



Research Article

The Role of Artificial Intelligence in Mathematics Education in Higher Education: A Literature Review

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Abstract

The digital transformation in higher education demands innovative, adaptive, and technology-driven learning approaches. Artificial Intelligence (AI) has emerged as a key technology with significant contributions to mathematics education at the tertiary level. This article aims to explore the role, effectiveness, and challenges of AI implementation in mathematics learning through a systematic literature review of 25 scholarly articles published between 2019 and 2024. The findings reveal that AI applications—such as adaptive learning systems, educational chatbots, predictive analytics, and AR/VR-based visualizations—enhance conceptual understanding, student engagement, and learning efficiency. However, integration of AI in mathematics education still faces several obstacles, including infrastructure limitations, educators' readiness, and ethical concerns regarding data privacy. This review recommends strategic actions such as enhancing digital literacy for lecturers and students, investing in digital infrastructure, and developing ethical frameworks to support AI-driven learning environments. Overall, AI has the potential to transform mathematics education in higher education into a more adaptive, inclusive, and sustainable process in the digital era.

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Introduction

In the era of the Industrial Revolution 4.0, digitalization in higher education is no longer a matter of choice but an inevitable necessity. Artificial Intelligence (AI) has emerged as one of the key innovations driving this transformation. In mathematics education, a field often regarded as challenging, AI has evolved from being merely a tool for computation and visualization into an intelligent system capable of providing instant feedback, functioning as a virtual tutor, and managing data-driven learning tailored to individual student needs (Luckin et al., 2016; Zawacki-Richter et al., 2019).

Over the past five years, research on the application of AI in mathematics education has grown significantly. According to a bibliometric analysis by Hossein-Mohand et al. (2025) and Subroto et al. (2024) there has been a surge in scientific publications on this topic between 2020 and 2024. Countries such as China, the United States, and India are the largest contributors to this body of research. This increase reflects a shift in approach, where AI is no longer used solely as a supporting tool but has become a central component in building more personalized, interactive, and collectively intelligent learning systems. A concrete example can be seen at Babson College in the United States by Solis (2024) which implemented “MathBot” to address gaps in mathematical understanding caused by the pandemic. The use of this technology has proven effective in improving first-year students' mastery of fundamental concepts.

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In Indonesia, a study by Fitriyah et al. (2023) found that the use of interactive Android-based e-modules can significantly improve students' academic performance, with an average N-Gain score of 0.79, which falls into the high category. In addition to cognitive achievement, the integration of AI also promotes the development of learner autonomy and critical thinking skills. However, a survey conducted by Harnawati and Hidayati (2024) involving prospective mathematics teachers revealed that, although AI is perceived as a promising technology, challenges such as limited infrastructure, low digital literacy, and ethical concerns related to technology remain major obstacles to its effective implementation in classroom settings.

Against this backdrop, this article aims to thoroughly examine the application of AI in mathematics education at the higher education level, assess its effectiveness in improving student learning outcomes, and identify the challenges associated with its integration. The findings are expected to contribute to the development of more adaptive, contextual, and sustainable learning strategies to meet the demands of 21st-century education.

Methodology

This study employs a descriptive qualitative approach using the method of systematic literature review to explore the role of Artificial Intelligence (AI) in mathematics education in higher education. Data were collected from scholarly articles published indexed in databases such as Scopus, SINTA, and Google Scholar. The search process was conducted using keywords such as “artificial intelligence,” “mathematics education,” and “higher education.” Selected articles met the criteria of topic relevance, publication timeframe, and use of either English or Indonesian language, resulting in a few articles being included for analysis.

Data analysis was carried out using a thematic approach to identify patterns related to the implementation, effectiveness, as well as challenges and opportunities of AI in mathematics learning. The validity of the findings was strengthened through source triangulation by comparing multiple articles and supporting documents (Braun & Clarke, 2006; Patton, 2015).

Results

A systematic review of a few selected scholarly articles reveals that Artificial Intelligence (AI) plays a significant role in driving innovation in mathematics

education at the higher education level. Overall, the main findings can be categorized into five major themes:

1. AI Innovations in Mathematics Education

The integration of AI has given rise to various innovative approaches in mathematics learning. Adaptive learning systems, such as Squirrel AI and Khan Academy, enable personalized instruction tailored to students' cognitive profiles (Cui et al., 2019; Mirea et al., 2025). Additionally, AI-powered chatbots and virtual assistants like ChatGPT and Watson Assistant are employed to provide interactive and just-in-time guidance. These technologies are also used to automate assessment and formative feedback, as well as to support the interactive visualization of abstract mathematical concepts, such as calculus and linear algebra (Pepin et al., 2025; Wardat et al., 2023).

2. Effectiveness of AI Implementation

Several studies report that the use of AI can improve students' conceptual understanding, learning motivation, and time efficiency. Intelligent tutoring systems offer a more personalized and adaptive learning experience. Research by Kulik & Fletcher (2016) and Wang et al. (2024) indicates that students using AI-based systems tend to achieve better academic outcomes compared to those engaged in traditional learning methods.

3. Challenges in AI Implementation

The implementation of AI in higher education still faces several challenges, including data privacy and ethical concerns, digital access disparities, the limited capacity of AI to address affective learning dimensions, and the readiness and competence of instructors. These factors significantly influence the effectiveness of AI integration in mathematics instruction (Luckin et al., 2016; Williamson, 2024; Zawacki-Richter et al., 2019).

4. Prospects for AI Development in Mathematics Learning

Technological advancements highlight the substantial potential of integrating AI with Augmented Reality (AR) and Virtual Reality (VR) to enhance the spatial understanding and visualization of mathematical concepts. Studies by Cao (2023) and Pinter & Siddiqui (2024) report increased learning outcomes and student engagement through such immersive approaches. Furthermore, the development of multimodal intelligent tutors and predictive learning analytics systems

represents a promising direction for personalized AI-driven learning (Chango et al., 2024).

5. Practical Challenges in Real-World Contexts

Practical implementation still encounters several barriers, including limited instructor competence, high costs associated with AI and AR/VR technologies, and the lack of large-scale studies examining AI effectiveness in real classroom settings (Tene et al., 2024).

Therefore, collaboration among technology developers, mathematics educators, and instructional designers is essential to develop contextualized, effective, and locally relevant AI-based learning systems.

Discussion

This literature review demonstrates that Artificial Intelligence (AI) has made a significant contribution to transforming the approach to mathematics education in higher education. AI functions not merely as a technological aid but as a strategic component in developing a more personalized, efficient, and adaptive learning ecosystem tailored to student needs.

The implementation of adaptive learning systems has proven to be highly effective in customizing content, difficulty levels, and learning strategies based on individual students' cognitive profiles. These findings reinforce the concept of personalized learning, which, in theory, enhances student engagement and academic achievement—particularly in mathematics, a subject characterized by its hierarchical and abstract nature. AI enables real-time instructional adjustments, a feature that is often unattainable through conventional teaching methods (Holmes et al., 2019; Khosravi et al., 2022).

Furthermore, the use of AI-based chatbots and virtual assistants supports self-directed learning that is both responsive and contextualized. These technologies provide accessible explanations of material, corrective feedback, and interactive problem-solving guidance. This approach aligns with the principle of just-in-time learning, enabling students to receive support precisely when it is needed, without relying on the instructor's immediate availability (Laun & Wolff, 2025).

Automated assessment and formative feedback are also among the key advantages of AI integration. These systems not only reduce instructors' administrative workload but also enhance the learning process by offering immediate and continuous feedback. This fosters the development of students' metacognitive skills and

promotes reflective learning practices (Luckin et al., 2016; Swiecki et al., 2022).

Nevertheless, the findings also highlight that the success of AI implementation is heavily influenced by several external factors. Ethical concerns and data privacy issues, limitations in digital infrastructure, and disparities in educators' digital competencies remain major obstacles. Without clear regulatory frameworks and ongoing training, AI integration may risk algorithmic bias, breaches of privacy, and inequitable access across institutions (Hartati et al., 2023).

Moreover, the future of AI in mathematics education is increasingly promising with the integration of Augmented Reality (AR) and Virtual Reality (VR) technologies. These immersive tools allow abstract mathematical concepts to be visualized more concretely and intuitively, which has been empirically shown to improve conceptual understanding and student interest. Additionally, multimodal intelligent tutors capable of processing input in text, voice, and image formats are considered effective in enriching the learning experience and accommodating diverse learning styles (Cao, 2023).

Ultimately, realizing effective and sustainable AI integration requires a systemic approach that includes enhancing educator capacity, investing in infrastructure, and fostering cross-disciplinary collaboration among educational institutions, technology developers, and policymakers. Without such synergy, the transformative potential of AI in mathematics education is unlikely to be fully realized.

Conclusion and Recommendation

The findings of this review affirm that Artificial Intelligence (AI) holds significant potential in transforming mathematics education at the higher education level. AI technologies can facilitate more adaptive learning experiences, enhance the effectiveness of instructional processes, and support the development of essential 21st-century skills, such as critical thinking, autonomous learning, and problem-solving. Nevertheless, several challenges must be addressed, including limited human resource readiness, accessibility and availability of digital infrastructure, and emerging ethical concerns related to data privacy and equitable access to technology.

To move forward, several strategic actions are recommended. First, there is a need to expand training opportunities for both lecturers and students to ensure

they can utilize AI technologies effectively in the learning process. Second, increasing investment in campus digital infrastructure is crucial to support the sustainable implementation of AI-based learning systems. Third, the development of regulatory frameworks addressing the ethical use of AI in education should be prioritized to ensure data protection, fairness, and transparency. Lastly, collaborative research among higher education institutions should be strengthened to evaluate the effectiveness of various AI platforms, with the goal of identifying models that best suit local needs and contextual characteristics in Indonesia.

References

- Braun, V., & Clarke, V. (2006). Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706QP063OA>
- Cao, L. (2023). A Meta-Analysis of The Impact of AR and VR Technologies on Mathematics Learning. *Journal of Education, Humanities and Social Sciences*, 23, 637–649. <https://doi.org/10.54097/EHSS.V23I.13133>
- Chango, W., Cerezo, R., Sanchez-Santillan, M., Azevedo, R., & Romero, C. (2024). Improving Prediction of Students' Performance in Intelligent Tutoring Systems Using Attribute Selection and Ensembles of Different Multimodal Data Sources. *Journal of Computing in Higher Education*, 33(3), 614–634. <https://doi.org/10.1007/s12528-021-09298-8>
- Cui, W., Xue, Z., & Thai, K.-P. (2019). Performance Comparison of an AI-based Adaptive Learning System in China. *Computer and Society*. <https://arxiv.org/pdf/1901.10268>
- Fitriyah, A., Manoy, J. T., & Fiangga, S. (2023). Pengembangan E-Modul Interaktif Berbasis Android untuk Siswa Kelas VII SMP Materi Penyajian Data. *MATHEdunesa*, 13(1), 1–15. <https://doi.org/10.26740/mathedunesa.v13n1.p1-15>
- Hartati, T., Fitria, N., Harahap, M. A. A., & Dasari, D. (2023). Data-Driven Education: Data Processing as a Key to Improving the Quality of Mathematics Education. *ALSYSTECH Journal of Education Technology*, 2(1), 45–57. <https://doi.org/10.58578/ALSYSTECH.V2I1.2361>
- Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial Intelligence in Education: Promises and Implications for Teaching and Learning*. 228. <https://unesdoc.unesco.org/ark:/48223/pf0000368021>
- Hosseini-Mohand, H., Hosseini-Mohand, H., Albanese, V., & Gómez, M. del C. O. (2025). AI in Mathematics Education: A Bibliometric Analysis of Global Trends and Collaborations (2020-2024). *Eurasia Journal of Mathematics, Science and Technology Education*, 21(2), em2576. <https://doi.org/10.29333/EJMSTE/15915>
- Khosravi, H., Shum, S. B., Chen, G., Conati, C., Tsai, Y. S., Kay, J., Knight, S., Martinez-Maldonado, R., Sadiq, S., & Gašević, D. (2022). Explainable Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence*, 3, 100074. <https://doi.org/10.1016/J.CAEAI.2022.100074>
- Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of Intelligent Tutoring Systems: A Meta-Analytic Review. *Review of Educational Research*, 86(1), 42–78. <https://doi.org/10.3102/0034654315581420>
- Laun, M., & Wolff, F. (2025). Chatbots in Education: Hype or Help? A Meta-analysis. *Learning and Individual Differences*, 119, 102646. <https://doi.org/10.1016/J.LINDIF.2025.102646>
- Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence Unleashed An argument for AI in Education*.
- Mirea, C. M., Bologa, R., Toma, A., Clim, A., Plăcintă, D. D., & Boboccea, A. (2025). Transforming Learning with Generative AI: From Student Perceptions to the Design of an Educational Solution. *Applied Sciences* 2025, 15(10), 5785. <https://doi.org/10.3390/AP15105785>
- Patton, M. Q. (2015). Qualitative Research & Evaluation Methods. In *Qualitative research and evaluation methods: Integrating theory and practice* (4th ed.). Sage Publications. <https://uk.sagepub.com/en-gb/eur/qualitative-research-evaluation-methods/book232962>
- Pepin, B., Buchholtz, N., & Salinas-Hernández, U. (2025). A Scoping Survey of ChatGPT in Mathematics Education. *Digital Experiences in Mathematics Education* 2025 11:1, 11(1), 9–41. <https://doi.org/10.1007/S40751-025-00172-1>
- Pinter, L., & Siddiqui, M. F. H. (2024). Enhancing Calculus Learning through Interactive VR and AR Technologies: A Study on Immersive Educational Tools. *Multimodal Technologies and Interaction* 2024, Vol. 8, Page 19, 8(3), 19. <https://doi.org/10.3390/MTI8030019>
- Solis, S. (2024). *Babson College Rolls Out AI MathBot to Help Students Learn - Axios Boston*. https://www.axios.com/local/boston/2024/09/17/babson-college-mathbot-ai-covid-learning-gap?utm_source=chatgpt.com
- Subroto, P. W., Malik, M., Raditya, A., & Saputra, N. N. (2024). A Bibliometric Analysis on Artificial Intelligence in Mathematics Education. *JRAMathEdu (Journal of Research and Advances in Mathematics Education)*, 1–15.

- <https://doi.org/10.23917/jramathedu.v9i1.2429>
- Swiecki, Z., Khosravi, H., Chen, G., Martinez-Maldonado, R., Lodge, J. M., Milligan, S., Selwyn, N., & Gašević, D. (2022). Assessment in The Age of Artificial Intelligence. *Computers and Education: Artificial Intelligence*, 3, 100075. <https://doi.org/10.1016/J.CAEAI.2022.100075>
- Tene, T., Marcatoma Tixi, J. A., Palacios Robalino, M. de L., Mendoza Salazar, M. J., Vacacela Gomez, C., & Bellucci, S. (2024). Integrating Immersive Technologies with STEM Education: A Systematic Review. In *Frontiers in Education* (Vol. 9). Frontiers Media SA. <https://doi.org/10.3389/feduc.2024.1410163>
- Wang, S., Wang, F., Zhu, Z., Wang, J., Tran, T., & Du, Z. (2024). Artificial Intelligence in Education: A Systematic Literature Review. *Expert Systems with Applications*, 252, 124167. <https://doi.org/10.1016/J.ESWA.2024.124167>
- Wardat, Y., Tashtoush, M. A., AlAli, R., & Jarrah, A. M. (2023). ChatGPT: A Revolutionary Tool for Teaching and Learning Mathematics. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(7). <https://doi.org/10.29333/EJMSTE/13272>
- Williamson, B. (2024). The Social life of AI in Education. In *International Journal of Artificial Intelligence in Education* (Vol. 34, Issue 1, pp. 97–104). Springer. <https://doi.org/10.1007/s40593-023-00342-5>
- Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on Artificial Intelligence Applications in Higher Education – Where are The Educators? *International Journal of Educational Technology in Higher Education* 2019 16:1, 16(1), 1–27. <https://doi.org/10.1186/S41239-019-0171-0>