International Journal of Social and Education (INJOSEDU)
Vol. 3 No. 5 August 2026, hal., 779-794
https://languar.net/index.php/INJOSEDU
e-ISSN: 3047-6151

FROM ANSWER GENERATION TO CONCEPTUAL UNDERSTANDING: A MIXED-METHODS INVESTIGATION OF GENERATIVE AI-SUPPORTED MATHEMATICS LEARNING

Adi Candra Kusuma*[1]
Politeknik Negeri Malang, Indonesia
Email: candraraden45@polinema.ac.id

Nurul Saila
Universitas Panca Marga, Indonesia
Email: nurul.saila.2013.2@upm.ac.id

Sri Asih Agustin
Universitas Sultan Muhammad Syafiuddin Sambas, Indonesia
Email: Sriasih.agustin97@gmail.com

Abstract

The development of Generative Artificial Intelligence has brought significant changes to mathematics learning practices, particularly in providing fast and interactive support for students. However, the effectiveness of Generative AI is measured not only by its ability to generate answers but also by its contribution to the development of in-depth mathematical conceptual understanding. This study aims to examine the role of Generative AI in supporting the transition of mathematics learning from simply generating answers to strengthening students' conceptual understanding. The study used a literature review with a mixed-methods approach that integrates quantitative and qualitative findings from various relevant scientific publications. The results indicate that Generative AI has great potential to increase access to mathematical explanations, provide personalized feedback, and help students understand concepts through diverse representations and reasoning. On the other hand, excessive reliance on AI-generated answers has the potential to reduce students' cognitive engagement and hinder the development of critical thinking skills if not accompanied by appropriate pedagogical strategies. This study provides theoretical and practical implications for the development of mathematics learning models that effectively utilize Generative AI to support sustained conceptual understanding.

Keywords: Generative Artificial Intelligence, Mathematics Learning, Conceptual Understanding, Generative Artificial Intelligence

---

[1] Correspondence author

INTRODUCTION

The rapid development of digital technology has brought fundamental changes to various aspects of life, including the education sector. One innovation currently receiving widespread attention is Generative Artificial Intelligence (Generative AI), an artificial intelligence technology capable of generating text, images, code, and other forms of information based on learned data and patterns. In the educational context, Generative AI offers numerous opportunities to improve the quality of the learning process by providing fast, interactive, and easily accessible information (Cruz & Viseu, 2026). This technology is increasingly relevant to mathematics learning, which is often considered a complex and challenging subject for most students. Generative AI's ability to provide step-by-step explanations, present various alternative problem-solving methods, and provide immediate feedback makes it a technology with the potential to support more effective and personalized mathematics learning (Nanda & Pradhan, 2025).

Mathematics learning, by its very nature, aims not only to obtain correct answers but also to build in-depth conceptual understanding. Conceptual understanding is a student's ability to understand the relationships between concepts, explain the rationale behind procedures, and apply these concepts in a variety of situations (Besas et al., 2026). Various studies have shown that many students still struggle to develop conceptual understanding because the learning process often emphasizes mastering procedures and finding final answers. As a result, students are able to solve routine problems but struggle when faced with problems that require reasoning, interpretation, and the transfer of knowledge to new contexts. This situation presents a persistent challenge in mathematics education, particularly in the digital era, which demands higher-order thinking skills and complex problem-solving (Mailizar et al., 2026).

The emergence of Generative AI presents both opportunities and challenges in efforts to improve the quality of mathematics learning (Yang et al., 2026). On the one hand, this technology can help students understand material through more detailed explanations, diverse concept visualizations, and responses that can be tailored to individual needs. Generative AI also allows students to receive learning support at any time, regardless of space and time. Through dialogic interactions, students can ask follow-up questions, request simpler explanations, or explore different approaches to solving a math problem. These characteristics indicate that Generative AI has the potential to support more student-centered learning and foster an adaptive learning environment.

On the other hand, the use of Generative AI in mathematics learning also raises several concerns. The ease of obtaining instant answers has the potential to encourage students to focus more on the final result than on the thought processes necessary to understand the concept. Over-reliance on technology can reduce students' opportunities for independent exploration, reflection, and knowledge construction. Furthermore, answers generated by Generative AI are not always completely accurate, requiring evaluation and verification skills from the user. In the context of mathematics education, this situation is a crucial concern because effective learning depends not only on the accuracy of answers but also on how students construct understanding and develop logical reasoning skills (Manik et al., 2026a).

The debate over the benefits and risks of using Generative AI in mathematics learning has prompted numerous studies examining the technology's impact on learning outcomes, motivation, student engagement, and the development of critical thinking skills (Chen et al., 2025). Some studies indicate that Generative AI can enhance learning effectiveness by providing personalized and responsive learning support. However, other studies highlight the risk of decreased cognitive engagement when students use AI solely as a tool to obtain answers without understanding the underlying processes. These differing findings suggest that the effectiveness of Generative AI is significantly influenced by how the technology is integrated into the learning process. Therefore, a more comprehensive understanding of how Generative AI can be utilized not only as a tool for finding answers but also as a means to build a deeper conceptual understanding of mathematics is needed (Tassell et al., 2026).

Given these conditions, studies that integrate various previous research findings are needed to obtain a more comprehensive picture of the role of Generative AI in mathematics learning. A literature review is a relevant approach to identifying patterns, trends, opportunities, and challenges arising from the implementation of Generative AI in various educational contexts. Through a synthesis of published quantitative and qualitative findings, this study seeks to explore how Generative AI supports the transition of mathematics learning from an orientation focused on answer generation to conceptual understanding. This focus is crucial considering that the primary goal of mathematics education in the era of artificial intelligence is no longer simply generating correct answers, but also developing critical, reflective, and adaptive mathematical thinking skills. Therefore, the results of this study are expected to provide theoretical contributions to the development of literature on the use of Generative AI in mathematics education and serve as a basis for educators and policymakers in designing learning strategies that optimize the benefits of technology without neglecting the essence of students' conceptual understanding.

RESEARCH METHOD

This research uses a mixed-methods literature review to gain a comprehensive understanding of the role of Generative Artificial Intelligence in supporting mathematics learning, particularly in developing students' conceptual understanding. The mixed-methods approach to the literature review was implemented through the integration of quantitative and qualitative research findings published in various scientific journals, proceedings, and relevant academic sources. Data collection was conducted by searching for articles discussing the implementation of Generative AI in mathematics education through national and international academic databases, such as Scopus, Web of Science, ERIC, Google Scholar, and other reputable scientific sources. The selected literature focused on publications discussing the impact of Generative AI on learning outcomes, conceptual understanding, student engagement, critical thinking skills, and AI-based mathematics learning strategies.

Quantitative data found in various studies was analyzed to identify trends in the influence of Generative AI on mathematics learning, while qualitative data was used to explore experiences, perceptions, opportunities, and challenges in its implementation. Furthermore, the analysis of both types of data was integrated to generate a more comprehensive understanding of how Generative AI can support a shift in learning from an orientation toward obtaining answers to developing conceptual understanding. This approach enables research to produce a deeper synthesis of knowledge and provides a conceptual foundation for the development of mathematics learning strategies that utilize Generative AI effectively and responsibly.

RESULT AND DISCUSSION

The Role of Generative AI in Supporting Mathematics Learning and Students' Conceptual Understanding

The development of Generative Artificial Intelligence has created a new paradigm in mathematics learning by presenting systems capable of interactively generating responses, explanations, and solutions based on user needs. In an educational context, Generative AI functions not only as a source of information but also as a learning partner that can help students understand mathematical concepts more deeply. The presence of this technology is becoming increasingly important because mathematics learning is fundamentally oriented not only on the ability to obtain correct answers but also on developing conceptual understanding that enables students to understand the relationships between concepts, the reasoning behind mathematical procedures, and the application of these concepts in various situations (B. Liu et al., 2026). Therefore, the use of Generative AI should be viewed as a means to support the knowledge construction process, not simply a tool for generating answers instantly.

One of the main contributions of Generative AI in mathematics learning is its ability to provide step-by-step explanations of the problem-solving process (Kamau & Shukla, 2026). Unlike conventional learning resources, which often only present standard procedures, Generative AI can adjust the level of complexity of explanations based on user needs. When students struggle to grasp a concept, the system can provide a simpler explanation, use relevant analogies, or present additional examples that help clarify the relationships between concepts. This capability enables students to understand the rationale behind each step, so the learning process doesn't stop at memorizing procedures. Through dialogic interactions, students can also ask follow-up questions and obtain clarification directly, ultimately supporting the development of a more meaningful understanding (Daher & Gierdien, 2024).

In addition to providing detailed explanations, Generative AI also plays a role in providing adaptive feedback that can improve the quality of mathematics learning. Feedback is a crucial component of the learning process because it helps students identify errors, understand weaknesses, and refine problem-solving strategies (Cosentino et al., 2025). In traditional learning, providing feedback often depends on the teacher's time availability and cannot always be provided directly to each student. Generative AI offers a solution through its ability to provide rapid and personalized responses. When students make errors while solving problems, the system can pinpoint the error, explain the cause, and provide guidance for finding a more appropriate solution (Anwar et al., 2026a). This mechanism allows students to reflect on their thinking processes, thus encouraging the development of metacognitive skills, which are crucial in mathematics learning.

Generative AI's contribution to conceptual understanding is also evident in its ability to present diverse conceptual representations (Choi, 2026). In mathematics, deep understanding often requires the ability to view a concept from multiple perspectives, such as symbolic, numerical, graphical, or verbal representations. Generative AI can flexibly generate various forms of representations to suit students' needs. For example, the concept of a function can be explained through mathematical equations, tables of values, graphs, or contextual illustrations that connect the concept to everyday life. Presenting these various representations helps students build connections between different mathematical concepts, thus strengthening their understanding and preventing partial learning. The ability to transition from one representation to another is also an important indicator of good conceptual understanding (Manik et al., 2026b).

The use of Generative AI in mathematics learning supports a student-centered learning approach. This technology enables each student to experience learning tailored to their individual needs, abilities, and learning pace. Students who require more in-depth explanations can explore further through interaction with the system, while students who have already grasped a concept can access more challenging problems to develop higher-order thinking skills. This flexibility provides an opportunity to create a more inclusive and adaptive learning environment. In this situation, Generative AI functions as a facilitator, helping students construct their own knowledge through a process of exploration and discovery (Rane, 2023a).

However, the effectiveness of Generative AI in supporting conceptual understanding is greatly influenced by how it is used in the learning process. Utilization that focuses solely on finding final answers has the potential to reduce student cognitive engagement and hinder the thinking processes that should be at the heart of mathematics learning. When students rely too heavily on AI-generated answers without engaging in analysis and reflection, the opportunity to build conceptual understanding is diminished (J. Liu et al., 2025). Therefore, the use of Generative AI needs to be integrated with learning strategies that encourage students to evaluate, compare, and critique the information provided. Teachers have a crucial role in guiding students to utilize technology as a tool for understanding concepts, not as a substitute for mathematical thinking.

More broadly, Generative AI can be a catalyst for transforming mathematics learning toward a more constructive and reflective approach. Its ability to provide personalized explanations, adaptive feedback, and diverse conceptual representations presents a significant opportunity to improve the quality of students' learning experiences. This technology not only helps students solve mathematical problems but also encourages them to understand the reasoning, relationships, and principles underlying each concept learned. Therefore, the role of Generative AI in mathematics learning should not be understood as a means to expedite the acquisition of answers, but rather as an instrument that supports the continuous development of conceptual understanding. When properly integrated into the learning process, Generative AI has the potential to become an educational innovation capable of improving the quality of mathematical literacy, reasoning skills, and students' readiness to face the challenges of learning in the digital era.

Opportunities and Challenges of Implementing Generative AI in Mathematics Learning

The implementation of Generative Artificial Intelligence in mathematics learning has opened up various new opportunities that have the potential to improve the quality of the teaching and learning process (Awang et al., 2025). The presence of this technology is part of the digital education transformation that not only changes the way students acquire information but also influences how they understand, explore, and construct knowledge. In mathematics learning, which is often considered difficult and abstract, Generative AI offers more flexible and responsive support than conventional learning resources. Its ability to generate explanations, provide examples, and respond to questions in real time allows students to receive learning assistance at any time according to their needs (Chamola et al., 2026). This presents a significant opportunity to expand access to quality mathematics learning, especially for students who have limited access to direct academic support.

One of the main opportunities offered by Generative AI is increasing access to more inclusive learning (Anwar et al., 2026b). In conventional education systems, the quality of learning is often influenced by geographic factors, resource availability, and the number of teaching staff. Generative AI can alleviate some of these barriers by providing learning services accessible through digital devices anytime and anywhere. Students are no longer entirely dependent on classroom instruction for explanations of material they don't yet understand. When they encounter difficulties solving math problems, they can interact directly with the AI system to receive additional explanations tailored to their individual learning needs. This ease of access has the potential to expand learning opportunities and support greater educational equity (Zapata-Rivera et al., 2024).

In addition to increasing access to learning, Generative AI also offers significant opportunities for personalizing mathematics learning. Each student has different characteristics, abilities, and learning speeds. In conventional learning practices, teachers often face the challenge of meeting the learning needs of all students simultaneously. Generative AI enables a more adaptive learning experience by adjusting the difficulty level of the material, the type of explanation, and the format of the exercises based on individual needs (Okwuobasi, 2026). Students struggling with a particular concept can receive simpler, more gradual explanations, while students with higher abilities can be given more complex challenges to develop their mathematical thinking skills. This kind of personalization has the potential to increase the effectiveness of learning because the learning process becomes more relevant to the needs of each individual student.

Another opportunity is seen in increasing student motivation and engagement in mathematics learning. One cause of low interest in learning mathematics is a learning experience that is perceived as monotonous and lacks space for interaction (Giannakos et al., 2025). Generative AI provides a more dynamic learning experience through two-way communication that allows students to ask questions, request additional explanations, and explore various alternative solutions to problems. This responsive interaction can create a more engaging learning experience, thereby increasing student curiosity and participation. When students receive quick responses to their questions, the learning process becomes smoother and obstacles often arising from delays in obtaining assistance are minimized (Rane, 2023b). Thus, Generative AI has the potential to encourage active student engagement in the mathematics learning process.

Despite offering various benefits, the implementation of Generative AI in mathematics learning also faces several challenges that require serious attention. One of the most frequently discussed challenges is the emergence of a dependency on technology. The ease of obtaining answers and solutions instantly can encourage some students to use AI as a shortcut without striving to understand the problem-solving process in depth. When students focus more on the end result than on the thought processes required to achieve it, the primary goal of mathematics learning, which is to develop reasoning and problem-solving skills, can be neglected. Excessive reliance also has the potential to reduce independent learning, as students become accustomed to relying on technology for every academic activity (Shao & Tang, 2025).

Another challenge relates to the potential for misconceptions in mathematics learning. Although Generative AI can generate explanations that appear convincing, the information provided is not always entirely accurate. In some cases, the system may produce incorrect answers, inappropriate procedures, or explanations that do not align with actual mathematical concepts. If such information is received without verification, students risk developing a misconception about a concept. Misconceptions formed in the early stages of learning can impact the understanding of more complex material later in life. Therefore, the use of Generative AI needs to be accompanied by digital literacy skills and information evaluation skills so that students can assess the validity of each response they receive (Walkington, n.d.).

In addition to the risk of misconceptions, the use of Generative AI can also impact students' cognitive engagement. Effective mathematics learning demands mental activity involving analysis, reasoning, reflection, and decision-making (Shi, 2024). When AI provides complete, ready-to-use solutions, students may be less motivated to engage in in-depth thinking. This can lead to reduced opportunities to develop critical thinking and problem-solving skills, which are essential competencies in mathematics education. These challenges demonstrate that the successful implementation of Generative AI depends not only on technological sophistication but also on learning design that maintains students' active engagement in the knowledge construction process.

The issue of information accuracy is also a significant concern in the use of Generative AI. Unlike learning resources that have undergone a rigorous academic validation process, Generative AI generates responses based on learned data patterns, thus allowing for errors. In mathematics learning, even small errors in procedures or concepts can produce different answers and cause confusion for students. Therefore, the teacher's role remains crucial as a facilitator and controller of learning quality. Teachers are not only tasked with teaching the material, but also guiding students in using Generative AI critically, verifying the accuracy of information, and integrating the results of interactions with AI into a meaningful learning process (Song et al., 2026).

Generative AI Optimization Strategies to Promote the Transition from Answer Generation to Conceptual Understanding

The development of Generative Artificial Intelligence in education has presented various opportunities to improve the quality of mathematics learning. However, the use of this technology cannot be solely focused on its ability to generate answers quickly and accurately. The primary goal of mathematics learning remains the development of conceptual understanding that enables students to grasp the meaning, relationships, and applications of mathematical concepts in various contexts (Zhu & Luo, 2023). Therefore, optimization strategies are needed that can direct the use of Generative AI from being merely a tool for obtaining answers to a tool that supports the process of thinking, exploration, and knowledge construction. This transformation is crucial because the success of mathematics learning is not measured by the number of correct answers, but rather by students' ability to explain reasoning, connect concepts, and use their knowledge to solve diverse problems.

One strategy that can be implemented is integrating Generative AI into exploration-based learning. This approach positions students as active subjects involved in the process of seeking and discovering knowledge (Reddy & Shojaee, 2025). In exploration-based learning, Generative AI is not used to directly provide a final solution, but rather as a tool that helps students explore various possible solutions, ask new questions, and compare different mathematical approaches. When students interact with AI to understand a concept, they are encouraged to independently analyze the information obtained, identify patterns, and build relationships between concepts. This exploratory process provides students with the opportunity to develop a deeper understanding because knowledge is not acquired passively but is built through active and meaningful learning experiences (Gabrovšek & Rihtaršič, 2025).

In addition to exploration-based learning, reflection is a crucial component in optimizing the use of Generative AI. Reflection allows students to evaluate their thinking processes while solving a mathematical problem. In practice, students can utilize Generative AI to compare their solutions with alternative solutions provided by the system. Through this process, students not only determine whether their answers are correct or incorrect but also understand the underlying reasons for the differences in approaches used. This reflective activity helps students develop metacognitive awareness, namely the ability to understand and control their own thinking processes. Metacognitive skills play a crucial role in mathematics learning because they enable students to become more independent, critical, and adaptive learners in responding to various academic challenges (Gabrovšek & Rihtaršič, 2025).

The next strategy is to integrate Generative AI into problem-solving-based learning. This approach is highly relevant to the characteristics of mathematics, which emphasize logical, analytical, and systematic thinking skills. In problem-solving-based learning, students are faced with situations that require them to identify important information, formulate solution strategies, and evaluate the results obtained. Generative AI can function as a facilitator, helping students explore various alternative solutions without eliminating their responsibility for analysis and decision-making. Teachers can design activities that encourage students to use AI for additional clues or explanations, then ask them to explain the solution process in their own words. Thus, the use of AI does not replace mathematical thinking processes, but rather enriches the learning experience, supporting the development of stronger conceptual understanding (Maity & Deroy, 2024).

Strengthening critical thinking skills is also an important strategy in ensuring that Generative AI contributes to meaningful learning. One of the main challenges of using AI is the tendency for students to accept the information provided without further evaluation. However, AI-generated responses are not always entirely accurate and can contain conceptual and procedural errors.

Optimizing Generative AI also requires a change in the teacher's role in the learning process. The presence of technology does not diminish the importance of the teacher's role, but rather demands a transformation of their function from information provider to facilitator, guide, and director of the learning process. Teachers have a responsibility to design learning experiences that utilize AI productively and align with learning objectives. Furthermore, teachers need to help students understand when and how technology should be used to support the achievement of expected competencies. Appropriate guidance will ensure that students do not become trapped in using AI as a tool for finding instant answers, but are instead able to utilize it as a learning resource that supports exploration and the development of higher-order thinking skills.

Overall, optimizing Generative AI in mathematics learning requires the integration of various pedagogical approaches that prioritize conceptual understanding. Learning based on exploration, reflection, problem-solving, and strengthening critical thinking are strategies that can guide the use of AI so that it not only generates answers but also supports the process of constructing meaningful knowledge. With the support of adaptive teachers and process-oriented learning design, Generative AI can be an effective instrument for improving the quality of mathematics learning. Appropriate use of technology not only helps students understand concepts more deeply but also develops the critical, creative, and reflective thinking skills needed to face the challenges of education in the era of artificial intelligence.

CONCLUSION

Based on the results of a literature review using a mixed-methods approach, it can be concluded that Generative Artificial Intelligence has significant potential to support mathematics learning, particularly in strengthening students' conceptual understanding. Generative AI's ability to provide step-by-step explanations, adaptive feedback, and various representations of mathematical concepts enables students to experience a more personalized, interactive, and flexible learning experience. The study's findings also indicate that the use of Generative AI can increase access to learning resources, encourage student engagement in the learning process, and help them understand the relationships between mathematical concepts more deeply. Thus, Generative AI functions not only as a tool for generating answers but also has the potential to support knowledge construction and the development of mathematical thinking skills.

However, the effectiveness of Generative AI implementation is highly dependent on the pedagogical strategies used in the learning process. Various challenges such as dependence on technology, potential misconceptions, decreased cognitive engagement, and the possibility of information inaccuracy indicate that the use of AI needs to be balanced with strengthening critical thinking, reflection, and problem-solving skills. Therefore, the integration of Generative AI in mathematics learning needs to be directed towards an approach that positions students as active learners through independent exploration, evaluation, and construction of understanding. With the right strategy, Generative AI can be an effective learning instrument to encourage the transition from an answer generation orientation to sustainable conceptual understanding, while also supporting the development of mathematical competencies that are relevant to educational needs in the digital era.

REFERENCES

Anwar, K., Sherlyna, A., Salsanifa, A. M., Tyas, H. A., Prayudistyan, S. E., Saputra, G. A., & Maulana, I. (2026a). GENERATIVE ARTIFICIAL INTELLIGENCE IN MATHEMATICS EDUCATION: A SYSTEMATIC REVIEW OF DATA-DRIVEN APPLICATIONS, LEARNING THEORIES, AND IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT GOAL. *AL JABAR: Jurnal Pendidikan Dan Pembelajaran Matematika*, *5*(2), 205–230. https://doi.org/10.46773/x224sd70

Anwar, K., Sherlyna, A., Salsanifa, A. M., Tyas, H. A., Prayudistyan, S. E., Saputra, G. A., & Maulana, I. (2026b). GENERATIVE ARTIFICIAL INTELLIGENCE IN MATHEMATICS EDUCATION: A SYSTEMATIC REVIEW OF DATA-DRIVEN APPLICATIONS, LEARNING THEORIES, AND IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT GOAL. *AL JABAR: Jurnal Pendidikan Dan Pembelajaran Matematika*, *5*(2), 205–230. https://doi.org/10.46773/x224sd70

Awang, L. A., Yusop, F. D., & Danaee, M. (2025). Current practices and future direction of artificial intelligence in mathematics education: A systematic review. *International Electronic Journal of Mathematics Education*, *20*(2), em0823. https://doi.org/10.29333/iejme/16006

Besas, J., Patac, L., & Jr, A. P. (2026). AI-Facilitated Self-Directed Learning and Mathematics Performance: A Mixed-Methods Study on ChatGPT Use among Generation Z Students. *International Journal of Contemporary Educational Research*, *13*(1), 15–30. https://eric.ed.gov/?id=EJ1505621

Chamola, V., Dave, D., Goyal, I., & Sharma, S. (2026). Generative Artificial Intelligence in STEM Education: A Review of Applications, Benefits and Challenges. *Expert Systems*, *43*(2), e70201. https://doi.org/10.1111/exsy.70201

Chen, S.-Y., Chen, W.-C., & Lai, C.-F. (2025). Generative AI as a reflective scaffold in a UAV-based STEM project: A mixed-methods study on students' higher-order thinking and cognitive transformation. *Education and Information Technologies*, *30*(17), 24787–24814. https://doi.org/10.1007/s10639-025-13758-4

Choi, W.-Y. (2026). Integrating Generative AI in University Mathematics: Reflective and collaborative learning as pedagogical safeguards. *Education and Information Technologies*. https://doi.org/10.1007/s10639-026-13945-x

Cosentino, G., Anton, J., Sharma, K., Gelsomini, M., Giannakos, M., & Abrahamson, D. (2025). Generative AI and multimodal data for educational feedback: Insights from embodied math learning. *British Journal of Educational Technology*, *56*(5), 1686–1709. https://doi.org/10.1111/bjet.13587

Cruz, S., & Viseu, F. (2026). AI-supported hybrid learning in exploratory geometry: For higher education. *European Journal of Science and*

Mathematics Education, *14*(3), 471–488. https://doi.org/10.30935/scimath/18798
Daher, W., & Gierdien, F. (2024). Use of Language By generative AI Tools in Mathematical Problem Solving: The Case of ChatGPT. *African Journal of Research in Mathematics, Science and Technology Education*, *28*(2), 222–235. https://doi.org/10.1080/18117295.2024.2384676
Gabrovšek, R., & Rihtaršič, D. (2025). Custom Generative Artificial Intelligence Tutors in Action: An Experimental Evaluation of Prompt Strategies in STEM Education. *Sustainability*, *17*(21), 9508. https://doi.org/10.3390/su17219508
Giannakos, M., Azevedo, R., Brusilovsky, P., Cukurova, M., Dimitriadis, Y., Hernandez-Leo, D., Järvelä, S., Mavrikis, M., & Rienties, B. (2025). The promise and challenges of generative AI in education. *Behaviour & Information Technology*, *44*(11), 2518–2544. https://doi.org/10.1080/0144929X.2024.2394886
Kamau, B., & Shukla, N. (2026). Experimentation and Potential for Generative AI Tools in Gateway Mathematics. *International Journal of Technology in Education and Science*, *10*(2), 191–218. https://eric.ed.gov/?id=EJ1506259
Liu, B., Zhang, W., & Wang, F. (2026). Can Generative Artificial Intelligence Effectively Enhance Students' Mathematics Learning Outcomes?—A Meta-Analysis of Empirical Studies from 2023 to 2025. *Education Sciences*, *16*(1), 140. https://doi.org/10.3390/educsci16010140
Liu, J., Sun, D., Sun, J., Wang, J., & Yu, P. L. H. (2025). Designing a generative AI enabled learning environment for mathematics word problem solving in primary schools: Learning performance, attitudes and interaction. *Computers and Education: Artificial Intelligence*, *9*, 100438. https://doi.org/10.1016/j.caeai.2025.100438
Mailizar, M., Hidayat, M., Syukri, M., & Wijayanti, D. (2026). Exploring the impact of generative AI on pre-service mathematics teacher TPACK: A mixed-method study. *Discover Education*, *5*(1), 453. https://doi.org/10.1007/s44217-026-01432-x
Maity, S., & Deroy, A. (2024). *The Future of Learning in the Age of Generative AI: Automated Question Generation and Assessment with Large Language Models* (arXiv:2410.09576). arXiv. https://doi.org/10.48550/arXiv.2410.09576
Manik, M., Sudiarta, P. I. G. P., & Suparta, I. N. (2026a). The Role of Artificial Intelligence and Multimodal Approaches in Enhancing Learning Engagement and Mathematics Conceptual Understanding Among Junior High School Students: A Systematic Literature Review. *EduMatSains : Jurnal Pendidikan, Matematika Dan Sains*, *10*(3), 134–149. https://doi.org/10.33541/edumatsains.v10i3.7597
Manik, M., Sudiarta, P. I. G. P., & Suparta, I. N. (2026b). The Role of Artificial Intelligence and Multimodal Approaches in Enhancing Learning

Engagement and Mathematics Conceptual Understanding Among Junior High School Students: A Systematic Literature Review. *EduMatSains : Jurnal Pendidikan, Matematika Dan Sains*, *10*(3), 134–149. https://doi.org/10.33541/edumatsains.v10i3.7597

Nanda, S. B., & Pradhan, D. K. (2025). Artificial Intelligence in Mathematics Education: A Systematic Review of Global Trends and Emerging Themes. *Journal of Mathematics, Science and Technology Education*, *2*(2), 153–175. https://doi.org/10.12973/jmste.2.2.153

Okwuobasi, M. C. (2026). Adoption and pedagogical use of generative artificial intelligence in K-12 mathematics/science/language classrooms: Challenges and opportunities. *International Journal of Applied Resilience and Sustainability*, *2*(2), 1188–1219. https://doi.org/10.70593/deepsci.0202049

Rane, N. (2023a). *Enhancing Mathematical Capabilities through ChatGPT and Similar Generative Artificial Intelligence: Roles and Challenges in Solving Mathematical Problems* (SSRN Scholarly Paper No. 4603237). Social Science Research Network. https://doi.org/10.2139/ssrn.4603237

Rane, N. (2023b). *Enhancing Mathematical Capabilities through ChatGPT and Similar Generative Artificial Intelligence: Roles and Challenges in Solving Mathematical Problems* (SSRN Scholarly Paper No. 4603237). Social Science Research Network. https://doi.org/10.2139/ssrn.4603237

Reddy, C. K., & Shojaee, P. (2025). Towards Scientific Discovery with Generative AI: Progress, Opportunities, and Challenges. *Proceedings of the AAAI Conference on Artificial Intelligence*, *39*(27), 28601–28609. https://doi.org/10.1609/aaai.v39i27.35084

Shao, H., & Tang, G. (2025). Empowering Mathematical Problem-Posing Pedagogy with Generative AI: A Theoretical Framework and Case Study. *2025 14th International Conference on Educational and Information Technology (ICEIT)*, 111–115. https://doi.org/10.1109/ICEIT64364.2025.10975950

Shi, W. (2024). *Leveraging Generative Artificial Intelligence to Enhance Mathematical Innovation and Practical Abilities of University Students*. *1*(11).

Song, Y., Kim, J., Liu, Z., Li, C., & Xing, W. (2026). Students' perceived roles, opportunities, and challenges of a generative AI-powered teachable agent: A case of middle school math class. *Journal of Research on Technology in Education*, *58*(3), 535–554. https://doi.org/10.1080/15391523.2024.2447727

Tassell, J., Novak, E., Little, T., & Feeney, E. (2026). *Preparing Elementary Mathematics Teachers for Responsible AI Use: An Exploratory Mixed?Methods Study Using a Short Online Module and Scenario?Based Discussions*. 777–789. https://www.learntechlib.org/primary/p/2129703/

Walkington, C. (n.d.). The implications of generative artificial intelligence for mathematics education. *School Science and Mathematics*, *n/a*(n/a). https://doi.org/10.1111/ssm.18356

Yang, X., Chen, R., & Chen, Z. (2026). AI-enabled blended teaching in Information Theory and Coding: An outcomes-based mixed-methods approach. *Frontiers in Education*, *11*. https://doi.org/10.3389/feduc.2026.1752893

Zapata-Rivera, D., Torre, I., Lee, C.-S., Sarasa-Cabezuelo, A., Ghergulescu, I., & Libbrecht, P. (2024). Editorial: Generative AI in education. *Frontiers in Artificial Intelligence*, *7*. https://doi.org/10.3389/frai.2024.1532896

Zhu, Q., & Luo, J. (2023). Generative Transformers for Design Concept Generation. *Journal of Computing and Information Science in Engineering*, *23*(041003). https://doi.org/10.1115/1.4056220