successfully identified twenty-one (N=21) commercialized AIME tools out of a total of 28 tools.

Regarding the countries in which AIME studies are conducted by category, several notable trends can be observed. China leads with the highest number of studies, totalling seven (N=7). The United States and Spain each follow closely with five studies each (N=5). Meanwhile, Portugal, Saudi Arabia and Indonesia each have two studies (N=2). Other countries such as Lithuania, Italy, Ireland, Romania, Russia, Slovenia, Turkey, Thailand, Jordan, Greece, Israel, Germany, and the Philippines have contributed with one study each.

In terms of technological categories, several tendencies can be observed. Notably, studies from China predominantly focused on Adaptive Learning Systems/ITS, with 4 out of 7 studies (N=7) falling into this category. In contrast, studies from the United States primarily focused on Chatbots, with 3 out of 5 studies (N=3) involving this category.

Commercialized AI-based Mathematical Education Tools

One of the goals of this study is to identify commercialized AIME tools, and their functionality, to know which AIME tools are best for educators. For that purpose, data regarding commercialized AIME tools have been updated as shown in **Table 5**.

Table 5. The list of identified AI educational tools

Item	AI Tools/Apps	Type of AI Tool	Functionality
1	Khan Academy	Pedagogical AI	Offers a comprehensive range of instructional videos and practice exercises in mathematics, covering topics from basic arithmetic to advanced calculus and linear algebra.
2	MathE	Pedagogical AI	Provides interactive tools and resources for learning mathematics, including problem-solving exercises and tutorials for students of various levels.
3	Snatchbot	Pedagogical AI	While primarily a chatbot platform, it can be used to create educational bots that help students with math problems through interactive, conversational interfaces.
4	ChatGPT	Generative AI	Utilizes natural language processing to assist with math education by explaining mathematical concepts and solving problems through step-by-step guidance in a conversational format.

Table 5 (Continued). The list of identified AI educational tools

Item	AI Tools/Apps	Type of AI Tool	Functionality
5	Bard	Generative AI	Generally used for content generation, but can be adapted for educational purposes, such as creating math problem sets or explanations of mathematical theories.
6	Zapper	Pedagogical AI	An augmented reality app that can be used to create engaging and interactive math learning experiences by overlaying digital information onto the real world.
7	HP Reveal	Pedagogical AI	Another augmented reality tool that can enhance math learning by allowing students to interact with 3D models and animations that explain complex math concepts.
8	Vuforia	Pedagogical AI	Offers augmented reality capabilities that can be used in math education to create interactive textbooks and educational materials that come to life with simulations and visualizations.
9	GeoGebra AR	Pedagogical AI	Allows users to place virtual 3D mathematical objects in real-world contexts using augmented reality, facilitating a deeper understanding of spatial relationships and geometry.
10	GeoGebra	Pedagogical AI	Provides dynamic mathematics software that combines geometry, algebra, spreadsheets, graphing, statistics, and calculus in one easy-to-use package.
11	ENTiTi Creator	Pedagogical AI	An augmented reality content creation tool that can be used to develop immersive and interactive math lessons and experiences.
12	Vlab	Pedagogical AI	Offers virtual lab experiences that can include mathematical simulations to help students understand mathematical principles through experimentation.
13	3D minigames	Pedagogical AI	These can be developed to teach mathematical concepts through engaging and interactive gaming environments.
14	CalcVR	Pedagogical AI	A virtual reality tool that enhances understanding of calculus. It allows users to explore and interact with 3D mathematical concepts and equations in a virtual environment, making complex calculus more accessible and engaging.
15	Eclipse VR	Pedagogical AI	Provides virtual reality experiences, which could be utilized to create immersive learning environments for geometry and spatial visualization.
16	NeoTrieVR	Pedagogical AI	Offers virtual reality software specifically designed for creating and interacting with 3D geometric figures, enhancing understanding of volume, area, and other properties.
17	Forum Graph	Pedagogical AI	Typically, a tool for creating graphs and charts that can be used in teaching statistical and algebraic concepts.
18	Photomath	Generative AI	Uses a smartphone camera to scan and solve mathematical problems, providing step-by-step explanations for each solution, which helps in learning and understanding math on the go.
19	Squirrel AI	Pedagogical AI	An adaptive learning platform that personalizes math education for students by adjusting the difficulty of tasks in real-time based on the learner's performance.
20	cleARmaths	Pedagogical AI	Focuses on augmented reality applications in math education, offering tools to visualize complex mathematical concepts through AR.

One of the goals of this study is to identify commercialized AI-based mathematical education (AIME) tools and classify them based on their functionality and type, to provide educators with a clearer understanding of their purposes. For this purpose, the data regarding commercialized AIME tools have been updated and categorized into Generative AI Tools and Pedagogical AI Tools, as shown in **Table 6**. Among the identified tools, the majority fall under the category of Pedagogical AI Tools (N=17), which are primarily designed to enhance teaching and learning through interactive platforms, such as GeoGebra, Khan Academy, and Squirrel AI. A smaller subset, categorized as Generative AI Tools (N=3), focuses on generating content or solutions dynamically, such as ChatGPT, Bard, and Photomath. These distinctions provide valuable insights into the current landscape of commercialized AIME tools and aim to guide educators in selecting the most suitable tools for their instructional needs and specific classroom contexts.

Emerging Trends and Future Directions in AIME

To identify emerging trends and future directions in AIME, the findings from 32 studies were analyzed using thematic analysis. The results of the thematic analysis identified six themes, as shown in **Table 6**.

Table 6 presents a thematic analysis of recent studies in Artificial Intelligence in Mathematics Education (AIME), highlighting emerging trends and future directions in the field. The growing use of Augmented Reality (AR) and Virtual Reality (VR) in mathematics education has shown promising results in enhancing students' motivation and problem-solving skills, as evidenced by studies from Elsayed and Al-Najrani (2021), Jones et al. (2023), Nindiasari et al. (2024), Romero et al. (2023), and Qawaqneh et al. (2023).

AI-driven analytics and feedback systems, have expanded from adaptive learning systems to chatbots, are significantly enhancing mathematics education by reducing math anxiety, and improving learning outcomes, with key contributions from Cai et al. (2021), Calonge et al. (2023), Getenet (2024), Inoferio et al. (2024), Jancarik et al. (2023), Moral-Sánchez et al. (2023), and Wardat et al. (2023). At the same time, personalization and adaptation, driven by AI and data in adaptive systems, are emphasized for their significant impact on enhancing learning experiences by tailoring instruction to individual student needs, supported by research from Azevedo et al. (2024), Shi and Rao (2022), Tan (2022), and Wang et al. (2023). On the other hand, the incorporation of AI in serious games and gamification effectively enhances learning and engagement through game-based learning environments, as demonstrated by Ferro et al. (2021).

Table 6. The themes emerged related to the trends and future directions of AIME

Themes	Reference
The growing use of Augmented/Virtual reality	Qawaqneh et al. (2023) Elsayed and Najrani (2021) Romero et al. (2023) Jones et al. (2023) Nindiasari et al. (2024)
The expanded roles of AI-driven analytics and feedback systems	Cai et al. (2021) Jancarik et al. (2023) Wardat et al. (2023) Calonge et al. (2023) Getenet (2024) Inoferio et al. (2024) Moral-Sánchez et al. (2023)
Emphasis on personalization and adaptation in mathematics education	Shi and Rao (2022) Wang et al. (2023) Tan (2022) Azevedo et al. (2024)
Incorporation of AI in serious games and gamification	Ferro et al. (2021)
The need for long-term impact and sustainability	Shi and Rao (2022) Wang et al. (2023) Tan (2022) Azevedo et al. (2024) Inoferio et al. (2024)
Teacher and student interaction with AI	Calonge et al. (2023). Wardat et al. (2023)

There is a notable call for longitudinal research to assess the long-term impacts of AIME on learning outcomes, student motivation, and educational equity, highlighted by studies from Azevedo et al. (2024), Inoferio et al. (2024), Shi and Rao (2022), Tan (2022) and Wang et al. (2023). Lastly, the dynamic between AI tools and traditional teaching methods is explored, suggesting the need to investigate how AI can support, rather than replace, human teachers. This includes examining the impact of AI on teacher roles, student-teacher interactions, and overall classroom dynamics, with insights from Calonge et al. (2023) and Wardat et al. (2023).

DISCUSSION

The result of **RQ1** reveals that AI in mathematics education has been applied across various educational levels, from primary to higher education. Most studies focused on secondary education, highlighting the potential of AI to address the specific challenges faced by this age group. In higher education, AI applications were primarily geared towards providing advanced problem-solving support and personalized learning experiences. Meanwhile, AI tools being used to develop foundational skills among young learners in primary school. This broad application across educational levels indicates the versatility of AI tools in catering to diverse learning needs and enhancing educational outcomes at all stages.

Meanwhile, **RQ2** identified AI tools employed and the respective categories. The results indicate that AIME tools were categorized into several distinct types, including adaptive learning systems, intelligent tutoring systems, chatbots, augmented reality, virtual reality, serious games, learning analytics and mathematics problem solver. Chatbots were the most prevalent in these recent years, followed by virtual reality tools demonstrated significant potential in making learning more interactive and engaging. Besides virtual reality, augmented reality technology has also become a quite prominent AI tool in AIME studies. Subsequently, adaptive learning systems and intelligent tutoring systems have attracted significant attention, emphasizing their effectiveness in providing personalized learning experiences and tailored feedback. Additionally, learning analytics has emerged as a rising AIME technology, offering valuable insights into student performance and learning patterns. By analyzing vast amounts of educational data, learning analytics helps educators identify areas where students struggle, enabling targeted interventions and support.

The least focused category of AIME is the integration of AI in serious games and the use of mathematics problem solver applications. Studies involving AI in serious games were conducted in 2021, while studies using mathematics problem solver applications were carried out in 2023. This could be interpreted as the integration of AI in serious games not gaining much traction, whereas the use of mathematics problem solver applications is a newly emerging aspect in AIME.

Chatbots, although the most popular among studies involving AIME, are only implemented at the university level and for adult learners. Similarly, AR and VR technologies are prominent at the school level. This can be interpreted as a tendency for chatbots to be more suitable for older students who can engage with complex interactive systems, while AR and VR technologies are effectively used to enhance engagement and understanding among younger students in school settings.

From another perspective, mathematics problem solver applications like Photomath are very practical for school students as they provide quick solutions to mathematical problems. However, these applications are currently limited to solving straightforward mathematical problems that do not involve word problems, making them more suitable for algebra-related questions. On the other hand, AR/VR applications are better suited for explaining geometric concepts. There are numerous commercial AR/VR applications available for educators, as listed in **Table 4**.

The results of **RQ3** identified 20 commercialized AI-based mathematical education (AIME) tools available on the internet, categorized into two distinct groups: Generative AI Tools and Pedagogical AI Tools. Generative AI Tools are systems designed to dynamically generate content, such as step-by-step solutions, explanations, or learning materials, based on user input. As of now, the main purposes of Generative AI Tools in mathematics education are to provide instant assistance for solving specific mathematical problems and to generate personalized explanations for complex concepts. Examples include ChatGPT, Photomath, and Bard, which are particularly useful for algebra, geometry, and other areas requiring immediate problem-solving.

In contrast, Pedagogical AI Tools are primarily designed to enhance teaching and learning processes, supporting educators and students across various contexts. One significant purpose of these tools is adaptive learning, as demonstrated by platforms like Squirrel AI and Khan Academy, which personalize learning experiences by providing adaptive feedback and tailoring content to individual student needs. This approach improves engagement and learning outcomes across diverse educational levels. Another key purpose is the use of augmented and virtual reality (AR/VR) technologies. Applications such as GeoGebra AR, cleARmaths, and Vuforia employ immersive technologies to visualize abstract concepts and facilitate interactive exploration of mathematics, particularly in areas like geometry and spatial reasoning. Additionally, Pedagogical AI Tools include 3D learning environments, exemplified by tools like CalcVR and NeoTrieVR, which allow students to interact with three-dimensional mathematical objects. These tools enhance understanding of mathematical properties such as volume, area, and spatial relationships and are particularly impactful for advanced topics like calculus and three-dimensional geometry.

Adaptive learning systems and ITS are highly flexible technologies suitable for all educational levels. Numerous commercial adaptive learning systems and ITS are available online; however, this study highlights only three: MathE, Squirrel AI, and Khan Academy. Among these, Khan Academy stands out as the most prominent adaptive system due to its free access for all users. Furthermore, Khan Academy incorporates numerous AI features, including a recently embedded chatbot that explains mathematical concepts and provides solutions to math problems, much like a human tutor (Khan Academy, 2023).

Learning analytics technology is typically not a standalone solution; instead, it is integrated into platforms such as Learning Management Systems, Adaptive Learning Systems, Moodle, and the also in GeoGebra application. It involves collecting and analyzing data about learners to optimize their educational experiences. This integration provides valuable insights into student performance, helps identify at-risk students, and personalizes learning, allowing educators to make data-driven decisions to improve teaching strategies and student outcomes (Aldowah et al., 2019).

The thematic analysis of AI in Mathematics Education (AIME) highlights several key trends and future directions. Studies show that AR and VR technologies significantly enhance student motivation and problem-solving skills by making abstract concepts more engaging and tangible. Another significant trend is the use of AI-driven analytics and feedback systems, especially chatbots, improve learning outcomes through real-time, personalized support and feedback (Cai et al., 2021; Jancarik et al., 2023; Wardat et al., 2023). The importance of personalization and adaptation is also highlighted, with adaptive learning systems and intelligent tutoring systems leading the way in creating customized learning experiences (Azevedo et al., 2024; Shi & Rao, 2022; Tan, 2022; Wang et al., 2022). Additionally, AI integration into serious games and gamification increases student engagement and reinforces mathematical concepts through interactive learning environments (Ferro et al., 2021).

The thematic analysis also identified future directions highlighted by these studies. The results indicate there is a strong need for longitudinal studies to evaluate the long-term impacts of AIME on learning outcomes, motivation, and educational equity (Cahyono et al., 2020; Demitriadou et al., 2020; Elsayed, 2023; Getenet, 2024; Nindiasari et al., 2024). Additionally, investigating the interaction between AI tools and traditional teaching methods is crucial to understanding how AI can complement and support human teachers (Wardat et al., 2023).

CONCLUSION

The aim of this systematic literature review (SLR) was to explore the application and impact of Artificial Intelligence in Mathematics Education (AIME) across various educational levels, identify the categories and types of AI tools employed, and highlight emerging trends and future directions in the field. This review provides a comprehensive overview of how AI technologies are being integrated into mathematics education and their potential to enhance learning outcomes.

The identified AI tools were categorized into two main groups, which are Generative AI Tools and Pedagogical AI Tools. This categorization highlights the complementary roles of Generative AI Tools and Pedagogical AI Tools in mathematics education. While Generative AI Tools excel in providing specific, on-demand problem-solving and content creation, Pedagogical AI Tools dominate in supporting broader instructional goals, offering personalized learning paths, interactive engagement, and immersive exploration. Together, these tools showcase the expanding potential of AI in transforming mathematics education.

The prominent AI tools identified include adaptive learning systems, intelligent tutoring systems, chatbots, augmented reality (AR), virtual reality (VR), serious games, learning analytics, and mathematics problem solver applications. The review also revealed that while the integration of AI in serious games and mathematics problem solver applications is less common, these areas are emerging and hold potential for future development. Furthermore, the use of learning analytics embedded in various educational platforms provides valuable insights into student performance, helping educators make data-driven decisions to improve teaching strategies. The review of adaptive systems also found that chatbot technology has been integrated into adaptive systems to aid in solving math problems, like a human tutor.

The implications of this SLR are manifold. It highlights the necessity for ongoing research and longitudinal studies to assess the long-term impacts of AIME on learning outcomes, motivation, and educational equity. Moreover, it emphasizes the need to investigate the interaction between AI tools and traditional teaching methods to understand how AI can best complement and support human teachers. This understanding will enable educators and policymakers to effectively utilize AI technologies to create more adaptive, efficient, and equitable educational experiences.

In summary, this SLR provides a detailed examination of the current landscape and future directions of AIME. By identifying key trends and effective AI tools, it offers valuable insights for educators, researchers, and policymakers aiming to enhance educational practices and outcomes through the integration of AI technologies. Whereas the future directions emphasize the need for long-term studies on AI's impact and how AI can best complement traditional teaching methods.

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