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A systematic review of artificial intelligence in mathematics education: The emergence of 4IR

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Abstract

The integration of artificial intelligence (AI) in mathematics education, focusing on its implications in the 4th Industrial Revolution (4IR) era. Through a comprehensive analysis of 10 relevant studies in Scopus and Google Scholar from 2015 to 2023, this review identifies the research methods, research instruments, participants, and AI tools used in mathematics education. Some key ideas include using AI-driven personalized learning and enhanced mathematics instruction, real-time assessment and feedback, curriculum development, and empowering educators, which were highlighted. The study aligns with the preferred reporting items for systematic reviews and meta-analysis. Based on the analysis, most studies reviewed utilized qualitative research methods. The study indicates that questionnaires were mainly used to gather data from students and teachers who were the most significant participants in the reviewed papers. Further results revealed that ChatGPT were the primary AI tool used in mathematics education, among other AI tools, as identified in this review. Additionally, this review discusses the transformative potential of AI in addressing educational disparities and preparing learners for the demands of 4IR.

Keywords: artificial intelligence, artificial intelligence tools, mathematics education, 4th Industrial Revolution, chatbot

INTRODUCTION

Artificial intelligence (AI) in mathematics education can revolutionize how students learn and interact with complex concepts. Using AI, teachers can provide personalized learning experiences tailored to each student's needs and abilities. Subsequently, AI can analyze student performance data to identify areas of weakness and provide additional support and resources to help students improve their understanding of mathematical concepts. With AI technology, the possibilities for engaging and enhancing mathematical education are endless. AI is arguably the driving technological force of the first half of this century and will transform virtually every industry, if not human endeavors at large (Davenport et al., 2020; Makridakis, 2017). Businesses and governments worldwide are spending massive amounts of money on AI (Dwivedi et al., 2021), and education cannot be left out in this regard.

AI incorporates the computational understanding and imitation of intelligent behavior in machines, enabling them to perform tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages (Hoffmann, 2022). Technology's rapid and steady growth in the 21st century has resulted in disruptive transformations in various areas. 4th Industrial Revolution (4IR) has emerged because of the convergence of digital technology, data analytics, and AI, altering how we live, work, and learn (Adelana et al., 2023; Moloi & Marwala, 2023; Opesemowo & Ndlovu, 2023; Rambe & Maime, 2023). Education is one of the critical areas undergoing this shift, particularly in the teaching and learning of mathematics. Since the beginning of human history, mathematics has been an essential discipline, contributing to scientific and technological advancements, cognitive growth, and logical reasoning. Structures and principles inherent to AI have created a framework for understanding complicated events and comprehending our world. In this era of technological progress and abundant information, the ability to read, interpret, and apply mathematical concepts is more vital than ever.

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Contribution to the literature

- This research seeks to unravel the research method most adopted for AI in mathematics education.
- Another contribution of this study is identification of the various research instruments utilized for data collection.
- Through the systematic review, this study contributes to provide valuable information for educators and policymakers to infuse AI technology into mathematics.

4IR is distinguished by the convergence of technology that blurs the distinctions between the physical, digital, and biological worlds. AI is at the center of this revolution, together with other technologies such as the Internet of things and big data (Bhat & Huang, 2021; Lee et al., 2022; Misra et al., 2022; Sharma et al., 2021; Tien, 2017). It has resulted in automation, data-driven decision-making, and the development of intelligent systems that can learn and adapt over time. These improvements have far-reaching ramifications for education, necessitating a change from traditional educational approaches to more adaptable and individualized ones. Similarly, 4IR's fusion of technologies requires an educational paradigm shift aligned with its dynamic and interconnected nature. In this scenario, AI appears as a powerful instrument capable of supplementing, refining, and reinventing mathematics education, encouraging a more significant grasp and appreciation for the subject.

The emergence of 4IR has been characterized by the introduction of AI, which involves algorithms (Oosthuizen, 2022). Recently, the attention of AI has been shifted to teaching mathematics education, which will aid the teaching and learning process of mathematics. If AI is deployed adequately in teaching and learning mathematics education, it will positively boost the mathematics performance of the learners. National Research Council of the USA argued that mathematics is vital for various tasks, including simulation constructions, statistical data analysis, and expressing and applying quantitative relationships. Mathematics education perfectly matches AI integration because of its structured character and the increasing demand for mathematics abilities in a data-driven economy (Singh et al., 2022). AI plays vital roles in mathematics education, such as personalized learning, real-time assessment and feedback, curriculum enhancement, and empowering educators.

Personalized learning is essential to mathematics education since it allows students to learn at their own pace and concentrate on areas requiring extra assistance (Yu et al., 2022; Zhilmagambetova et al., 2023). Algorithms can monitor students' performance and personalize the learning experience to their specific needs using AI integration (Fernandes et al., 2023; (Opesemowo & Adekomaya, 2024). This improves students' understanding of mathematical ideas and increases their confidence and motivation. Furthermore, AI can provide real-time assessment and feedback (Hooda et al., 2022), allowing students to track their progress and find areas for growth rapidly. This immediate feedback loop develops a more profound knowledge of mathematical ideas and will enable students to overcome misconceptions quickly. In addition, AI technology can provide recommendations for additional resources and practice materials based on each student's strengths and weaknesses (Alam, 2023). This ensures that students can access the right tools and materials to enhance their mathematical skills further.

Moreover, AI can also assist teachers in identifying struggling students and intervening early to provide extra support and assistance (Srinivasa et al., 2022). By leveraging AI in mathematics education, students can become more actively engaged in their learning journey and achieve better results. However, none of these reviews provides a detailed analysis of how AI has been deployed in mathematics education, which this study delved into. The study aimed to fill this gap in the literature by examining the research method adopted for AI integration into mathematics education. It explored the various research instruments utilized for data collection, the respondents, and AI tools used to teach mathematics education. This study seeks to provide deeper and valuable insights for educators and policymakers to incorporate AI technologies into mathematics education and inform future research and practice in the field by conducting a comprehensive analysis.

Research Questions

This study systematically analyzed and synthesize empirical published articles focusing on AI in mathematics education in the classroom. For relevance, this study was restricted to articles dealing with AI in mathematics education at the elementary, secondary, and university school levels. In light of this, being grounded in mathematics starts at the elementary school level (Hill & Seah, 2023, 2017; Rittle-Johnson, 2017). Hence, the research questions for this study were:

1. What is research method adopted for AI in mathematics education?
2. What kind of research instruments are used for data collection?
3. Who are respondents?

4. What kind of AI tools were used in identified papers?

METHODOLOGY

Search Strategy

The study adopted the advanced document search to identify relevant and appropriate literature on AI in mathematics education. The search strategy was fashioned using keywords such as "AI", "mathematics education", and "4IR" in the Scopus database and Google Scholar. Initially, without setting the data parameters, 1,020 articles were found. The search was conducted on 11th July 2023 without specifying any criteria, and a total of 562 papers comprising conference papers, book chapters, books, conference reviews, conference proceedings, book series, editorials, magazines, reports, lecture notes, errata, and articles in press were expunged from the first search. Therefore, 458 papers of peer-reviewed academic journal articles documented in English and published from 2015 to 2023 emerged for selection criteria.

Selection Criteria

Preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement proposed by Moher et al. (2009) was adopted for sorting articles. In PRISMA statement, a 27-item evidence-based checklist, including a four-phase workflow diagram, is provided for evaluating systematic reviews that have been published. PRISMA aims to ensure consistency and accountability that is devoid of bias when documenting the systematic literature analysis. The primary objective of the selection criteria was to identify existing research and empirical investigations of AI used in mathematics education. The following inclusion criteria were used to select the papers reviewed for this study. These are studies on the use of AI in teaching and learning mathematics in schools, studies that describe AI tools used in mathematics education, and studies published in peer-reviewed journals written in English Language only and published between 2015 to 2023. However, the criteria were carefully chosen to ensure that the selected papers were relevant to the research topic and met a certain level of rigor. By including studies on the use of AI in mathematics education, the research team aimed to comprehensively understand the current landscape and the potential impact of AI in the field. In addition, the requirement for peer-reviewed journal publications helped to ensure the reliability and accessibility of the information gathered. By setting these specific criteria, the study strived to maintain a transparent and unbiased approach to analyzing the literature on AI in mathematics education.

Quality Assessment

To ascertain quality assessment, the authors deleted all articles not published between 2000 and 2015, none-journal articles, articles not focusing on AI, mathematics education, and 4IR articles not published in English. The authors transferred the identified papers' titles, abstracts, keywords, authors' names, journal names, and publication years to an MS Excel spreadsheet. The article's abstract was rigorously examined for purity, rationality, and adherence to the established criteria. However, the four PRISMA review processes were not distorted as criteria for the study. In addition, twenty-nine articles were removed based on duplication of records. The titles of articles were scrutinized, resulting in the removal of twenty-nine articles because they were not concentrating on the study's keywords (i.e., AI, mathematics education, and 4IR).

PRISMA Systematic Review Method

Identification

The articles identified were sourced from the Scopus database and Google Scholar database. From both databases, a total of 110 published papers were discovered using the main construct or variables of the study; that is, 90 articles were from the Scopus database, while 20 articles were identified using Google Scholar.

Screening

In this method, we adopted several inclusion and exclusion criteria. In ensuring proper scrutiny of the review process, systematic review articles, books, book chapters, proceedings, or conference papers were not included in the articles selected while focusing solely on AI, mathematics education, and 4IR published journal articles between 2015 to 2023. Nevertheless, countries or regions, where the papers were published were not considered for exclusion. At the end of the screening process, authors focused on articles with at least one mathematics reference. During the screening process, 23 articles were spotted as not complying with the study's requirements, while 29 papers were discovered as duplicates. In addition, there are only 58 articles left.

Eligibility

In determining the eligibility of all the 110 articles that fit the study's selection process, each article's title, abstract, methodology, results, and discussion were thoroughly reviewed. At this junction, 100 journal articles were found to be culpable for not fully addressing AI in mathematics education in 4IR era. To this end, 10 articles were selected in the final stage of the systematic review process, as presented in **Figure 1**.

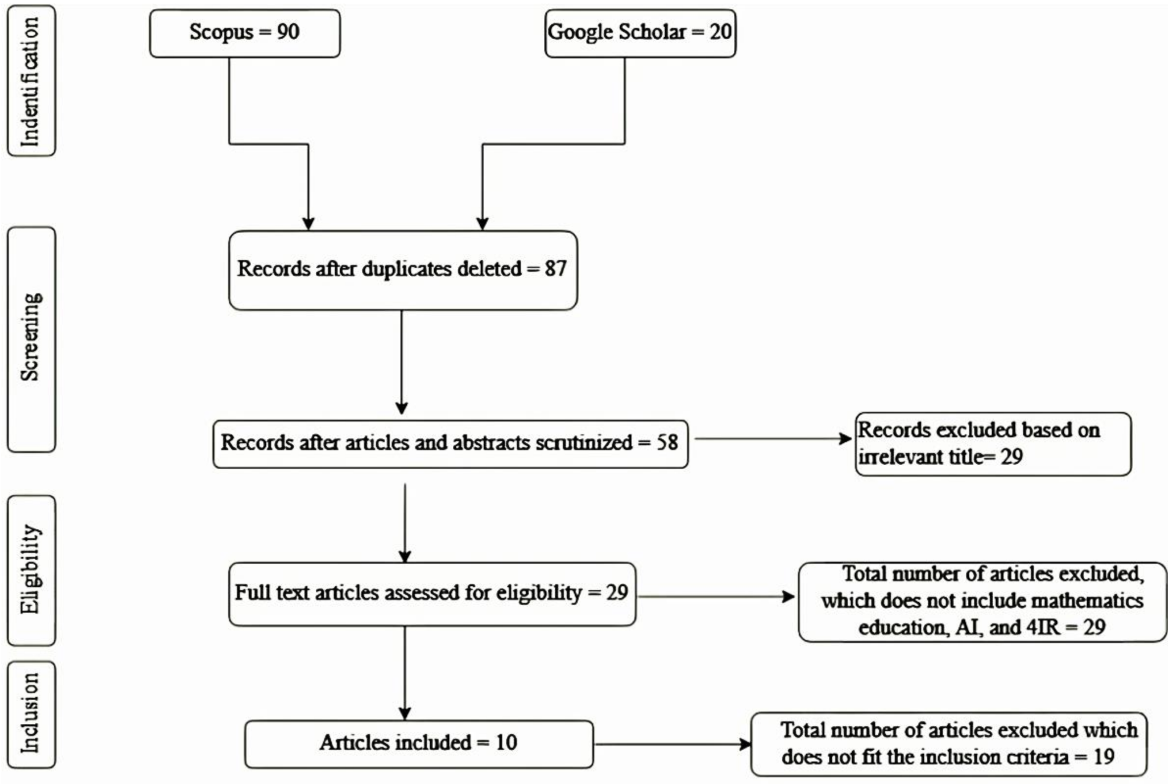

Figure 1. PRISMA flow diagram (Source: Authors' own elaboration)

Inclusion & exclusion

For the inclusion criteria, articles published between the year 2015 to 2023 were selected, while articles below 2014 were excluded from the review. Also, articles published in the English language were included in the review, whereas articles published using languages other than English were excommunicated.

In addition, the publication stage of the selected articles was considered. Finally, published articles were included, and articles in the press were excluded. Therefore, 10 published articles were reviewed for this study.

Table 1 shows list of the 10 reviewed journals in this study.

Table 1. List of 10 reviewed journals in this study

Reference	Title	Data collection	Research design	Respondent	AI tool
Büscher (2020)	Scaling up qualitative mathematics education research through artificial intelligence methods	Video recording	N/A	Professional development course	Coding & transcribing
Chiang (2021)	Estimating the artificial intelligence learning efficiency for civil engineer education: A case study in Taiwan	Questionnaire	Survey	University students	Data envelopment analysis & Mahalanobis distance approaches
Ferro et al. (2021)	Gea2: A serious game for technology-enhanced learning in STEM	Questionnaire	Quasi experimental design	Students & teachers	Gae2
Flogie and Aberšek (2015)	Transdisciplinary approach of science, technology, engineering and mathematics education	Questionnaire	Experimental	Students & teachers	Not specified
Forbus et al. (2020)	Sketch worksheets in science, technology, engineering, and mathematics classrooms: Two deployments	Not specified	N/A	Instructors	Sketch worksheets
Lee and Yeo (2022)	Developing an AI-based chatbot for practicing responsive teaching in mathematics	Online form	Design-based research	Pre-service schoolteachers	Chatbots

Table 1 (Continued). List of 10 reviewed journals in this study

Reference	Title	Data collection	Research design	Respondent	AI tool
Schindler and Lilienthal (2022)	Students' collaborative creative process and its phases in mathematics: An explorative study using dual eye tracking and stimulated recall interviews	DUET & SRI	Case study approach	Graduate education students	Dual eye-tracking
Schindler et al. (2022)	Small number enumeration processes of deaf or hard-of-hearing students: A study using eye tracking and artificial intelligence	Eye-tricking device & stimuli	Experimental	3rd to 5th grade students	Cluster algorithm
Sun et al. (2023)	A theoretical framework for a mathematical cognitive model for adaptive learning systems	Questionnaire & interview	Survey	Primary & secondary teachers	ISM
Wardat et al. (2023)	ChatGPT: A revolutionary tool for teaching and learning mathematics	Triangulation	Instrumental study	Students & educators	Chatbots

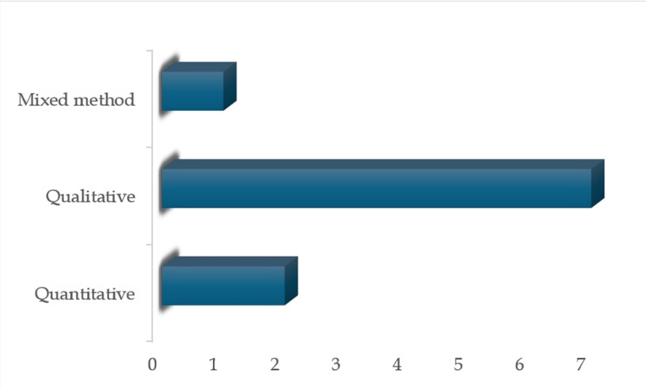

Figure 2. Methodology used by authors (Source: Authors' own elaboration)

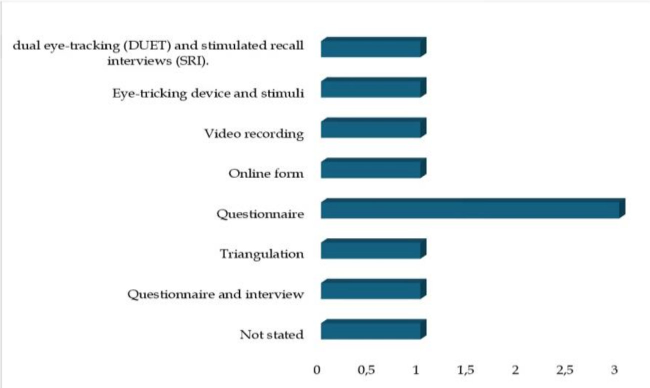

Figure 3. Data collection analysis (Source: Authors' own elaboration)

RESULTS

The systematic analysis of the study conducted between 2015 to 2023 on AI in mathematics education in this paper was used to answer the research question.

RQ1. What Is Research Method Adopted for AI in Mathematics Education?

The first research question focused on the research method adopted for AI in mathematics education. The findings showed that the reviewed study used three research methodologies: quantitative, qualitative, and mixed methods. The findings also demonstrate that 70% (n=7) of the examined study used qualitative research method (Büscher, 2020; Ferro et al., 2021; Flogie & Aberšek, 2015; Lee & Yeo, 2022; Schindler et al., 2022; Wardat et al., 2023) indicating that majority of the reviewed study utilized qualitative method. Subsequently, it was uncovered that 20% (n=2) of the examined study were quantitative research methods (Chiang, 2021; Flogie & Aberšek, 2015). Lastly, the mixed method was used with 10% (n=1) of the reviewed study (Sun et al., 2023) (**Figure 2**).

RQ2. What Kind of Research Instruments Are Used for Data Collection?

Research question two presents the method of data collection. It showed that most of the study sample employed questionnaires (i.e., n=3: Chiang, 2021; Ferro et al., 2021; Flogie & Aberšek, 2015). In addition, one reviewed study used a questionnaire and interview (i.e., Sun et al., 2023) to collect data. Others used various methods of data collection, such as dual eye-tracking (DUET) and stimulated recall interviews (SRI) (Schindler et al., 2022), online form (Lee & Yeo, 2022) did not specify the method of data collection. In addition, a questionnaire was the most commonly used data collection method (**Figure 3**).

AI in mathematics education in the new era of 4IR. These methods allow researchers to gather both quantitative and qualitative data, providing a comprehensive understanding of the research topic. Questionnaires enable researchers to collect data from many participants, while interviews allow in-depth exploration of participants' experiences and perspectives.

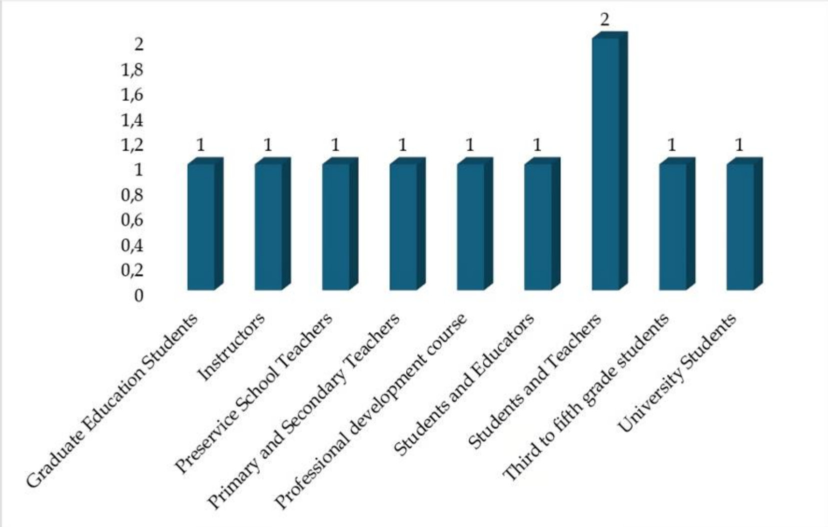

Figure 4. Sample respondents (Source: Authors' own elaboration)

Including video recording as a data collection method suggests a focus on capturing non-verbal cues and behaviors. Triangulation, on the other hand, involves using multiple data sources or methods to enhance the validity and reliability of findings. Using eye-tracking devices and stimuli indicates a focus on studying visual attention and perception. Finally, combining DUET and SRI suggests a sophisticated approach to understanding participants' thought processes and decision-making. Overall, the variety of data collection methods employed in this study reflects researchers' commitment to capturing a comprehensive range of data for analysis and interpretation. Also, it allows researchers to explore various aspects of AI implementation and its effects on teaching and learning practices in mathematics education.

RQ3. Who Are Respondents?

To address this research question, the articles (n =10) used for this systematic study showed that data were collected from various respondents, as shown in **Figure 4**. The authors organized their data from different respondents. The respondents range from graduate education students to university students. However, the authors (Ferro et al., 2021; Flogie & Aberšek, 2015) used students and teachers as their respondents, representing the highest number of respondents for this review.

In addition, Büscher (2020), Chiang (2021), Forbus et al. (2020), Lee and Yeo (2022), Schindler et al. (2022); Schindler and Lilienthal (2022), Sun et al. (2023), and Wardat et al. (2023) indicated graduate education students, instructors, pre-service teachers, primary and secondary teachers, professional development course, students and educators, third to fifth grade students, and university students, respectively as respondents in their study. Subsequently, these studies included diverse respondents, allowing for a comprehensive topic analysis. Including students and teachers as respondents ensures that the perspectives of both groups are well represented, providing a more well-rounded understanding of the subject. Also, including graduate education students, instructors, and pre-service teachers further inflates the scope of the research, allowing for in-depth insights from individuals actively involved in the field of education. Including various grade levels, such as primary and secondary teachers and third to fifth-grade students, provides a broader perspective on the topic, considering the different experiences and challenges faced at various stages of education. Moreover, the inclusion of university students and educators in the studies acknowledges the importance of higher education in shaping teaching practices and educational approaches. Overall, these studies' diverse range of respondents enhances the findings' validity and applicability, contributing to a more comprehensive understanding of AI in mathematics education.

RQ4: What Kind of AI Tools Were Used in Identified Papers?

Research question four focuses on the various AI tools utilized by the author. AI tools range from specific methodologies, such as interpretive structural modeling (ISM) and dual eye-tracing, to broader approaches, including ChatGPT and coding/transcribing. The studies reviewed indicated that more authors used ChatGPT as a revolutionary AI tools for teaching and learning mathematics in schools. The study includes Lee and Yeo (2022) and Wardat et al. (2023). Büscher (2020), Chiang (2021), Ferro et al. (2021), Forbus et al. (2020), Schindler et al. (2022), Schindler and Lilienthal (2022), and Sun et al. (2023) utilized Sketch worksheets, ISM, coding and transcribing, cluster algorithm, data envelopment analysis and Mahalanobis distance approaches, DUET, and Gae2, respectively. One reviewed study (Flogie & Aberšek, 2015) failed to specify AI tool used. **Table 2** shows distribution of AI tools.

Table 2. Distribution of AI tools

Reference	AI tools	Frequency (n)	Percentage (%)
Büscher (2020)	Coding and transcribing	1	10
Chiang (2021)	Data envelopment analysis & Mahalanobis distance	1	10
Ferro et al. (2021)	Gae2	1	10
Flogie and Aberšek (2015)	Not stated	1	10
Forbus et al. (2020)	Sketch worksheets	1	10
Lee and Yeo (2022)	ChatGPT	1	10
Schindler and Lilienthal (2022)	Dual eye-tracking	1	10
Schindler et al. (2022)	Cluster algorithm	1	10
Sun et al. (2023)	ISM	1	10
Wardat et al. (2023)	ChatGPT	1	10
Total		10	100

DISCUSSION

The study focused on the review of AI in mathematics education: the emergence of 4IR. The first research question reviews the methodology adopted for AI in mathematics education by the sample studies. This study reveals the three research methods (i.e., qualitative, quantitative, and mixed method research) were used in the review study. The study reviewed 10 research-published articles. We discovered that the qualitative research method was the most prominent methodology used by researchers. This result aligns with Ogegbo and Ramnarain (2022), who also uncovered in their systematic review of computational thinking in science classrooms that qualitative research design was the most common research method used by authors. The prevalence of qualitative research methods in the reviewed studies strongly emphasizes exploring subjective experiences, perspectives, and meanings related to the research topic. This approach allows for a deep understanding of the phenomenon under investigation, providing rich and detailed insights that may not be captured through quantitative methods alone. This result opposes the findings of Mohamed et al. (2022) in a similar review study, which stated that researchers often use the use of quantitative method approach since it emphasizes the objective measurement and analysis of statistical, mathematical, or numerical data gathering via questionnaires and surveys for the used of AI in mathematics education.

Subsequently, it is essential to note that qualitative and quantitative methods have strengths and limitations. While quantitative methods provide numerical data that can be easily analyzed and compared, qualitative methods offer a more in-depth understanding of the complexities and nuances of a particular phenomenon. They allow researchers to gather context-specific information on human experiences, behavior, attitudes, and emotions within specific sociocultural contexts (Dzogovic & Bajrami, 2023; Onyemah & Omoponle, 2022). Therefore, combining both approaches can provide a more comprehensive and holistic view of the research topic. In the context of AI in mathematics education, a mixed-methods approach could be particularly beneficial in capturing the multifaceted nature of how AI is applied in the field. This would involve collecting quantitative data on the effectiveness of AI tools and qualitative data on the experiences and perceptions of teachers and students using these tools. By integrating these different perspectives, researchers can gain a more nuanced understanding of the impact of AI on mathematics education and make more informed recommendations for future practice and research.

Another main research question answered in this review was using the data collection method. It was uncovered that questionnaires are the foremost form of data collection, among others. Questionnaires allow researchers to gather large amounts of data from a wide range of participants relatively efficiently. This method is often preferred for its ability to collect standardized responses, making it easier to analyze and compare results across different studies. Arundel (2023) reported that questionnaire testing is essential for ensuring high-quality data collection and achieving content validity, inter-rater validity, and reliability. In addition, questionnaires can be easily distributed and completed by participants at their convenience, making them a convenient option for researchers conducting studies with limited resources or time constraints. However, it is essential to note that questionnaires also have limitations. One major drawback is the potential for response bias (Adewuyi & Oluwole, 2016; Wetzel et al., 2016), where participants may provide inaccurate or socially desirable responses and can skew the data and lead to misleading conclusions. Another limitation is the lack of depth in responses, as questionnaires typically only remain valuable for researchers to gather large amounts of data efficiently.

Further research questions were raised to identify the respondents in the reviewed articles. It was detected that various respondents served as participants in the reviewed articles. This includes graduate education students, instructors, pre-service schoolteachers, primary and secondary teachers, professional development courses, students and educators, students and teachers, 3rd to 5th grade students, and university students. This study indicates that most of the authors of the reviewed articles used students and teachers in their research. This finding is in tandem with a similar survey by Kurowski et al. (2022), whose report focused on primary school teachers, pupils, and parents. The diverse range of respondents in the sample provides a comprehensive perspective on the effectiveness of the reviewed articles across various educational levels. The emphasis on students and teachers in their studies aligns with the importance of understanding the impact of educational interventions on these critical stakeholders.

The survey of Kurowski et al. (2022) further supports the notion that involving primary school teachers, pupils, and parents is crucial in evaluating the success of educational initiatives.

The last research question that this study answered was to identify the various AI tools used in mathematics education. Emphasis on these AI tools was necessary to understand how teachers improve the learning of mathematics education concepts. In this review study, ChatGPT was spotted to have the highest percentage of AI tools, which accounted for 20%.

In contrast, sketch worksheets, ISM, coding and transcribing, data envelopment analysis, Mahalanobis distance approaches, and dual accounted for 10%, respectively. Consequently, one reviewed paper did not disclose AI tool used. These results further showed how ChatGPT has contributed to AI in mathematics education. This result supports the study of Wardat et al. (2023), who acknowledged that using ChatGPT in mathematics education has shown promise in improving learning outcomes and increasing student engagement. It is also known that ChatGPT can enhance mathematics capabilities and increase educational success by providing learners with essential mathematical knowledge on various topics.

However, several studies (Adiguzel et al., 2023; Deng & Yu, 2023; Lee & Yeo, 2022; Wu & Yu, 2023) have explored using ChatGPT, such as ChatGPT, in teaching mathematics. Their studies have found that ChatGPT can provide comprehensive instruction and assistance in geometry, increasing educational success by offering learners basic mathematics knowledge.

ChatGPT can provide students with personalized support and instant feedback, guiding them through complex mathematical problems and identifying areas, where they may need additional assistance. By offering an interactive learning experience, ChatGPT helps students build confidence in their mathematical skills, ultimately leading to tremendous success in the subject. Also, using ChatGPT in mathematics education can alleviate the burden on teachers, giving them more time to concentrate on other academic activities and providing additional support to students outside the classroom.

CONCLUSIONS & RECOMMENDATIONS

With AI driving 4IR, integrating AI into mathematics education represents a shift with immense potential. Collaboration between educators, researchers, and technologists will be critical as we traverse this dynamic terrain to reshape the future in which AI empowers learners and prepares them for the challenges and opportunities of 4IR as an innovation characterized as the bedrock of any developed society.

However, the path to this future is not without difficulties, including issues surrounding ethics, accessibility, and the striking balance between AI and human abilities. This investigation into AI’s role in mathematics education aims to reveal the way forward, promoting collaboration and dialogue among educators, policymakers, and technologists as we navigate 4IR’s undiscovered areas.

By examining the intersection of AI and mathematics education, we can uncover new ways to enhance learning experiences and equip students with the necessary skills for success in a rapidly evolving digital world. The potential benefits of integrating AI into mathematics education are enormous, from personalized learning experiences to real-time feedback and assessment. But AI can be used responsively if ethical considerations are carefully addressed and equitably in educational settings. Also, ensuring accessibility for all learners, regardless of their background or abilities, is crucial in harnessing full potential of AI in education. As we strive to balance AI and human abilities in mathematics education, collaboration and open dialogue will be critical in shaping a future, where AI empowers learners to triumph in 4IR and beyond.

Limitations

This systematic review study has its limitations, like any other study. This review was restricted by the selection criteria used for including relevant literature in mathematics education, possibly affecting the generalizability of this study. It is also important to note that the findings of this study may not apply to all educational settings or populations due to the specific criteria used for selecting literature. Additionally, the scope of this study may not encompass all aspects of mathematics education, potentially limiting the depth of analysis and conclusions that can be drawn. Also, the study was constrained to AI, which was not written in full. Despite these limitations, this study provides valuable insights and contributes to the existing knowledge in mathematics education. It is constrained in terms of number of reviewed publications, which may impact the inferences of the results. But findings of this study can still be used to inform future research and practice in mathematics education.

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Ethical statement: The authors stated that the ethical issues were adhered to, and secondary data were used in this study. By utilizing secondary data, the study was able to build upon existing research and provide valuable insights into the topic at hand. Therefore, the study results were more robust and reliable due to the careful consideration of ethical issues and the use of secondary data sources.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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