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Using AI for the Personalization of Mathematics and Science Education in Students

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Abstract: This research review explores the role of artificial intelligence (AI) in personalizing mathematics and science education to enhance student learning experiences and outcomes. The study synthesizes current research to examine how AI-driven technologies—such as adaptive learning systems, intelligent tutoring, and real-time feedback mechanisms—support individualized instruction aligned with students' learning styles, paces, and cognitive needs. Findings indicate that AI significantly improves engagement, conceptual understanding, and problem-solving skills by leveraging data analytics and machine learning to deliver tailored content. These systems are grounded in established educational theories, including Mastery Learning and the Zone of Proximal Development. However, challenges remain, including unequal access to technology, algorithmic bias, data privacy concerns, and limited teacher preparedness, which hinder equitable implementation. The review also identifies gaps in longitudinal and context-specific research, particularly in under-resourced educational settings. The study concludes that while AI holds transformative potential for STEM education, its effective integration requires ethical design, inclusive policies, teacher training, and pedagogical alignment. For sustainable impact, AI should be implemented as a supportive tool within human-centered educational frameworks rather than a standalone solution.

Keywords: Artificial Intelligence; Personalized Learning; Mathematics Education; Science Education; Adaptive Systems

Introduction

The rapid advancement of artificial intelligence (AI) has significantly transformed various sectors, with education emerging as one of the most promising domains for AI integration (Charles et al., 2025; Kobeissi et al., 2025; Yousefi et al., 2025). In recent years, the application of AI in educational settings has evolved beyond simple automation to more sophisticated roles, particularly in personalizing learning experiences. Mathematics and science, as foundational disciplines requiring deep conceptual understanding and problem-solving skills, often present challenges for students due to their abstract nature and cumulative structure (Ekundayo & Ezugwu, 2025; Geng & Liang, 2024; Lü et al., 2025). Traditional one-size-fits-all teaching approaches frequently fail to address the diverse learning paces, styles, and cognitive levels of students, leading to disengagement, knowledge gaps, and unequal learning outcomes. This growing disparity highlights the need for more adaptive and responsive educational strategies (Cao et al., 2025; Paulick & Palacios, 2025; Zeng et al., 2025).

In this context, AI-driven personalization has emerged as a transformative solution to tailor instruction to individual learner needs (Anderson et al., 2025). By leveraging machine learning algorithms, natural language processing, and data analytics, AI systems can assess student performance in real time, identify misconceptions, and deliver customized content, feedback, and learning pathways (Liu et al., 2025). For instance, intelligent tutoring systems (ITS)

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and adaptive learning platforms have demonstrated effectiveness in improving student engagement and achievement in STEM subjects by dynamically adjusting difficulty levels and providing targeted support. Theoretically grounded in constructivist learning theory and Vygotsky's Zone of Proximal Development, these technologies facilitate scaffolded learning experiences that align with each student's developmental trajectory (Arnau-González et al., 2025).

Despite the growing body of empirical evidence supporting AI's potential in education, challenges remain in its equitable implementation, data privacy, algorithmic bias, and teacher-AI collaboration (Pikhart & Al-Obaydi, 2025). Moreover, the integration of AI in mathematics and science education is still uneven across different educational contexts, particularly in under-resourced regions where access to digital tools is limited (Payadnya et al., 2025). According to UNESCO (2023), over 50% of students in low- and middle-income countries lack access to basic digital learning infrastructure, exacerbating existing educational inequalities. Even in well-resourced environments, the effective deployment of AI requires careful alignment with pedagogical goals and curriculum standards (Hu et al., 2025).

This research aims to explore the current state, opportunities, and challenges of using AI to personalize mathematics and science education. By synthesizing recent scholarly works, case studies, and technological innovations, the study seeks to understand how AI can be leveraged to enhance individualized learning, improve conceptual mastery, and support inclusive education. The focus lies on examining the mechanisms through which AI personalization influences student motivation, learning outcomes, and equity in STEM education. Ultimately, this research contributes to a deeper understanding of the transformative potential of AI in reshaping pedagogical practices and fostering more responsive, student-centered learning environments in critical academic domains.

Method

This study employs a qualitative literature review methodology, specifically a systematic thematic review, to explore and analyze existing scholarly works on the application of artificial intelligence (AI) in personalizing mathematics and science education (Cernasev et al., 2025). The method was chosen to ensure a comprehensive, structured, and evidence-based synthesis of current knowledge, enabling the identification of key trends, effective practices, challenges, and theoretical underpinnings in the field. The review process followed a multi-stage approach: (1) definition of research questions, (2) identification of relevant keywords and databases, (3) selection of academic sources based on inclusion and exclusion criteria, (4) critical appraisal of selected literature, and (5) thematic analysis and synthesis of findings.

The primary research question guiding this review is: How can artificial intelligence be effectively utilized to personalize learning experiences in mathematics and science education, and what are the pedagogical, technological, and ethical implications of such implementations? To answer this, a systematic search was conducted across reputable academic databases, including ERIC, Google Scholar, ScienceDirect, SpringerLink, and IEEE Xplore, using keyword combinations such as "artificial intelligence in education," "AI personalization," "adaptive learning in STEM," "intelligent tutoring systems," "mathematics education technology," and "science learning personalization."

Inclusion criteria focused on peer-reviewed journal articles, conference proceedings, and authoritative reports published between 2018 and 2024, ensuring the relevance and currency of the data. Only studies that explicitly addressed AI-driven personalization in K–12 or higher education contexts within mathematics and/or science disciplines were included. Theoretical frameworks, empirical studies, case analyses, and meta-analyses were all considered to provide a balanced and multidimensional perspective.

Selected studies were analyzed through thematic coding based on key dimensions: types of AI technologies used (e.g., machine learning, natural language processing, recommendation systems), pedagogical models applied, learning outcomes reported, implementation challenges, and equity considerations. The analysis was further informed by established educational theories such as constructivism, Bloom's mastery learning, and the cognitive theory of multimedia learning, which helped interpret how AI supports individualized learning processes.

By adopting a rigorous and transparent methodological framework, this literature review ensures the reliability and validity of its findings, offering a robust foundation for understanding the role of AI in transforming STEM education through personalization. The systematic approach also allows for the identification of research gaps and future directions, contributing to both academic discourse and practical implementation strategies.

Result and Discussion

This literature review synthesizes current research on the use of artificial intelligence (AI) in personalizing mathematics and science education through a systematic thematic analysis. The findings are organized around key themes that emerged from the reviewed literature, reflecting both the transformative potential and critical challenges of AI integration in STEM learning environments.

AI-Driven Personalization Enhances Learning Outcomes in STEM

A consistent body of evidence indicates that AI-powered adaptive systems significantly improve student performance in mathematics and science (Pesovski et al., 2025). Intelligent tutoring systems (ITS), such as Cognitive Tutor and ASSISTments, utilize machine learning to analyze student interactions, detect misconceptions, and deliver tailored feedback. Meta-analyses Lim & Kim (2025) report moderate to large effect sizes (d = 0.47–0.63) in learning gains when AI personalization is implemented with curriculum-aligned content. These systems support mastery learning by allowing students to progress only after achieving conceptual understanding, aligning with Bloom's (1984) theory of learning for mastery (An & Ngo, 2025).

Adaptive Feedback and Real-Time Assessment Improve Engagement

One of the most impactful features of AI in education is its ability to provide immediate, formative feedback. Studies show that students exposed to AI-generated feedback in mathematics problem-solving demonstrate higher persistence and reduced cognitive load (Kılıç & Çelik, 2025). In science education, natural language processing (NLP)-enabled platforms assess open-ended responses and guide students through inquiry-based learning, increasing motivation and self-regulated learning (Wu et al., 2024). This reflects principles from Vygotsky (1978) sociocultural theory, where AI acts as a digital scaffold within the Zone of Proximal Development (ZPD) (Zhao et al., 2025).

Multimodal AI Systems Cater to Diverse Learning Needs

Modern AI platforms support personalized learning paths by integrating multimedia content—videos, simulations, interactive exercises—based on individual learning preferences and performance history (Mohammadi et al., 2025). This multimodal approach aligns with Mayer's Cognitive Theory of Multimedia Learning (2021), which emphasizes reducing extraneous cognitive load while enhancing meaningful learning (Ji et al., 2025). For instance, AI-driven platforms like Khan Academy and DreamBox adapt not only content difficulty but also presentation style, benefiting visual and kinesthetic learners alike (Elabd et al., 2025).

Equity and Access Remain Critical Barriers

Despite technological advances, significant disparities exist in the accessibility of AI-enhanced education (Worku, 2025). UNESCO (2023) reports that approximately 50% of students in low- and middle-income countries lack reliable internet access or digital devices, limiting the scalability of AI tools (Obhi et al., 2025). Furthermore, algorithmic bias—where AI models are trained on non-diverse datasets—can disadvantage underrepresented groups, perpetuating existing educational inequities (Parashar & Jaiswal, 2025). These findings underscore the need for inclusive design and policy interventions to ensure equitable AI deployment.

Ethical and Data Privacy Concerns Require Strong Governance

The extensive data collection required for AI personalization raises ethical concerns regarding student privacy, informed consent, and data ownership (Mienye & Swart, 2025). Several studies highlight risks of data misuse and lack of transparency in commercial AI platforms (Chhor et al., 2025). To address these, scholars advocate for ethical AI frameworks—such as those proposed by the OECD (2021)—that emphasize accountability, explainability, and student-centered design (Lee & Lee, 2025).

Teacher Role and Professional Development Are Crucial

AI does not replace teachers but redefines their role as facilitators and interpreters of AI-generated insights (Vlcek & Sedova, 2025). However, many educators lack the training to effectively integrate AI tools into pedagogy. Research by Shi et al. (2025) emphasizes the importance of professional development programs that build teachers' data literacy and pedagogical adaptability. Successful AI integration occurs when teachers collaborate with AI systems to inform instructional decisions, rather than relying solely on automated recommendations (Wang et al., 2025).

Gaps in Longitudinal and Contextual Research

While current literature demonstrates short-term cognitive benefits, there is a scarcity of longitudinal studies assessing the long-term impact of AI personalization on academic achievement, metacognition, and career readiness in STEM (Fishman, 2025). Additionally, most studies are conducted in high-income, urban settings, limiting generalizability (Felbel et al., 2025). Future research should explore socio-emotional outcomes, cultural responsiveness, and implementation models in diverse educational contexts (Lü et al., 2025).

The integration of AI in mathematics and science education has demonstrated measurable improvements in student achievement (Kim et al., 2025). Adaptive learning systems, such as intelligent tutoring systems (ITS), use machine learning algorithms to analyze student responses, diagnose misconceptions, and dynamically adjust instructional content. For example, the ASSISTments platform has been shown to improve algebra performance by 15–20% in middle school students, while Cognitive Tutor has enhanced problem-solving skills in high school physics (Schmidt et al., 2025)

These outcomes align with Bloom's (1984) Mastery Learning Theory, which posits that students achieve higher levels of understanding when given sufficient time and targeted support to master each concept before progressing (Ali et al., 2024). AI systems operationalize this principle by continuously assessing student mastery and offering personalized remediation, thus minimizing knowledge gaps that often accumulate in traditional classrooms. Moreover, Constructivist Learning Theory (Vygotsky, 1978) supports the idea that learning is an active, individualized process. AI facilitates this by enabling students to explore concepts at their own pace, receive contextual feedback, and engage in iterative learning—key components of knowledge construction in STEM disciplines (Wang et al., 2024).

A defining feature of AI in education is its capacity to deliver immediate, formative feedback (Alwakid et al., 2025). Unlike traditional assessment methods that may take days to return results, AI systems provide instant responses, allowing students to correct errors and deepen understanding in real time. This immediacy has been linked to increased motivation and reduced frustration, particularly in complex subjects like calculus or chemical reactions (Benseddik et al., 2025).

This aligns with Skinner's (1958) Operant Conditioning Theory, where timely reinforcement strengthens desired behaviors—in this case, persistence in problem-solving. Additionally, Self-Regulated Learning (SRL) Theory emphasizes the importance of feedback in helping students monitor their progress, set goals, and adapt strategies. AI tools support SRL by visualizing learning trajectories, tracking performance trends, and prompting reflection (Brunner et al., 2025).

For instance, platforms like Khan Academy use dashboards to display student progress, encouraging metacognitive awareness. In science classrooms, AI-powered simulations (e.g., PhET Interactive Simulations enhanced with AI analytics) allow students to experiment, observe outcomes, and receive guidance—fostering inquiry-based learning grounded in inquiry learning theory (Araya et al., 2025). AI enables differentiation by adapting not only content difficulty but also presentation modalities—text, video, audio, simulations—based on individual preferences and performance. This multimodal personalization is particularly effective in science education, where abstract concepts (e.g., molecular structures, wave-particle duality) benefit from visual and interactive representations (Bauer et al., 2025).

This approach is grounded in Mayer's Cognitive Theory of Multimedia Learning (CTML) (2021), which asserts that people learn more deeply from words and pictures than from words alone, provided the design minimizes cognitive overload (Oje et al., 2023). AI optimizes this by selecting the most effective media format for each learner and pacing information delivery to match cognitive capacity. Furthermore, Universal Design for Learning (UDL) principles (Rose & Meyer, 2002) are inherently supported by AI, as it allows multiple means of representation, expression, and engagement. For students with learning differences—such as dyscalculia in mathematics or difficulties with scientific reasoning—AI provides alternative pathways to understanding, promoting inclusivity (Caviola et al., 2024).

Despite its potential, AI personalization risks exacerbating educational inequalities. Students in low-income, rural, or under-resourced schools often lack access to devices, reliable internet, or technical support (Buslón et al., 2025). UNESCO (2023) estimates that over 50% of learners worldwide cannot access digital learning tools, creating a "digital divide" that limits the scalability of AI solutions (Greaves et al., 2025). This contradicts the principle of equitable education emphasized in global frameworks such as the UN Sustainable Development Goal 4 (SDG 4). Moreover, algorithmic bias presents a hidden threat: AI models trained on non-diverse datasets may misdiagnose or underserve students from marginalized backgrounds. For example, speech recognition systems may struggle with non-native accents, disadvantaging English language learners in science classrooms (Li & Pei, 2024).

Thus, while AI promises personalization, its benefits are currently unevenly distributed. Technological determinism—the belief that technology alone can solve educational problems—must be challenged. Infrastructure investment, policy reform, and community engagement are essential to ensure that AI serves all students, not just the privileged few. AI systems collect vast amounts of sensitive student data, including behavioral patterns, response times, and emotional cues (via affective computing). While this data enables personalization, it also raises serious concerns about privacy, consent, and surveillance.

Theoretical and Ethical Frameworks: The OECD Principles on AI (2021) and General Data Protection Regulation (GDPR) emphasize transparency, accountability, and user control. However, many commercial AI platforms operate as "black boxes," making it difficult for educators and students to understand how decisions are made. This lack of algorithmic explainability undermines trust and violates the ethical principle of informed autonomy. Additionally, critical data studies Hardy et al. (2025) warn against the "datafication" of education, where students are reduced to data points and learning is commodified. Educators must advocate for ethical AI design that prioritizes pedagogical goals over corporate interests.

AI does not replace teachers but transforms their role into that of a learning facilitator and data interpreter. However, many educators feel unprepared to work with AI-generated insights. A study by Song et al. (2025) found that only 30% of teachers in the UK received training on using AI tools, despite increasing adoption in schools. This highlights the need for technological pedagogical content knowledge (TPACK), a framework that integrates technology, pedagogy, and subject matter expertise. Effective AI integration requires teachers to understand not only how the tool works, but also how to interpret its outputs and adapt instruction accordingly. Professional development programs should focus on building data literacy, critical thinking about AI recommendations, and collaborative lesson planning with AI systems. When teachers are empowered as co-designers rather than passive users, AI becomes a true partner in personalized instruction.

While current research emphasizes cognitive and performance outcomes, there is limited longitudinal evidence on the long-term effects of AI personalization on student identity, self-efficacy, or STEM career aspirations. Most studies are short-term, conducted in controlled environments, and focused on high-income countries. Future studies should adopt mixed-methods approaches to explore socio-emotional dimensions of AI-supported learning. Additionally, research must expand to diverse cultural and socioeconomic contexts to ensure global relevance. The development of open-source, ethically designed AI tools could promote transparency and equity in educational innovation.

The synthesis of findings reveals that AI has transformative potential in personalizing mathematics and science education, supported by robust theoretical foundations in learning science. However, its success is contingent upon equitable access, ethical design, teacher empowerment, and alignment with pedagogical goals. Rather than viewing AI as a standalone solution, it should be integrated into a holistic educational ecosystem that values both technological innovation and human-centered teaching. This literature review underscores the importance of critical, theory-informed analysis in evaluating educational technologies. By grounding AI applications in established learning theories and addressing real-world challenges, educators and policymakers can harness AI to create more inclusive, adaptive, and effective STEM learning environments.

Conclusion

This study concludes that artificial intelligence (AI) holds significant potential in personalizing mathematics and science education by enhancing learning outcomes, student engagement, and conceptual understanding through adaptive systems such as intelligent tutoring and data-driven feedback, supported by learning theories including Mastery Learning, Zone of Proximal Development (ZPD), and the Cognitive Theory of Multimedia Learning (CTML). However, its implementation faces critical challenges, including unequal access, algorithmic bias, data privacy concerns, and insufficient teacher readiness, which limit its benefits—particularly in under-resourced communities. To address these issues, improvements are needed in designing inclusive and transparent AI systems, strengthening ethical frameworks, providing TPACK-based teacher training, and conducting longitudinal, context-sensitive research to explore long-term impacts and socio-emotional aspects of learning. With a human-centered and equitable approach, AI can become a transformative tool in creating more adaptive, inclusive, and effective STEM education for all students.

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