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A survey on leveraging artificial intelligence tools for enhancing advanced mathematical education and problem-solving

Hadeel N. Abosaooda[1,2], Syaiba Balqish Ariffin[1], Osamah Mohammed Alyasiri[3]
[1]School of Mathematical Sciences, Universiti Sains Malaysia, Penang, Malaysia
[2]General Directorate of Education of Holy Karbala, Ministry of Education, Karbala, Iraq
[3]Department of Information Technology Engineering, Polytechnic College of Karbala, Al-Furat Al-Awsat Technical University, Karbala, Iraq

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ABSTRACT

Artificial intelligence (AI) has increasingly shaped education, with ChatGPT developed by OpenAI, emerging as a prominent tool due to its ability to generate contextually relevant language and support learning. This survey investigates the integration of ChatGPT into mathematics education, focusing on three dimensions. First, it explores innovative strategies for creating interactive and personalized learning environments that adapt to individual student needs. Second, it evaluates ChatGPT's specific advantages in mathematics instruction, including providing tailored feedback, assisting with problem-solving, and deepening conceptual understanding. Third, it addresses the challenges of adopting ChatGPT in advanced mathematics education, such as risks of over-reliance, the necessity of balancing AI with traditional pedagogy, and the importance of ongoing professional development for educators. Recent studies highlight ChatGPT's potential to solve complex mathematical problems, such as those in linear algebra and word problems, while also noting limitations related to accuracy and the preservation of critical thinking skills. The findings demonstrate that ChatGPT can significantly enhance mathematics education by supporting personalized learning and complex problem-solving. Therefore, this study will contribute to the discourse on AI in education by identifying opportunities, challenges, and implications for equity, pedagogy, and the responsible integration of ChatGPT in future classrooms.

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Corresponding Author:

Syaiba Balqish Ariffin
School of Mathematical Sciences, Universiti Sains Malaysia
Penang 11800, Malaysia
Email: balqishariffin@usm.my

1. INTRODUCTION

Artificial intelligence (AI) has significantly impacted numerous aspects of our daily lives, especially through intelligent agents that perform a wide range of functions [1]–[5]. Among these innovations, ChatGPT, an AI-powered chatbot developed by OpenAI, has gained attention for its conversational capabilities across diverse topics. ChatGPT is built on the generative pre-trained transformer (GPT) model, a state-of-the-art machine learning framework that has revolutionized natural language processing (NLP) [6]. The success of GPT, particularly its ability to generate human-like responses, is rooted in deep learning techniques and its training on vast, diverse datasets that span the internet [7], [8]. Despite ChatGPT's impressive performance, one of the central challenges it addresses is understanding and responding to complex, context-sensitive prompts; an essential feature for applications in both text and image generation

[8]. This ability allows users to interact dynamically, creating relevant visuals and solving intricate problems based on human input, including educational and scientific contexts.

Within academic circles, AI chatbots have proven their utility across a variety of fields, serving as a tool for information retrieval, organization, and generation, thus enabling interdisciplinary research. Studies highlight their growing relevance in mathematical education [9]–[13], problem-solving [14], [15], healthcare [16]–[18], industry, and business [19]–[21], as well as creative fields like communication, arts, and culture [22]–[24]. However, one specific area where ChatGPT has been extensively studied is in mathematics education. Several papers have documented ChatGPT's potential in solving mathematical problems and providing insights into concepts such as linear algebra and word problem comprehension [25]–[30].

Despite these advancements, challenges remain, particularly in the realm of teaching and learning (TnL) mathematics. Prior works have primarily focused on the technological integration of AI tools in TnL mathematics [31]–[35], mathematics instruction [36], mathematics curriculum develop [37], mathematics exam [38], mathematical modeling [39], and mathematics education [40]–[44], but gaps still exist regarding the balance between AI-driven teaching methods and traditional approaches. In particular, concerns have been raised about over-reliance on AI, the effectiveness of feedback provided by ChatGPT, and the need for sustained professional development for educators.

This paper aims to address these unsolved problems by offering a comprehensive analysis of ChatGPT's role in transforming mathematics education. Specifically, it explores new pedagogical approaches that make mathematics more interactive and personalized for students. The first section of the paper details these pedagogical methods, showing how ChatGPT enhances student engagement and supports adaptive learning environments. The second section delves into the comparative advantages of ChatGPT over other technologies in terms of providing individualized feedback, fostering problem-solving skills, and encouraging logical thinking. The third section discusses both the opportunities and risks associated with integrating ChatGPT into advanced mathematics instruction, including the potential for over-dependence on AI and the challenges posed by balancing technology with traditional methods. The final commentary that merges these reflections substantiates the articles, outlining a transformative vision for math education with ChatGPT and the challenges to its effective use.

2. STRATEGIES FOR INTEGRATING CHATGPT IN MATHEMATICS EDUCATION AND PROBLEM SOLVING

A variety of advancements are becoming common across several areas due to the integration of AI. Such occurrences are particularly true in education, especially in mathematics. With technological advancements, education has taken on a new force, moving towards more personalized development of students due to the assistive features related to interaction. Besides, AI is useful for educators. It helps them evaluate the student's proficiency levels to offer methods for personalized teaching that are appropriate to use for learners with specific needs. This is the reason why integrating AI into mathematical education makes the learning process more efficient and purposeful. There are many different examples of AI applications, but we focus only on one platform in this study: ChatGPT.

Yeo *et al*. [43] stated that personalized feedback from ChatGPT is beneficial for students, as they receive custom explanations and insights tailored to their specific needs. One of the best things about teaching with chat is that it is feasible to receive real-time answers to the questions asked in the process of learning, which is a huge advancement compared to classical ways, helping in establishing the understanding and making the adjustments very fast. Meanwhile, the capability of ChatGPT to solve intricate mathematical problems has improved learning opportunities and contributed to inclusive pedagogy in large class-sized settings by allowing multiple students at once. Moreover, the adoption of the AI tool also boosts problem-solving skills, logical reasoning, and understanding of the relationship that mathematics has with computer science, improving data literacy as well as statistical knowledge in a more computational thinking world.

An evaluation was conducted on ChatGPT's performance across various tasks. This includes a test on the ability to handle a financial arithmetic problem [44]. The topic of this problem was focused on how to calculate the instalment payments on an item purchased after an upfront payment, which is a common way loans or financing will be dealt out. The task involved a purchase totaling 1,200 reais, with an upfront payment of 300 reais and a plan to settle the balance in 12 monthly instalments. The suggested solution by ChatGPT was highly accurate and well-elaborated. It accurately deduced that the balance payable would be 900 reais after an initial payment of 300 reais had been made. After dividing this sum by 12, it is indeed how the ChatGPT came to the right conclusion that one instalment would amount to 75 reais. Moreover, the solution was structured in a very logical way, where every step that needed to be taken had been outlined in detail. Overall, the calculations for determining instalment payments were well understood by ChatGPT.

Taani and Alabidi [34] has dealt with a comprehensive examination of how mathematics education is being looked at these days with support from ChatGPT. The analysis of the ChatGPT edited chat transcripts

shows a trend towards bringing technology and AI into place to ensure more customized learning. In response to the results from both the inclusion and the digital future priorities, western nations have continued to respond through the implementation of blended learning environments and a focus on computational thinking, data literacy and statistics. Thus, the impact of the results on the future of mathematics instruction continues to focus on problem-solving and critical thinking. This also focuses on making connections and using interdisciplinary knowledge, as it continues to be focused on relentlessly pursuing equity and inclusion. AI is expected to revolutionize mathematics education, which may be achieved if there is consistent implementation with planned professional development and pedagogically driven design. Notably, mathematics education is still an emergent area, and both teachers and lecturers need to keep abreast of technological and pedagogical developments. In ensuring that their students can be successful in a rapidly changing educational system, educators are required to be committed to adapting to these changes while maintaining high-quality education.

A study is conducted to assess the mathematical capabilities of ChatGPT, comparing its performance to that of Minerva [26]. The mathematical problems chosen for this assessment were pretty advanced to begin with, presenting considerable challenges to AI. In their findings, they highlight the following key observation: there is a substantial gap between formal mathematics, which does have large databases of proofs (such as lean's library of formal mathematical proofs), and natural language datasets for mathematical proof used to test language models, which tend to focus mainly on elementary mathematics. The researchers deduced that one thing these datasets have in common is that ChatGPT's mathematical proficiency is better than the average graduate student in mathematics.

The research investigated the perspectives of main stakeholders, including students and educators, on the integration of AI in mathematics education, especially following the introduction of ChatGPT [33], [45]. The methodology part employed a qualitative case study design, unfolding in two main phases: content analysis of interviews, followed by user experience exploration [45]. On the other hand, the research design in [45] utilized a mixed-methods research design, combining quantitative and qualitative approaches for a more holistic examination of how ChatGPT would affect mathematics education.

Both studies show that ChatGPT enjoys advanced mathematical capabilities and demonstrates the potential for improved education results. It provides users with the basics of mathematics knowledge as well as help on diverse topics, having all sorts of assistance, especially concerning geometry. The overall sentiment on social media towards integrating ChatGPT for educational purposes, as well as math teaching, is overwhelmingly positive, with good excitement over its perceived benefits.

Despite this enthusiasm, however, some took a more cautious approach to using ChatGPT in education [45]. A variety of challenges were recognized in the second phase, which focused on user experiences in three educational scenarios. The step taken in Supriyadi and Kuncoro [33], strove to offer a perspective on the use of ChatGPT in mathematics education: it highlights some of the potential positives but also provides insight into significant downsides and needed development.

Wardat *et al*. [32] was conducted to investigate the learning interests of mathematics students utilizing ChatGPT, adopting a quantitative descriptive methodology. This study looks specifically at 30 fourth-semester students majoring in mathematics education at the University of Pekanbaru, Riau Province, Indonesia. Findings on non-test instruments are divided into five categories to collect data and then analyzed using Microsoft Excel formula to compute the overall percentage for each category. The results indicated the domain of "learning experience" with 81.29%, "interest" of 81.04%, "enjoyment" of 78.62%, "self-efficacy" of 80.04%, and 80.64% for "learning goals". As a result, the overall mean percentage on all domains was 80.33%. Based on the findings, students' interest in learning mathematics via ChatGPT is evaluated as "very good". This significant finding underscores ChatGPT's effectiveness as an engaging and motivational educational tool for mathematics students, highlighting its potential to enhance learning experiences and outcomes in this field.

Meanwhile, Dao and Le [46] performed a comprehensive test on ChatGPT in dealing with multiple-choice mathematics questions sourced from the Vietnamese national high school graduation examination (VNHSGE), conducting tests across various subjects and levels of difficulty. Their research categorized 250 questions across four categories of difficulty: knowledge (K); comprehension (C); application (A), and high application (H), spanning ten mathematical themes. The results emphasized that ChatGPT's variable performance has the highest accuracy at 83% for level K questions, but a significant drop to 10% accuracy for the most challenging H-level questions.

In similar research, an extensive inquiry [47] was conducted into the various applications of ChatGPT within the framework of Vietnamese education. While it is justified to be discussed in various series, this study has identified numerous benefits that ChatGPT can offer for anyone involved with the educational stakeholders, including administrators, teachers, and students. Through Truong, the work of ChatGPT could be revolutionized in Vietnam to reshape how education works with its potential for a significant overhaul, emerging as new learning and teaching methods.

Apart from that, many researches illuminated the substantial roles AI bots, such as ChatGPT, may play in enhancing linear algebra instruction [28]–[30], [48]. By using a variety of assessment methods, making sure they are communicating openly and being approachable about potential issues, as well as receiving the opportunity to resubmit assessed work with constructive feedback, is where these kinds of AI tools can enable more fairness in marking. AI bots may facilitate basic calculations and tasks to free students from the automated routine and operational efficiency types of activities, so that they can engage in solving more challenging problems. This will not only make their work faster with basic operations but also boost their wideness of analysis and problem-solving ability.

Finally, some articles have assessed ChatGPT's ability to solve mathematical problems, revealing that its performance noticeably varies when it is required to show the steps involved in reaching a solution [49]–[53]. They conducted a study that evaluated the competency of ChatGPT for solving these problems, but in addition to that, they also created and released a dataset containing responses by ChatGPT to mathematical word problems. It provides valuable means to other researchers so they can investigate AI in educational situations (specifically, problem-solving processes of mathematical problems). The release of this dataset highlights the necessity for transparency and replicability in AI research, which is essential to better understand both the strengths and limitations of ChatGPT and similar AI tools with educational applications [31], [52].

3. THE TRANSFORMATIVE ADVANTAGES OF CHATGPT IN EDUCATION AND PROBLEM SOLVING

Yeo *et al*. [43] stressed the major benefits thereof in mathematics education using ChatGPT. With its powerful NLP capabilities, ChatGPT deciphers students' queries in plain human text and conducts dialogues to provide personalized explanations and feedback. This helps in handling a lot of complex mathematical issues, which enhances the learning and also makes it quite interactive, hence influences as well because of its NLP support. Such support is indispensable, ensuring every learner has access to the necessary guidance and assistance.

Whilst Borba and Junior [44] shows that ChatGPT is able to not only provide accurate mathematical solutions but also elaborate solutions in a detailed yet interpretable way. This particular example reinforces the clear, questioning style of the model for presenting steps during the resolution of problems concerning financial arithmetic. The response is of high quality, demonstrating ChatGPT as a powerful educational tool, especially in topics needing deep insight and elaborate explanations through financial calculations. This proves the promise of our tool in that it could benefit learning as well as help students understand better deep, complex mathematical concepts within the educational context.

The investigation of ChatGPT's view of the future of mathematics education has important things to contribute to how beneficial it can be in transforming and integrating cutting-edge technologies [33]. Virtual and augmented reality are enabling the development of immersive learning experiences in which students can actively interact with data to discover mathematical concepts that are more tangible through discovery-based learning. AI-driven is sure to reign supreme via adaptive learning experiences and intelligent tutoring systems capable of providing customized feedback, while the application of gamification tactics will only work wonders in enhancing student engagement.

Such data-driven decision-making of people to enhance educational outcomes is hardly possible without the application of learning analytics that could revolutionize instructional approaches. Joint problem-solving environments are enabled by the expansion of online learning platforms. In fact, adaptive learning technologies can be seen as the solution to personalized education, dynamically adjusting instructional content to match each student's learning trajectory. The integration of mobile learning and bring your own device (BYOD) policies could further democratize access to educational resources, ensuring seamless incorporation of technology into everyday learning. The current focus on computational thinking as an essential 21st-century skill is a clear signal of the potential for coding and programming to be included in a standard mathematics curriculum. However, the effective uptake of these technological advancements in mathematics education requires careful planning and provisioning for teacher capacity-building and the development of guidelines to ensure that technology genuinely enhances mathematical instruction and learning.

Spreitzer *et al*. [26] concluded that ChatGPT appears to be most useful as a mathematical assistant for fact-based questions, essentially functioning as a mathematical search engine and knowledge base interface. Furthermore, it revealed that ChatGPT can answer questions in undergraduate-level mathematics. It seems that this variant of the language model is great for mathematical tasks from the elementary to the college level. However, at the graduate level, mathematics often becomes too complex and abstract, challenging ChatGPT and reducing its capabilities.

Supriyadi and Kuncoro [33] suggested several critical areas for further investigation to ensure the safe and responsible use of chatbots in educational settings, especially in the domain of mathematics education. These fields are instrumental in the development of a frame for the ethical, secure, and effective

implementation of chatbot technologies such as ChatGPT in TnL. It should be noted that the attention paid to the area of safety and accountability reflects the intention to develop provisions and standards concerning the issues of privacy, data security, and the proper operation of the technology in terms of the information provided. It is also vital that the study focuses on analyzing the pedagogical impacts of chatbot usage on student learning outcomes, motivation, and engagement. In doing so, it establishes and resolves any concerns necessitated in using the chatbots in an academic environment.

The analysis of students' learning interests within Wardat *et al*. [32] shows that all dimensions fall within the category of 'very good,' except for the 'feeling of happiness' aspect, which is rated as 'good.' Therefore, the research states that the mathematics interest of the students involved is 'very good' on average, equaling 80.33%. The identified results show that learners' interest can be improved by engaging in learning media such as ChatGPT, which helps hold students' attention. This underscores the effectiveness of integrating innovative tools like ChatGPT in educational settings to foster a more stimulating and motivating learning environment for students, particularly in the study of mathematics.

On the other hand, there are studies undertook an extensive exploration into the possibilities that ChatGPT presents for the Vietnamese educational landscape, with a focus on its integration into high school mathematics [46], [47]. Based on the research conducted by the authors, it is evident that ChatGPT has tremendous potential to increase learning and provide individual communication. It helps to show that the utilization of technology for education in the updated version could modernize Vietnamese high schools in terms of learning. It may provide personalized instruction and capture the interest of the students through interactive and technologically advanced forms of communication. Dydak [48] sheds light on the potential of AI bots to revolutionize the TnL of linear algebra, not only by augmenting the logistical aspects of education but also by enriching the pedagogical experience. Through careful implementation, AI bots can enhance educational outcomes, promote efficiency, and foster essential higher-order thinking skills among students.

Indeed, some researchers pointed out that the rise of AI bots offers a unique chance to bolster critical thinking within educational settings [28]–[30], [48]. At the same time, the fact that these technologies occasionally offer incorrect solutions allows educators to use these mistakes as examples. This method can be used by teachers to teach their students how to assess the accuracy of information, despite how advanced such information is. This implies that this method has a strong focus on developing critical thinking skills, which are essential not only for academic achievements but also for success in general. The integration of AI bots into the teaching of linear algebra and potentially other subjects is seen as a way to not only make educational processes more efficient but also significantly improve the learning experience. By doing so, it prepares students with the essential critical thinking skills needed to effectively navigate and engage with the increasingly digital and AI-integrated world around them.

Finally, research in [31], [32] demonstrated that ChatGPT's understanding of the place value system for numbers in mathematics word problem solutions is critical. The findings showed that the accuracy of ordering permutation multiplets was generally lower than that of the source multiplets. Additionally, it was observed that as the number of elements in the source multiplet increased, the difference in ordering accuracy between the source multiplet and the permutation multiplet also grew. Here, understanding place value influences the accuracy of arithmetic problem-solving and is vital for improving ChatGPT's ability to solve mathematical problems.

4. CHALLENGES AND CONSIDERATIONS IN LEVERAGING CHATGPT FOR ADVANCED MATHEMATICAL EDUCATION AND PROBLEM SOLVING

A study reveals that the incorporation of AI tools like ChatGPT in the education sector faces several issues [42]. There is a possibility that students may become over-dependent on AI. Consequently, their ability to reason, think and understand problems logically may be undermined. Another issue likely to emerge is that even with adequate training, AI lacks emotional intelligence, which is important in motivating and making the learner understand the content being taught. The issues of data privacy, the need to check the solutions AI provides, teachers' responses, and the prevention of essential cognitive skills development urge a cautious approach to the implementation of AI in education. However, to ensure that learning outcomes are improved with the incorporation of AI tools like ChatGPT, some of the issues mentioned above must be discussed and addressed to an extent [43].

Borba and Junior [44] describes the advantages and disadvantages of using ChatGPT in mathematics education. Many disadvantages exist, such as plagiarism issues, since the tool works with natural language. However, when it comes to the advantages, ChatGPT is capable of becoming an effective educational tool by creating individual tasks depending on the student's level of preparation. Taani and Alabidi [34], on the role of ChatGPT in education, proposes that the inability of robots and AI to replace human educators is general and valid for a particular educational context. Note that human educators are essential in the learning environment due to their unique and outstanding qualities. Human educators establish a meaningful, human bond with students, demonstrate emotional intelligence, are comfortable in all

kinds of instructional situations, and have vast pedagogical knowledge. Moreover, as was mentioned above, educators help students develop non-cognitive skills and have a key role in the promotion of social growth.

Humans are exceptional in delivering education to others due to their ability to tailor learning experiences to the needs of students and assist in their learning. Note that robots and AI are unable to perform this behavior. Therefore, the implementation of robots and AI in the educational systems should be considered supplementary to the traditional teaching methods rather than a complete replacement. The integration of such technologies provides opportunities for enhancing the educational setting in terms of enriching teachers' capabilities and improving instruction to provide students with tailored educational experiences. Thus, the future of education, as proposed by the current research, involves enriching educational establishments to reinforce teachers' support. This ensures a rather efficient as well as personalized learning process for students.

ChatGPT often appears to comprehend the questions presented to it, but it does not consistently provide accurate answers [47]. This is due to the extent to which the model can address and solve complex mathematical problems, particularly as opposed to more sophisticated or specialized AI. The inaccuracy of answers drawn signifies that there is a space for improvement concerning both the model's problem-solving algorithms and its mathematical concept comprehension.

Investigation into ChatGPT's capabilities in geometry reveals limitations in the model's depth of understanding and its effectiveness in rectifying misconceptions [33]. The results of the study show that the accuracy and efficiency of the solution provided by ChatGPT could differ dramatically. This is because it greatly depends on the functions' complexity, data, and requests made by users to interact with this model. Nonetheless, ChatGPT will become an advanced tool capable of handling even more complicated mathematical problems. The research provides several significant research directions to ensure the cautious and proper integration of chatbots, such as ChatGPT, to teach mathematics. One of the suggestions of the study is the necessity to elaborate strategies to enhance the model's comprehension of mathematics and the ability to provide responses and corrections. The research also states that it is essential to devise a framework to protect the ethical use of AI in educational settings. This framework has to be concerned with privacy, accuracy, and the pedagogical side of the incorporation of AI tools in the process of learning. By pursuing these avenues, the goal is to enhance ChatGPT's utility as an educational resource, thereby enriching the learning experience and outcomes in mathematics education.

Wardat *et al*. [32] acknowledges that while ChatGPT provides significant advantages in terms of accessing information and learning support, there is a concurrent risk that students might become overly dependent on technology. This overreliance could inadvertently diminish the crucial role that educators play in the learning process. In conclusion, the research indicates that it is incorrect to see the above situation as a problem, and it should be regarded as an opportunity for joint innovation. It suggests that the emphasis should be placed on creating and developing an education system with a joint application of digital tools, including ChatGPT, in continuation and enhancement of traditional teaching techniques. This might create an essential balance between another irreplaceable constituent of the educational process and technological innovations and result in a more productive and dynamic setting in the digital era.

The research in [46], [47] argued that integrating ChatGPT with mathematics education at the high school level in Vietnam provides a wide range of benefits that can revolutionize the way mathematics is taught and learned. At the same time, the country experiences several vital challenges. They relate to the issues of language adaptation, data privacy, and the guarantee of equal access to technology. Each of the identified challenges should be regarded seriously so that teachers and policymakers will need to develop a comprehensive strategy for overcoming the challenges. Provided that ChatGPT is integrated into the high school curriculum, the technology undoubtedly has a considerable positive impact. Such efforts will not only enhance learning outcomes but also equip students with the skills and knowledge they need to thrive in the 21st-century global landscape.

5. DISCUSSION

This section consolidates the key findings from various studies to examine ChatGPT's role in enhancing mathematical learning and problem-solving. Beyond summarizing results, it addresses the broader implications of these findings. It also discusses the limitations and potential areas for future research.

5.1. Investigation of user experiences

Research from diverse educational contexts shows that both students and teachers value ChatGPT's ability to offer interactive engagement and personalized feedback [33], [45]. However, while the benefits of tailored feedback are clear, this growing appreciation raises the question of the long-term impact on students' independent problem-solving abilities. Excessive reliance on AI might lead to reduced cognitive engagement, which emphasizes the need for balanced integration of AI tools. Future studies should focus on understanding the cognitive shifts that occur when learners increasingly depend on AI-driven assistance and how educators can foster deeper critical thinking while using such tools.

5.2. ChatGPT's enhanced mathematical capabilities

The capability of ChatGPT to explain complex mathematical concepts effectively [43], [44], underscores its utility in helping students grasp difficult topics. Yet, this enhanced capability also brings challenges: while AI excels at providing accurate answers and explanations, it may inadvertently encourage passive learning. It is crucial to critically assess how well students internalize these explanations. In the future, research should investigate how interactive AI systems can promote active learning techniques, such as encouraging students to ask reflective questions or engage in self-explanation strategies while using the tool, to ensure a deeper comprehension of mathematical principles.

5.3. ChatGPT's role in solving mathematical problems

Findings reveal that ChatGPT's accuracy varies significantly depending on the mathematical domain and the complexity of the problem [46]. This variability highlights the current limitations of AI in handling advanced mathematical problem-solving, especially with abstract or multistep problems. While high accuracy is achieved in simpler tasks, ChatGPT's challenges with more difficult questions indicate that AI-driven educational tools are not yet fully capable of replacing human expertise in complex learning environments. Further research is required to improve AI's algorithms for advanced problem-solving and explore how AI can complement rather than substitute traditional instruction for complex mathematical topics.

5.4. Implications of using ChatGPT in mathematics education

The integration of ChatGPT into mathematics education offers numerous advantages, such as personalized learning experiences and innovative pedagogical approaches. However, this also comes with significant challenges, including concerns over data privacy, increased digital divides, and the potential for AI to replace crucial aspects of traditional teaching methods [32]. Schools must navigate these issues carefully by implementing ethical guidelines and promoting digital equity. In the future, educators and policymakers will need to explore how AI can be deployed to bridge gaps in access to education rather than exacerbate them, particularly in under-resourced or rural areas where technological infrastructure may be lacking.

5.5. The future of mathematics education with ChatGPT

The transformative potential of ChatGPT in education is evident, but its implementation will require a careful balance between technology and traditional pedagogy. Existing research suggests that the future of mathematics education will be defined by a blend of computational thinking, critical problem-solving, and interdisciplinary connections [44]. However, it is essential to recognize that AI is only as effective as the educators and students who use it. The success of AI tools like ChatGPT will depend on continued professional development for teachers and a thoughtful approach to integrating these tools into curriculum. Future research should examine how to best train educators to use AI tools effectively and explore strategies for combining AI with hands-on learning experiences to foster deeper engagement and critical thinking.

5.6. Exploring the capabilities of ChatGPT in mathematical modeling

The analysis and synthesis of outcomes from the chosen studies suggest that ChatGPT has a significant positive impact on the learning of mathematics. The tool is beneficial in terms of individualizing instruction for each student. Thus, using the tool in teaching can foster critical thinking and the development of problem-solving skills. The research in [33], [43] showcased ChatGPT's effectiveness in developing alternative problem-solving strategies, which is consistent with its capabilities for supporting mathematical modelling. ChatGPT tool offers valuable aid regarding the process of creating the model. The analysis and interpretation of the specified option is a vital part of the tool that learners and researchers can use to design models that simulate real-life situations.

In other words, the ChatGPT tool can be defined as a device that connects learners and researchers to high-end mathematical tools. As a result, the specified approach can be seen as a concerned understanding and a cross-disciplinary approach to increase the level of skills in computational processes. It inspires a range of creative approaches to educational and professional needs. Furthermore, it is a progressive approach since the ChatGPT tool is considered to be a device that extends the information technology possibilities in order to help users achieve experience and knowledge aimed to prepare them for success in our highly complicated world.

6. IMPLICATIONS AND FUTURE DIRECTIONS

The findings of this paper indicate that ChatGPT has significant potential to enhance mathematics education by promoting personalized learning and facilitating complex problem-solving. However, several challenges and open questions remain. The variability in ChatGPT's performance, particularly in handling more complex mathematical problems, points to the need for ongoing improvements in AI algorithms. Additionally, the potential for over-reliance on AI and the ethical implications of its use in education require careful consideration.

In the future, educators and researchers should focus on how to maximize the benefits of AI while mitigating its risks. This includes exploring how AI tools can be integrated into classrooms to complement and replace traditional methods, ensuring equitable access to technology, and continuing to develop pedagogical strategies that foster critical thinking and active learning. By addressing these challenges, the future of mathematics education with AI can be both dynamic and transformative.

7. CONCLUSION

The utilization of ChatGPT for mathematics teaching is a remarkable advancement in the use of AI. The findings from many researchers concur that the model is exceptional in a range of areas, including offering a personalized learning experience, supporting the solving of complex problems, and promoting a deeper understanding of concepts. Much potential could be realized if educators and policymakers could overcome these problems. It is also essential to manage the risks associated with implementing such technology. Specifically, such risks include ensuring equal access to technology, preserving the integrity of the educational process, and ensuring balance in the use of such tools with reliance on human skills. Overall, since the discipline of mathematical education has been modified many times, it now depends on how properly and responsibly AI technologies such as ChatGPT are integrated so that the talents of the young mathematicians of tomorrow will be revealed.

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This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Hadeel N. Abosaooda	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
Syaiba Balqish Ariffin	✓	✓		✓	✓	✓		✓		✓	✓	✓		✓
Osamah Mohammed Alyasiri	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state there is no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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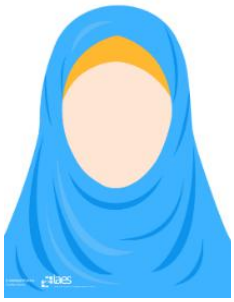
BIOGRAPHIES OF AUTHORS



Hadeel N. Abosaooda received her B.Sc. degree in Mathematics Education from the College of Education for Pure Sciences, University of Karbala, Iraq, in 2014, and her M.Sc. degree in the Teaching of Mathematics from the School of Mathematical Sciences, Universiti Sains Malaysia, in 2024. She is currently a lecturer at the General Directorate of Education of Holy Karbala, Ministry of Education, Karbala, Iraq. Her research interests include mathematics education, mathematical modeling, problem-solving in mathematics, artificial intelligence, and AI Chatbots. She can be contacted at email: hadeel.nafea92@gmail.com.

Syaiba Balqish Ariffin specializes in computational and robust statistics. She is currently a senior lecturer at the School of Mathematical Sciences, Universiti Sains Malaysia. Her research focuses on developing innovative techniques for predictive modeling, outlier detection, machine learning, and data mining by integrating robust statistical methods. Her work particularly addresses challenges related to high-dimensional data, data limitations, accessibility, and data quality. She can be contacted at email: balqishariffin@usm.my.

Osamah Mohammed Alyasiri received the B.Sc. degree in Computer Science from Mustansiriyah University, Iraq, in 2009, the M.Sc. degree in Computer Science from BAMU, India, in 2013, and the Ph.D. degree in Computer Science (Knowledge Engineering/Data Mining) from the School of Computer Sciences, Universiti Sains Malaysia (USM), Malaysia, in 2025. He is currently a lecturer with the Department of Information Technology Engineering, Polytechnic College of Karbala, Al-Furat Al-Awsat Technical University, Karbala, Iraq. His research interests include artificial intelligence, knowledge engineering, data mining, NLP, pattern recognition, text mining, text classification, information retrieval, machine and deep learning, feature selection, feature extraction, optimization, and AI chatbots. He can be contacted at email: osama.alyasiri@atu.edu.iq.