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AI as a teaching augmentor: A review of the integration of AI in science education

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Abstract The integration of Artificial Intelligence (AI) in science education has witnessed significant advancements, transforming traditional teaching and learning practices. This narrative review examines the roles of AI in science education over a decade (2013–2022), focusing on three key areas, namely, AI-based instructional tools that offer personalized and adaptive learning experiences; AI-enabled learning environments that facilitate immersive and interactive exploration of scientific concepts; and AI-supported assessment tools that enhance feedback and evaluation processes. The study highlights the potential of synergistically integrating these roles to create dynamic and adaptive educational systems. It also addresses challenges such as ethical considerations, teacher preparedness, and resource disparities, which influence AI adoption and efficacy in science education. By exploring current trends, practices, and outcomes, this review underscores AI's capacity to augment traditional teaching methods, fostering student engagement, critical thinking, and personalized learning pathways. Recommendations for teacher training and curriculum development are provided to ensure effective integration and sustainable implementation of AI technologies in science education.

Keywords: artificial intelligence, instructional tools, learning environments, science teaching, teaching augmentor

1. Introduction

In the 1950s, McCarthy, Minsky, Rochester, and Shannon introduced the concept of artificial intelligence, envisioning machines capable of using language, forming abstractions and concepts, solving problems typically handled by humans, and enhancing their own capabilities (McCarthy et al., 2006). Following this proposal, AI has been developed to replicate human cognitive abilities in machines, enabling them to execute tasks such as teaching, learning, reasoning, problem-solving, and natural language comprehension. AI systems leverage algorithms and data for decision-making, often enhancing their performance via machine learning techniques. In education, AI technologies create personalized, adaptive learning experiences, enhance instructional tools, enable immersive learning environments, and provide automated, data-driven assessments to improve teaching and learning outcomes (Mnguni, 2023, 2024). While worldwide adoption of AI in education has seen a sharp increase over the last decade, research on AI in education has been ongoing for over 30 years. Early research in the 1980s and 1990s focused on developing Intelligent Tutoring Systems that provide personalized instruction and feedback to students, enhancing their learning experiences (Nkambou et al., 2010). These systems utilized rule-based AI to mimic the teaching process and adapt to individual student needs. In the 2000s, the advent of more sophisticated machine learning algorithms and increased computational power led to the development of more advanced AI applications. Researchers began exploring AI's potential in automating administrative tasks, supporting decision-making, and facilitating adaptive learning environments (Luckin & Holmes, 2016). Studies highlighted AI's role in providing real-time feedback, predicting student performance, and identifying at-risk students.

Recent years have seen a surge in the use of AI to augment teaching through immersive learning environments, such as virtual and augmented reality, and AI-driven assessment tools that offer detailed analytics on student performance (Zawacki-Richter et al., 2019). Despite these advancements, there remains a need for comprehensive research to understand the impacts and best practices for AI integration in various educational contexts, particularly in science education.

2. The Integration of AI in Education

The extent to which AI is used to augment or replace current methods has not been intensively explored. Teaching augmentation with AI would involve enhancing existing educational methods and tools rather than replacing them entirely (Luckin & Holmes, 2016). Augmentation leverages AI to support and improve traditional teaching practices. The replacement of current methods with AI would imply a shift where AI takes over significant aspects of teaching and learning processes, potentially reducing the role of human educators. This approach could lead to standardized, one-size-fits-all education systems driven primarily by algorithms, which could overlook the nuances of human interaction and the benefits of adaptive, context-sensitive teaching (Selwyn, 2019). While AI-driven augmentation enhances the educational experience by supporting teachers

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and enriching student learning, complete replacement risks devaluing the essential human elements of empathy, motivation, and contextual understanding that are vital in effective education. Therefore, a balanced approach, integrating AI to augment but not replace traditional teaching methods, is generally considered the optimal path for leveraging technology in science education. However, research must determine how AI is currently integrated into science education.

The integration of AI in education varies across different regions, with certain countries spearheading the adoption. Notably, the United States and China have made significant strides in this area, substantially improving their educational processes and learning outcomes. In China, the focus is on nurturing local AI talent and reducing educational inequities (Mu, 2023). There is a shift in emphasis from merely completing academic curricula to enhancing students' abilities and promoting holistic development through AI-enabled learning (Huang, 2021). In the USA, AI adoption in education is anticipated to grow, especially in higher education, as interdisciplinary, project-driven courses are being introduced to foster collaboration and knowledge sharing (Crompton & Burke, 2023). In both the US and China, AI is perceived as a competitive advantage in higher education, providing opportunities to streamline administrative processes and improve learning outcomes.

In Africa, AI has been used to transform learning environments to minimize educational disparities (Nja et al., 2023). This includes integrating African ethical values and promoting responsible AI development through ethics courses and capacity-building initiatives (Kiemde & Kora, 2022). Research in South Africa points to AI technology's potential to advance sustainable development goals in higher education, enhance student outcomes, and foster a collaborative learning environment (Nja et al., 2023; Opesemowo & Adekomaya, 2024). In Egypt, researchers are exploring AI's impact on students' acceptance, motivation, and behavioral intentions toward AI in education (Ragheb et al., 2022; Strzelecki & ElArabawy, 2024). In Nigeria, the growing awareness and application of AI in business analytics are driving its adoption in educational contexts (Osasona et al., 2024). Research focusing on AI knowledge and perception highlights the need for educator preparedness and targeted training. These initiatives present significant opportunities to enhance learning outcomes, stimulate innovation, and address educational challenges by leveraging AI technologies and implementing focused training programs (Mnguni, 2024).

In Southeast Asia, countries like Indonesia, Thailand, and Malaysia are advancing AI integration in education to improve learning outcomes and educational processes (Jendia & Ismail, 2023). In Indonesia, AI applications have enhanced educational efficiency and quality (Hasanah & Budiyono, 2024). Malaysia's development of personalized reading materials for primary school pupils using AI exemplifies its potential to transform traditional teaching methods (Jendia & Ismail, 2023). Studies on AI's role in improving students' English writing skills underscore its capacity to expand academic knowledge and technological awareness (Ahmad et al., 2024). Responsible AI integration in Indonesia facilitates student learning (Aripin et al., 2024). AI technologies, such as ChatGPT and Intelligent Tutoring Systems, are used to improve the effectiveness of e-learning and elevate the quality of education. In Thailand, AI-enhanced digital virtual classrooms are fostering creativity and innovation among undergraduate students in STEAM fields (Wannapiroon & Pimdee, 2022).

Globally, AI's transformative potential in education is recognized as a dynamic and innovative breakthrough. Experts are optimistic about AI's positive impact on education (Khan & Maysoon Khojah, 2022). AI integration is viewed as a pathway to shaping future professionals' learning trajectories, although data security and staff training challenges persist. Professional education increasingly incorporates AI into curricula to ensure graduates can use AI ethically and responsibly in their careers (Ning et al., 2024). While some countries lead in AI integration to enhance educational outcomes, addressing ethical considerations, privacy issues, and staff training is crucial for the effective and responsible implementation of AI in education.

3. Problem Statement and AIM of the Research

Despite the increasing integration of AI in various educational contexts, there remains a significant gap in comprehensive research focusing on the effective application of AI in science education. Current literature predominantly addresses the general potential of AI technologies. However, there is a paucity of in-depth studies that explore the specific trends, practices, and outcomes associated with AI tools tailored for science education. Additionally, current research often overlooks the contextual nuances and diverse educational settings in which these AI technologies are applied. Consequently, educators and policymakers lack clear, evidence-based guidelines on best practices for implementing AI in science education. In light of this, this manuscript aims to address this deficiency by exploring strategies used for integrating AI in science education by qualitatively reviewing emerging trends, practices, and reported outcomes in integrating AI in science education.

4. Classification of AI Integration Approaches

While the literature does not provide a succinct model demonstrating how AI can be integrated into science education, the current author posits that the integration can be classified into three interrelated categories, namely, AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment tools (Figure 1). This model (Figure 1), synthesized from the literature reviewed in Tables 1–3, illustrates that the categories of AI integration may operate independently or overlap, depending on the specific learning objectives. Each category's depth of AI integration varies, allowing for tailored approaches that meet specific educational goals. The intersection of these categories suggests a synergistic integration of AI, promoting a holistic educational experience that adapts to diverse learning needs and optimizes outcomes. This multifaceted integration underscores the potential of AI to enhance instructional quality, learning engagement, and assessment accuracy.

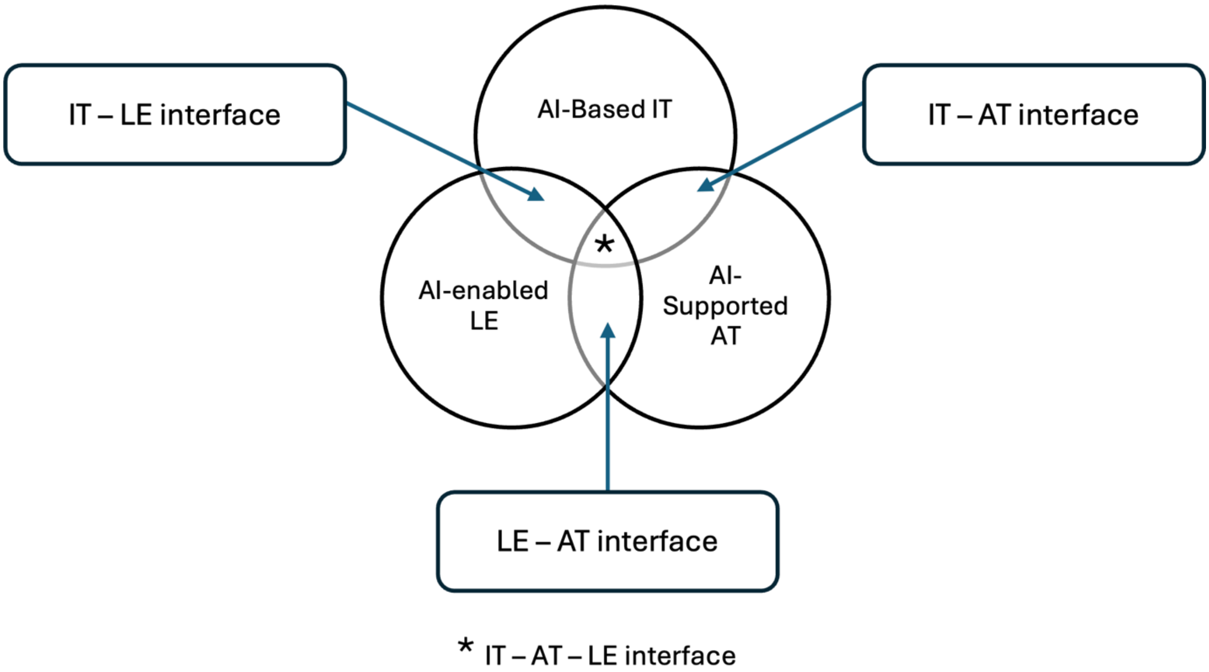

Figure 1 The model for classifying AI integration strategies in science education into instructional tools (IT), assessment tools (AT), and learning environments (LE). The model depicts each component considered independently and where different components interface.

Researchers suggest that AI-based instructional tools are educational resources and applications incorporating AI technologies to enhance teaching and learning (Celik, 2023; Chou et al., 2022). They are designed to provide interactive and dynamic learning experiences (Celik, 2023; Chou et al., 2022). These tools can range from virtual laboratories and simulations to Intelligent Tutoring Systems and adaptive learning platforms. AI-based instructional tools are developed to provide real-time feedback, personalized learning pathways, and adaptive assessments (Chou et al., 2022). They can be used to analyze student performance data and provide feedback based on individual learning needs, enhancing student engagement, motivation, and learning outcomes.

AI-enabled learning environments are designed to create immersive learning experiences by integrating AI technologies (Kashive et al., 2020; Mnguni, 2023). They are educational settings that leverage AI technologies to optimize the learning experience for students (Kashive et al., 2020). These environments can include virtual, augmented, and mixed-reality platforms, allowing students to explore and interact with scientific concepts in a virtual or augmented environment. AI-enabled learning environments provide hands-on, experiential learning opportunities and can facilitate a deep understanding of complex scientific concepts (Cope et al., 2021). They can also support collaborative learning and enable students to work on authentic scientific problems, leading to higher engagement and motivation.

AI-support assessment tools provide automated assessment and personalized student feedback (Hwang et al., 2020). AI-supported assessment refers to using AI technologies to enhance evaluation and feedback processes (Hwang et al., 2020). These systems use AI techniques, such as natural language processing, machine learning, and data analytics, to analyze student responses and provide feedback based on predefined criteria. AI-supported assessment systems can be used for formative and summative assessments, providing targeted feedback, identifying misconceptions, and supporting self-regulated learning. These systems can save teachers' time in grading and provide immediate feedback to students, leading to improved learning outcomes (Hwang et al., 2020).

The current trends in AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment in science education demonstrate the potential of AI to transform traditional teaching and learning practices. These trends emphasize the importance of leveraging AI to provide personalized, adaptive, and interactive learning experiences, which enhance student engagement, motivation, and learning outcomes. Integrating AI in science education also presents opportunities for more efficient and effective assessment and feedback processes and the creation of experiential learning environments. However, some related challenges in pedagogical practices must be addressed to fully harness AI's potential.

4.1. AI-based instructional tools and AI-enable learning environments in science education

Researchers (e.g., Table 1) have demonstrated the critical role of AI-based Instructional Tools in augmenting teaching by supporting teachers and learners to achieve improved learning outcomes. These tools redefine teaching and learning by seamlessly integrating technology to support teachers and learners. This augmentation promotes personalization, interactivity, and collaborative engagement, ultimately leading to enhanced learning outcomes and a reimagined educational experience.

For example, Adaptive Learning systems, powered by Intelligent Tutoring Systems, augment teaching by providing personalized instruction and real-time feedback tailored to individual students' needs. In this regard, teachers facilitate learning through AI-based Instructional Tools by designing and overseeing AI integration, while learners actively engage with adaptive content to enhance their understanding. Research (Akkila et al., 2017; Ma et al., 2014) demonstrates that such strategies improve learning outcomes and increase student engagement, setting a foundation for personalized education. Similarly, Automated Essay Scoring tools using Natural Language Processing augment efficiency in grading while supporting iterative skill development. Teachers enhance the process by providing contextual insights, while learners use AI-generated feedback to refine their work. Studies (Contreras et al., 2019) underscore the dual benefits of increased efficiency and enhanced learner autonomy. Immersive technologies such as Virtual and Augmented Reality have been shown to offer opportunities to explore complex concepts interactively (Tan & Waugh, 2013). In this instance, teachers guide these explorations by integrating them into lesson plans while learners actively participate, fostering deeper understanding and motivation (Delello, 2014; Tan & Waugh, 2013). Complementing this, Robotics-based learning, informed by Computer Vision, emphasizes practical STEM engagement, encouraging collaborative problem-solving and hands-on learning (Wawan et al., 2022). Other tools, such as Chatbots and Virtual Labs, support teaching and learning by promoting independent learning and safe experimental exploration while teachers ensure meaningful oversight while learners gain autonomy and engage with complex tasks in flexible environments (De Jong et al., 2014; Hwang & Chang, 2021).

4.2. AI supported assessment in science education

AI-supported assessment also plays a critical role in augmenting teaching by enhancing the evaluation of learning and the feedback processes (Table 2). These tools, driven by advanced AI strategies, integrate real-time data analysis, personalized feedback, and adaptive support, creating a dynamic assessment environment that supports teachers and learners in achieving improved outcomes.

Research shows that automated Essay Scoring and Automated Feedback, both utilizing Natural Language Processing, streamline evaluation and feedback processes. These tools offer immediate, actionable insights into writing and performance, enabling learners to iteratively refine their skills while teachers focus on nuanced guidance and deeper instructional tasks (Contreras et al., 2019; Zhu et al., 2020). The consistency and efficiency in grading improve the quality of assessment and promote self-regulated learning. Adaptive Assessment and Intelligent Tutoring Systems, powered by Machine Learning and Knowledge Tracing, personalize tasks and provide targeted scaffolding based on learners' progress. Teachers use insights from these systems to design tailored interventions, while learners engage actively with adaptive tools, fostering deeper understanding and autonomy. These approaches enhance motivation and mastery of knowledge (Ciolacu et al., 2018; Duffy & Azevedo, 2015). Peer Assessment and Learning Analytics complement automated processes by integrating human and AI insights. Data-driven peer evaluations and predictive analytics help students develop critical thinking and reflective skills while enabling early identification of at-risk learners. Teachers facilitate these processes, designing interventions and fostering engagement to improve outcomes (Bañeres et al., 2020; Darvishi et al., 2022).

While still under development, current research demonstrates that AI-supported assessments redefine traditional approaches by seamlessly integrating advanced technologies to enhance efficiency, personalize learning experiences, and foster greater engagement. By enabling teachers to focus on higher-order instructional tasks and empowering learners with real-time, actionable feedback, these tools promote a collaborative and adaptive learning ecosystem that drives improved educational outcomes and prepares students for future learning challenges.

4.3. AI supported assessment in science education

The literature further suggests that AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment tools can be integrated (Figure 1). For example, Intelligent Tutoring Systems can be embedded in Virtual Reality environments to provide personalized tutoring, allowing students to engage in immersive learning while receiving real-time feedback and adaptive instruction (Pharswan, 2022) (Table 3). Similarly, Automated Essay Scoring systems, coupled with intelligent feedback, can grade students' work and offer detailed, personalized insights on writing skills and content understanding, thus guiding further learning (Contreras et al., 2019; Sethi & Singh, 2022). Virtual Labs can also integrate capabilities for continuously monitoring and assessing students' activities, providing real-time feedback through learning analytics (Vozniuk et al., 2015). Comprehensive AI learning platforms can integrate different elements to offer a holistic learning experience, adapting to individual student needs and providing continuous assessment and engaging learning scenarios (Hsieh & Chen, 2019). These strategies demonstrate AI's potential to create dynamic, personalized, and effective educational experiences in science education.

Table 1 Summary of AI-based instructional tools for integrating AI in science education.

Strategy	Type of AI	Augmentation Strategies	Teacher's Role	Learner's Role	Reported Outcomes	Examples of literature
Adaptive Learning	Intelligent Tutoring Systems	Provides personalized instruction and real-time feedback tailored to individual needs, enhancing engagement and outcomes.	Designs and oversees AI integration provides supplemental guidance and monitors progress.	Actively engages with adaptive content and applies feedback to improve understanding.	Improved student learning outcomes, increased engagement, and personalized instruction. Customized learning experiences for individual students.	Akkila et al. (2017); Ma et al. (2014)
Automated Essay Scoring	Natural Language Processing	Enhances grading efficiency and consistency, provides immediate, actionable feedback, and supports writing skill development.	Reviews AI-generated feedback, offers contextual insights and addresses nuanced issues.	Utilizes feedback to revise and improve writing skills iteratively.	Efficient and consistent grading, feedback, and improved writing skills	Contreras et al. (2019); Sethi and Singh (2022)
Virtual and Augmented Reality	Virtual Reality (VR) and Augmented Reality (AR)	Creates immersive environments for exploring complex concepts interactively, fostering deeper understanding and motivation.	Facilitates exploration, contextualizes experiences, and integrates with broader lesson plans.	Actively participates in VR/AR simulations, exploring and constructing knowledge interactively.	Enhanced understanding of complex science concepts, increased motivation and engagement	Delello (2014); Tan and Waugh (2013)
Robotics	Computer Vision and Educational Robotics	Enables hands-on, interactive STEM activities, improving engagement and problem-solving skills through practical learning.	Guides robotic activities connects tasks to curriculum goals and encourages collaborative learning.	Engages in hands-on activities, experiments, and collaborative problem-solving with robotics.	Increased student interest and engagement in science activities; improved problem-solving skills, hands-on learning experiences, and increased interest in science.	Wawan et al. (2022).
Chatbots	Natural Language Processing	Offers real-time, personalized assistance, answering queries, and promoting independent learning.	Provides oversight on chatbot content, clarifies complex topics, and encourages inquiry.	Seeks support from chatbots for clarification and feedback, promoting self-directed learning.	Personalized assistance, increased engagement, self-directed learning, and learning outcomes.	Hwang & Chang (2021).
Virtual Labs	Machine Learning	Simulates laboratory experiments, offering a safe, flexible exploration of scientific principles and processes.	Designs experiments, contextualizes lab activities and interprets results alongside students.	Actively performs virtual experiments, analyzes results, and applies concepts to problem-solving.	Increased student understanding of complex concepts	De Jong et al. (2014)

Gamification	Reinforcement Learning	Rewards progress through game-like elements, enhancing motivation, engagement, and persistence in tasks.	Sets goals, monitors learner progress and integrates gamified tasks with broader learning objectives.	Completes gamified challenges, earns rewards, and stays motivated to achieve learning goals.	Improved student motivation and interest in STEM subjects	Chans and Portuguez Castro (2021)
Simulations	Expert Systems	Creates virtual problem-solving scenarios, allowing students to explore and apply concepts in realistic settings.	Facilitates simulation use, provides scaffolding for problem-solving, and interprets outcomes.	Engages in simulations, experimenting with different solutions and learning from outcomes.	Improved student problem-solving skills.	Avramiotis and Tsaparlis (2013); Ceberio et al. (2016)
Data Analytics	Neural Networks	Analyzes student performance data for personalized feedback, progress tracking, and targeted interventions.	Uses analytics to identify student needs, adjust teaching strategies, and provide timely support.	Responds to personalized interventions, tracks progress, and reflects on learning patterns.	Improved student understanding of experimental data analysis.	Lau et al. (2019)

Table 2 Examples of AI-supported assessment in science education enhance the assessment of learning and feedback processes.

Strategy	Type of AI	Augmentation Strategies	Teacher's Role	Learner's Role	Reported Outcomes	Examples of literature
Automated Essay Scoring	Natural Language Processing	Evaluates and grades essays consistently, providing immediate feedback on writing quality and content.	Monitor AI outputs, provide supplementary feedback, and address nuanced issues.	Review feedback to improve writing and critical thinking skills.	Efficient and consistent grading, feedback, and improved writing skills	Contreras et al. (2019); Sethi and Singh (2022)
Adaptive Assessment	Machine Learning	Personalizes assessments to individual learning levels, adjusting difficulty based on student performance.	Interpret AI-driven insights to tailor instructional strategies.	Engage with adaptive tasks and reflect on feedback to guide self-paced learning.	Improved personalization and adaptivity in assessment tasks based on individual students' learning needs and performance. Enhanced engagement and motivation in students towards learning.	Ciolacu et al. (2018)
Automated Feedback	Natural Language Processing	Offers immediate, personalized feedback on tasks, enabling self-regulated learning and knowledge enhancement.	Ensure alignment of feedback with learning objectives and provide clarification.	Actively apply feedback to improve performance and deepen understanding.	Immediate and personalized feedback to students, facilitating self-regulated learning and promoting deeper understanding.	Zhu et al. (2020).
Peer Assessment	Data Analytics	Enhances the quality and reliability of peer feedback through	Facilitate peer assessment processes and encourage	Provide thoughtful feedback and	Improved critical thinking and evaluative skills in students. Increased engagement and active	Darvishi et al. (2022)

		data-driven insights on performance and trends.	reflective discussions.	learn through peer interactions.	participation in the assessment process.	
Automated Grading	Computer Vision	Speeds up grading of assignments, especially for objective tasks, reducing teacher workload.	Validate AI-generated grades and focus on higher-order instructional tasks.	Review grades and seek clarification on automated feedback if needed.	Faster and more efficient grading process with reduced grading workload for teachers. Enhanced feedback delivery and formative assessment opportunities.	Patole et al. (2016).
Learning Analytics	Predictive Analytics	Identifies at-risk students and trends in learning behaviors, enabling targeted interventions.	Use analytics to design interventions and support individualized learning plans.	Reflect on analytics-based feedback to enhance engagement and achievement.	Early identification of at-risk students and personalized interventions to improve learning outcomes. Improved student engagement, retention, and academic performance.	Bañeres et al. (2020)
Intelligent Tutoring System	Knowledge Tracing	Provides real-time, adaptive support and scaffolding based on learners' progress and knowledge state.	Guide learners in using tutoring systems and supplement automated instruction.	Engage actively with the system to build understanding and autonomy.	Adaptive support and feedback to students based on their knowledge state improved student learning outcomes and mastery of knowledge, enhancing student motivation and engagement in the learning process.	Duffy and Azevedo (2015)

Table 3 Interfacing instructional tools, assessment tools, and learning environments.

Interface	Examples of AI Strategies	Augmentation Strategies	Teacher's Role	Learner's Role	Examples of literature
AI-based Instructional Tools + AI-enabled Learning Environments	Intelligent Tutoring Systems in Virtual Reality provide personalized tutoring in a VR environment, enabling immersive learning and adaptive feedback.	Facilitates engagement through immersive, interactive scenarios while offering real-time feedback tailored to individual needs.	Acts as a guide, monitors progress, and supports students' cognitive and emotional development.	Actively participates in immersive learning experiences and applies real-time feedback to enhance understanding.	Pharswan (2022)
AI-based Instructional Tools + AI-supported Assessment Tools	Automated Essay Scoring with Intelligent Feedback grades work and provides detailed, personalized feedback on writing and content understanding.	Enhances formative and summative assessment processes, saving time for more focused instruction.	Facilitates discussions on AI-provided feedback and supports learners' skill improvement.	Reviews AI feedback to refine their skills, engages in self-directed learning to address gaps.	Contreras et al. (2019), Sethi and Singh (2022)
AI-enabled Learning Environments + AI-	In Virtual Labs with Learning Analytics, AI continuously monitors and assesses student	Creates a safe, exploratory learning environment while analyzing progress	Guides scientific inquiry clarifies concepts and supports	Engages in hands-on experimentation and applies feedback to	Vozniuk et al. (2015)

supported Assessment Tools	progress, providing real-time feedback and insights.	and identifying learning obstacles.	experimentation through mentorship.	improve scientific reasoning and skills.	
AI-based Instructional Tools + AI-enabled Learning Environments + AI-supported Assessment Tools	Comprehensive AI Learning Platforms integrate tools, environments, and assessments, adapting to students' needs and offering continuous learning and feedback.	Coordinates the use of the platform, interprets analytics, and personalizes interventions based on student needs.	Collaborates with the AI system, actively engages in learning, and reflects on progress.		Hsieh and Chen (2019)

5. Understanding the Current Trends

Current literature demonstrates a transformation in science education driven by the adoption of AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment tools. This evolution marks a shift from traditional methods relying on lectures, chalkboards, and printed materials to digital, AI-supported approaches. The unique AI capabilities driving this evolution are that AI technologies offer personalized and adaptive learning experiences, immersive environments, and efficient assessment methods, enhancing student engagement, motivation, and learning outcomes while addressing educational challenges and promoting critical thinking and self-directed learning.

5.1. AI as a teaching augmentor

There is evidence of growing trends where AI facilitates interactions between the teacher and student, the learning materials and student, and the learning environment and students. In this sense, AI's role can be defined as a learning facilitator. This observation has critical implications for teachers, whose roles in the era of constructivism, inquiry-based learning, and learner-centered learning have primarily been that of learning facilitators (Jagtap, 2016). However, teachers are limited in facilitating learning as they cannot provide personalized learning, real-time and immediate analytics, and feedback. They also experience bias, subjectivity, fatigue, and burnout, affecting students' academic achievement (Madigan et al., 2023). Consequently, AI is emerging as an alternative learning facilitator by addressing these teacher limitations, suggesting a need to rethink the role of the teacher. AI tools can support teachers by reducing the administrative burden, allowing them to focus more on mentoring and supporting students' cognitive and emotional needs (Zawacki-Richter et al., 2019). AI can also support learners by offering personalized learning based on individual student learning needs and real-time analytics (Luckin & Holmes, 2016). In this sense, AI is a Teaching Augmentor designed to enhance and support teachers by providing AI-based instructional tools, creating AI-enabled learning environments, and offering AI-supported assessment tools, facilitating personalized learning, real-time feedback, and adaptive teaching strategies.

The growing adoption of AI may also be attributed to the knowledge explosion over the last century when teachers and traditional learning methods struggled to keep pace with rapid knowledge generation. Consequently, relying solely on traditional learning methods that use printed learning materials may hinder learners' ability to access the most current information. These traditional methods have also been cited for fostering cognitive overload, leading to poor academic achievement (Chang & Ley, 2006). However, printed learning materials such as textbooks remain essential in science education by providing reference guides and structured instructional frameworks (Lau et al., 2018). Therefore, integrating AI does not necessitate the abandonment of printed materials. Instead, AI should augment these tools by providing real-time updates and personalized learning experiences. For instance, AI can supplement textbooks with interactive content and up-to-date information, ensuring learners engage with the latest scientific discoveries (Yang et al., 2023). This approach allows teachers to focus more on facilitating critical thinking and problem-solving skills rather than solely delivering content. Therefore, augmenting traditional learning materials with AI creates a more dynamic and responsive learning environment that supports current knowledge acquisition and the enduring value of structured learning frameworks.

Literature suggests that AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment tools generally improve learning outcomes compared to traditional methods. This improvement is primarily due to AI's ability to offer personalized learning experiences tailored to individual students' preferences and needs (Yang et al., 2023). AI provides immediate feedback and sophisticated data analytics, enabling adaptive learning paths and targeted interventions (Luckin & Holmes, 2016). Despite these benefits, the essential human interaction between teachers and learners, which includes offering affective and moral support, cannot be replaced by AI (Ruzek et al., 2016). Human teachers play a crucial role in motivating students, addressing their emotional needs, and fostering a supportive learning environment, aspects that AI cannot replicate. Therefore, while AI enhances learning outcomes, it should not replace teachers. Instead, AI can serve as a Teaching Augmentor, supporting teachers by handling routine tasks and providing insights, thus allowing them to focus more on student engagement and personalized instruction (Williamson & Eynon, 2020). Integrating AI in education should be viewed as a way to augment, rather than replace, the vital role of teachers for maximum learner benefit.

5.2. Implications for teacher training and scienc teaching

The current trends in the integration of AI in science teaching have several implications for teacher training and science teaching. Institutions for teacher training may need to revise their curricula to integrate the emerging role of AI as a Teaching Augmentor. This involves incorporating technical training on AI tools and redefining the role of teachers, acknowledging that AI is assuming some of their traditional responsibilities. Training programs focusing on effective strategies for augmenting teaching with AI are also essential. These programs should use AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment methods to enhance teaching practices and improve student learning outcomes (Mnguni, 2024). Teachers should also be trained to leverage AI to foster teamwork, problem-solving, and critical thinking skills among students (Zawacki-Richter et al., 2019). This training should emphasize how AI can support instructional strategies, allowing teachers to focus more on mentoring and engaging with students personally (Yang et al., 2023). Moreover, science education curricula must be updated to include AI literacy, ensuring that teachers and students are proficient with AI technologies and their applications. This includes developing pedagogical strategies integrating AI to facilitate personalized and adaptive learning (Luckin & Holmes, 2016). Ongoing professional development is also critical. Institutions should provide continuous support through workshops, seminars, and online courses to keep teachers updated on AI advancements and pedagogical strategies. This ensures that educators can effectively integrate AI into their teaching practices over time, fully harnessing its potential to enhance student learning outcomes.

6. Future Perspectives

The integration of AI in science education as a teaching augmentor presents promising avenues for future research and practical implementation. However, the current literature remains largely exploratory, necessitating more nuanced investigations into context-specific applications and long-term outcomes. One key direction for expansion involves examining the pedagogical implications of AI as a teaching augmentor across different scientific domains and educational levels. For instance, how AI supports inquiry-based learning in physics may differ significantly from its role in conceptual understanding in biology. Such specificity remains underexplored and warrants detailed investigation (Mnguni et al., 2024).

Practically, the current review suggests a need for comprehensive professional development frameworks that empower educators to implement AI tools effectively. In this regard, teacher training programs should focus on technical skills and pedagogical strategies for integrating AI in ways that align with curriculum goals and learner diversity (Luckin & Holmes, 2016). Nonetheless, infrastructural disparities, ethical concerns, and institutional resistance pose significant challenges to widespread adoption and require adequate policy developments to enable the effective integration of AI in science education.

Methodologically, future research would benefit from mixed-methods approaches, combining the statistical rigor of quantitative studies with the depth of qualitative inquiry to capture the complex dynamics of AI-mediated learning environments. Additionally, advances in machine learning and adaptive technologies offer opportunities to design more personalized and responsive educational interventions (Zawacki-Richter et al., 2019). These developments also underscore the necessity for interdisciplinary collaborations between science education, cognitive science, data analytics, and ethics, to ensure that AI applications are pedagogically sound, equitable, and contextually appropriate (Kiemde & Kora, 2022).

Therefore, while the current study lays a foundational understanding, future research must move beyond descriptive overviews to critical, context-sensitive analyses that address both the potential and pitfalls of AI in science education. Such work is essential to develop robust, scalable, and ethically informed AI-enhanced learning ecosystems.

7. Final Considerations

The trends reported in this manuscript highlight the potential of AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment to augment teaching in science education. These technologies offer personalized and adaptive instruction opportunities, immersive and interactive learning experiences, and timely feedback, which can enhance student engagement, motivation, and learning outcomes. While the benefits of AI integration in science education are evident, there are still opportunities for future research. Further studies are needed to examine the impact of specific AI tools and techniques on student engagement, motivation, and achievement in science. Such research should also consider specific challenges and opportunities, such as those faced in developing countries.

Furthermore, the potential of AI in supporting personalized and adaptive learning requires exploration and addressing the ethical, legal, and social implications of AI integration. Additionally, investigating the role of AI in promoting interdisciplinary and collaborative learning can contribute to developing evidence-based guidelines and best practices. Based on the current trends, integrating AI in science education is promising to improve teaching, learning, and assessment practices. By leveraging AI-based instructional tools, AI-enabled learning environments, and AI-supported assessment approaches, educators can enhance student engagement, motivation, and learning outcomes in science education. Continued research and exploration in this field will further advance the integration of AI and contribute to evidence-based guidelines, fostering the development of effective AI-driven practices in science education.

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Ethical Considerations

Not applicable.

Conflict of Interest

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References

Ahmad, D., Latif, I., Arafah, B., & Suryadi, R. (2024). Defining the Role of Artificial Intelligence in Improving English Writing Skills Among Indonesian Students. *Journal of Language Teaching and Research, 15*(2), 568-678. https://doi.org/10.17507/jltr.1502.25

Akkila, A. N., Almasri, A., Ahmed, A., Al-Masri, N., Abu Sultan, Y. S., Mahmoud, A. Y., Zaqout, I., & Abu-Naser, S. S. (2017). Survey of Intelligent Tutoring Systems up to the end of 2017. *International Journal of Academic Information Systems Research, 3*(4), 36 – 49.

Aripin, I., Gaffar, A. A., Jabar, M. B. A., & Yulianti, D. (2024). Artificial intelligence in biology and learning biology: A literature review. *Jurnal Mangifera Edu, 8*(2), 41-48. https://doi.org/10.31943/mangiferaedu.v8i2.185

Avramiotis, S., & Tsaparlis, G. (2013). Using Computer Simulations in Chemistry Problem-Solving. *Chemistry Education Research and Practice, 14*(3), 297–311. https://doi.org/10.1039/C3RP20167H

Bañeres, D., Rodríguez, M. E., Guerrero-Roldán, A. E., & Karadeniz, A. (2020). An early warning system to detect at-risk students in online higher education. *Applied Sciences (Basel, Switzerland), 10*(13), 4427. https://doi.org/10.3390/app10134427

Ceberio, M., Almudí, J. M., & Franco, Á. (2016). Design and application of interactive simulations in problem-solving in university-level physics education. *Journal of Science Education and Technology, 25*(4), 590–609. https://doi.org/10.1007/s10956-016-9615-7

Celik, I. (2023). Towards Intelligent-TPACK: An empirical study on teachers' professional knowledge to ethically integrate artificial Intelligence (AI)-based tools into education. *Computers in Human Behavior, 138*(107468), 107468. https://doi.org/10.1016/j.chb.2022.107468

Chang, S. L., & Ley, K. (2006). A learning strategy to compensate for cognitive overload in online learning: Learner use of printed online materials. *Journal of Interactive Online Learning, 5*(1), 104-117.

Chans, G. M., & Portuguez Castro, M. (2021). Gamification as a strategy to increase motivation and engagement in higher education chemistry students. *Computers, 10*(10), 132. https://doi.org/10.3390/computers10100132

Chou, C.-M., Shen, T.-C., Shen, T.-C., & Shen, C.-H. (2022). Influencing factors on students' learning effectiveness of AI-based technology application: Mediation variable of the human-computer interaction experience. *Education and Information Technologies, 27*(6), 8723–8750. https://doi.org/10.1007/s10639-021-10866-9

Ciolacu, M., Tehrani, A. F., Binder, L., & Svasta, P. M. (2018). Education 4.0-Artificial Intelligence Assisted Higher Education: Early Recognition System with Machine Learning to Support Students' Success. In 2018 IEEE 24th International Symposium for Design and Technology in Electronic Packaging(SIITME) (pp. 23–30). *IEEE*. http://doi.org/10.1109/SIITME.2018.8599203

Contreras, J. O., Hilles, S., & Abubakar, Z. B. (2019). Automated essay scoring using ontology generator and natural language processing with question generator based on Bloom's taxonomy's cognitive level. *International Journal of Engineering and Advanced Technology, 2019*(1), 2448–2457. http://doi.org/10.35940/ijeat.A9974.109119

Cope, B., Kalantzis, M., & Searsmith, D. (2021). Artificial Intelligence for education: Knowledge and its assessment in AI-enabled learning ecologies. *Educational Philosophy and Theory, 53*(12), 1229–1245. https://doi.org/10.1080/00131857.2020.1728732

Crompton, H., & Burke, D. (2023). Artificial Intelligence in higher education: the state of the field. *International Journal of Educational Technology in Higher Education, 20*(1), 1-22. https://doi.org/10.1186/s41239-023-00392-8

Darvishi, A., Khosravi, H., Sadiq, S., & Gašević, D. (2022). Incorporating AI and Learning Analytics to Build Trustworthy Peer Assessment Systems. *British Journal of Educational Technology, 53*(4), 844–875. https://doi.org/10.1111/bjet.13233

De Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: the Go-Lab federation of online labs. *Smart Learning Environments, 1*(3), 1-16. https://doi.org/10.1186/s40561-014-0003-6

Delello, J. A. (2014). Insights from pre-service teachers using science-based augmented reality. *Journal of Computers in Education, 1*(4), 295–311. https://doi.org/10.1007/s40692-014-0021-y

Duffy, M. C., & Azevedo, R. (2015). Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system. *Computers in Human Behavior, 52*, 338–348. https://doi.org/10.1016/j.chb.2015.05.041

Hasanah, A., & Budiyono, S. (2024). Pemanfaatan Model Pembelajaran Futuristik Berbasis Artificial Intelligence (AI) dalam Dunia Pendidikan. *Al-DYAS, 3*(2), 615–625. https://doi.org/10.58578/aldyas.v3i2.2880

Hsieh, M. C., & Chen, S. H. (2019). Intelligence augmented reality tutoring system for mathematics teaching and learning. *Journal of Internet Technology, 20*(5), 1673-1681.

Huang, X. (2021). Aims for cultivating students' key competencies based on artificial intelligence education in China. *Education and Information Technologies, 26*(5), 5127–5147. https://doi.org/10.1007/s10639-021-10530-2

Hwang, G.-J., & Chang, C.-Y. (2021). A review of opportunities and challenges of chatbots in education. *Interactive Learning Environments, 31*(7), 1–14. https://doi.org/10.1080/10494820.2021.1952615

Hwang, G.-J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence, 1(*100001), 1-5. https://doi.org/10.1016/j.caeai.2020.100001

Jagtap, P. (2016). Teachers role as facilitator in learning. *Scholarly Research Journal, 3*(17), 3903–3905.

Jendia, J., & Ismail, H. H. (2023). Developing personalized reading materials for Malaysian primary school pupils using ChatGPT: A review. *International Journal of Academic Research in Business and Social Sciences, 13*(12), 3174-3189. https://doi.org/10.6007/ijarbss/v13-i12/20172

Kashive, N., Powale, L., & Kashive, K. (2020). Understanding user perception toward artificial Intelligence (AI) enabled e-learning. *International Journal of Information and Learning Technology, 38*(1), 1–19. https://doi.org/10.1108/ijilt-05-2020-0090

Khan, M. A., Khojah, M., & Vivek. (2022). Artificial Intelligence and Big Data: The Advent of New Pedagogy in the Adaptive E - Learning System in the Higher Educational Institutions of Saudi Arabia. *Education Research International, 2022*(1), 1263555. https://doi.org/10.1155/2022/1263555

Kiemde, S. M. A., & Kora, A. D. (2022). Towards an ethics of AI in Africa: rule of education. *AI and Ethics, 2*(1), 35–40. https://doi.org/10.1007/s43681-021-00106-8

Lau, E. T., Sun, L., & Yang, Q. (2019). Modeling, prediction, and classification of student academic performance using artificial neural networks. *SN Applied Sciences, 1*(982), 1-10. https://doi.org/10.1007/s42452-019-0884-7

Lau, K. H., Lam, T., Kam, B. H., Nkhoma, M., Richardson, J., & Thomas, S. (2018). The role of textbook learning resources in e-learning: A taxonomic study. *Computers & Education, 118*, 10–24. https://doi.org/10.1016/j.compedu.2017.11.005

Luckin, R., & Holmes, W. (2016). *Intelligence Unleashed*: An Argument for AI in Education. London: Pearson.

Ma, W., Adesope, O. O., Nesbit, J. C., & Liu, Q. (2014). Intelligent tutoring systems and learning outcomes: A meta-analysis. *Journal of Educational Psychology, 106(*4), 901–918. https://doi.org/10.1037/a0037123

Madigan, D. J., Kim, L. E., Glandorf, H. L., & Kavanagh, O. (2023). Teacher burnout and physical health: A systematic review. *International Journal of Educational Research, 119*(102173), 1-12. https://doi.org/10.1016/j.ijer.2023.102173

McCarthy, J., Minsky, M. L., Rochester, N., & Shannon, C. E. (2006). A proposal for the Dartmouth summer research project on artificial intelligence, August 31, 1955. *AI Magazine, 27*(4), 12-12. https://doi.org/10.1609/aimag.v27i4.1904

Mnguni, L. (2023). A critical reflection on the affordances of Web 3.0 and artificial intelligence in life sciences education. *Journal of Pedagogical Sociology and Psychology, 5*(2), 1-9. https://doi.org/10.33902/jpsp.202322298

Mnguni, L. (2025). A qualitative analysis of South African pre-service Life Science teachers' behavioral intentions for integrating AI in teaching. *Journal for STEM Education Research, 8*(1), 230-256. https://doi.org/10.1007/s41979-024-00128-x

Mnguni, L., Nuangchalerm, P., El Islami, R. A. Z., Sibanda, D., Sari, I. J., & Ramulumo, M. (2024). The behavioural intentions for integrating artificial intelligence in science teaching among pre-service science teachers in South Africa and Thailand. *Computers and Education: Artificial Intelligence, 7*(100334), 1-12. https://doi.org/10.1016/j.caeai.2024.100334

Mu, C. (2023). Research on talents cultivation model of application-oriented undergraduate in the era of AI. In Proceedings of the 4th International Conference on Modern Education and Information Management, *ICMEIM 2023* (pp. 190-198). Wuhan, China. https://doi.org/10.4108/eai.8-9-2023.2339997

Ning, Y., Zhang, C., Xu, B., Zhou, Y., & Wijaya, T. T. (2024). Teachers' AI-TPACK: Exploring the relationship between knowledge elements. *Sustainability, 16*(3), 978. https://doi.org/10.3390/su16030978

Nja, C. O., Idiege, K. J., Uwe, U. E., Meremikwu, A. N., Ekon, E. E., Erim, C. M., Ukah, J. U., Eyo, E. O., Anari, M. I., & Cornelius-Ukpepi, B. U. (2023). Adoption of artificial intelligence in science teaching: From the vantage point of the African science teachers. *Smart Learning Environments, 10*(42), 1-19. https://doi.org/10.1186/s40561-023-00261-x

Nkambou, R., Bourdeau, J., & Mizoguchi, R. (2010). Introduction: What are intelligent tutoring systems, and why this book? In R. Nkambou, J. Bourdeau, & R. Mizoguchi (Eds.), Advances in Intelligent Tutoring Systems (pp. 1–12). *Springer*. https://doi.org/10.1007/978-3-642-14363-2_1

Opesemowo, O. A. G., & Adekomaya, V. (2024). Harnessing artificial intelligence for advancing Sustainable Development Goals in South Africa's higher education system: A qualitative study. *International Journal of Learning Teaching and Educational Research, 23*(3), 67–86. https://doi.org/10.26803/ijlter.23.3.4

Osasona, F., Daraojimba, A. I., Atadoga, A., Onwusinkwue, S., Obi, O. C., & Dawodu, S. O. (2024). Ai integration in Business Analytics: A review of USA and African trends. *Computer Science & IT Research Journal, 5*(2), 432–446. https://doi.org/10.51594/csitrj.v5i2.793

Patole, S., Pawar, A., Patel, A., Panchal, A., & Joshi, R. (2016). Automatic system for grading multiple choice questions and feedback analysis. *International Journal of Technical Research and Applications,* 3(39), 16–19.

Pharswan, H. (2022*). Intelligent tutoring in a VR classroom (Master's thesis*). Rochester Institute of Technology, NY 14623, Estados Unidos.

Ragheb, M. A., Tantawi, P., Farouk, N., & Hatata, A. (2022). Investigating the acceptance of applying chatbot (Artificial intelligence) technology among higher education students in Egypt. *International Journal of Higher Education Management, 8*(2), 1-13. https://doi.org/10.24052/ijhem/v08n02/art-1

Ruzek, E. A., Hafen, C. A., Allen, J. P., Gregory, A., Mikami, A. Y., & Pianta, R. C. (2016). How teacher emotional support motivates students: The mediating roles of perceived peer relatedness, autonomy support, and competence. *Learning and Instruction, 42*, 95-103. https://doi.org/10.1016/j.learninstruc.2016.01.004

Selwyn, N. (2019). *Should robots replace teachers?*: AI and the future of education. John Wiley & Sons.

Sethi, A., & Singh, K. (2022). Natural language processing-based automated essay scoring with parameter-efficient transformer approach. Proceedings of the 6th International Conference on Computing Methodologies and Communication (*ICCMC), Erode, India, 6*(1), 749–756. https://doi.org/10.1109/ICCMC53470.2022.9753760

Strzelecki, A., & ElArabawy, S. (2024). Investigation of the moderation effect of gender and study level on the acceptance and use of generative AI by higher education students: Comparative evidence from Poland and Egypt. *British Journal of Educational Technology, 55*(3), 1209–1230. https://doi.org/10.1111/bjet.13425

Tan, S., & Waugh, R. (2013). Use of Virtual Reality in teaching and learning molecular biology. In Y. Cai (Ed.), 3D immersive and interactive learning (pp. 17–43). *Springer*. https://doi.org/10.1007/978-981-4021-90-6_2

Vozniuk, A., Rodríguez-Triana, M. J., Holzer, A., Govaerts, S., Sandoz, D., & Gillet, D. (2015, June). Contextual learning analytics apps to create awareness in blended inquiry learning. In Proceedings of the International Conference on Information Technology Based Higher Education and Training (ITHET) (pp. 1-5). *IEEE*. https://doi.org/10.1109/ITHET.2015.7218029

Wannapiroon, N., & Pimdee, P. (2022). Thai Undergraduate Science, Technology, Engineering, Arts, and Math (STEAM) creative thinking and innovation skill development: a conceptual model using a digital virtual classroom learning environment. *Education and Information Technologies, 27*(4), 5689–5716. https://doi.org/10.1007/s10639-021-10849-w

Wawan, C., Fenyvesi, K., Lathifah, A., & Ari, R. (2022). Computational thinking development: Benefiting from educational robotics in STEM teaching. *European Journal of Educational Research, 11*(4), 1997–2012. https://doi.org/10.12973/eu-jer.11.4.1997

Williamson, B., & Eynon, R. (2020). Historical threads, missing links, and future directions in AI in education. *Learning, Media and Technology, 45*(3), 223–235. https://doi.org/10.1080/17439884.2020.1798995

Yang, H., Kim, J., & Lee, W. (2023). Analyzing the alignment between AI curriculum and AI textbooks through text mining. *Applied Sciences, 13*(18), 10011. https://doi.org/10.3390/app131810011

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, 16*(39), 1-27. https://doi.org/10.1186/s41239-019-0171-0

Zhu, M., Liu, O. L., & Lee, H. S. (2020). Using cluster analysis to explore students' interactions with automated feedback in an online Earth science task. *International Journal of Quantitative Research in Education, 5*(2), 111–135. https://doi.org/10.1504/IJQRE.2020.111452