International Journal of Science Education and Teaching
Vol. 4, No. 3, pp. 158-177, Sep. – Dec. 2025
http://doi.org/10.14456/ijset.2025.11

Academic Article

Strategies for Utilizing AI Technology to Enhance Science Learning Management within the STEM Education Approach

Phongsak Phakamach[1*], Pinya Sukwiphat[2], Songdet Sonjai[3], Natchaya Sommartdejsakul[4] and Ritthidech Phomdee[4]
[1]*Rattanakosin International College of Creative Entrepreneurship, Rajamangala University of Technology Rattanakosin, Thailand*
[2]*Thatphanom College, Nakhon Phanom University, Thailand*
[3]*Faculty of Education, Pitchayabundit College, Thailand*
[4]*Advanced Future Talent Academy (AFTA), Thailand*
*Email: phongsak.pha@rmutr.ac.th

Received: 29 May. 2025 Revised: 24 Sep. 2025 Accepted: 25 Sep. 2025

Abstract. The integration of Artificial Intelligence (AI) to enhance science learning within the STEM education approach is a significant advancement with the potential to revolutionize education. This paper explores four main strategies for utilizing AI: personalized learning, creating experiential learning environments, enhancing management and assessment efficiency, and fostering future skills. These strategies focus on adapting content to individual learners through intelligent tutoring systems, leveraging AI-powered virtual labs and simulations for realistic hands-on learning, using AI to reduce teachers' administrative burdens via automated assessment and deep learning analytics, and developing essential computational thinking and AI literacy for the 21st century. However, implementing AI in education presents significant challenges, including a lack of personnel knowledge and skills, infrastructure and budgetary constraints, and issues related to ethics, privacy, and data security. Furthermore, potential negative impacts include increased educational inequality if technology access is uneven, and the risk that over-reliance on AI might diminish students' critical thinking skills. To maximize the benefits of AI integration and mitigate these risks, this paper recommends crucial approaches. These include substantial investment in professional development, meticulous planning of infrastructure and policies concerning data usage and ethics, promoting continuous research and evaluation, and fostering collaboration among all stakeholders. Comprehensive implementation of these recommendations will enable educational institutions to fully harness AI's potential, creating high-quality and sustainable STEM learning for youth in the digital education era. While AI offers strategies to enhance STEM learning, its successful integration requires overcoming challenges like skill gaps and ethical concerns through professional development, careful planning, and stakeholder collaboration to create high-quality, sustainable education.

Keywords: AI Technology; Science Learning Management; STEM Education; Digital Education

INTRODUCTION

In the 21st century, technological advancements are rapidly and ceaselessly progressing, particularly with the advent of Artificial Intelligence (AI). AI has revolutionized our lives, work, and learning in unprecedented ways (Sposato, 2025). Within the educational context, AI holds immense potential to transform learning management, especially in Science, Technology, Engineering, and Mathematics (STEM) education, which forms the crucial foundation for driving national innovation and development (Vodenko & Lyausheva, 2020; Phakamach, 2023). Zhan et al. (2022) argued that STEM learning is not merely about memorizing scientific facts or mathematical formulas; it promotes critical thinking, problem-solving, creativity, and collaboration. Therefore, integrating AI into the management of science learning within a STEM framework is not just an option but an urgent necessity. This integration is vital to equip learners with the essential skills and competencies needed to navigate the challenges of a future world increasingly driven by rapidly changing and unpredictable technology (Kang, 2023; Jafari & Keykha, 2024). Modern STEM education must adapt to these shifts, and AI is key to making learning more effective and accessible for everyone, as well as inspiring students to explore the world of science with greater enthusiasm and deeper understanding. This article will provide an overview of strategies for using AI to enhance science learning within a STEM approach, which will help students develop their full potential and be ready to pursue in-demand STEM careers in the future (Cook & Cook, 2024; Payadnya et al., 2025).

AI offers unprecedented opportunities to enhance the efficiency and effectiveness of science learning management within the STEM approach. STEM learning often faces several limitations, such as restricted access to resources, a scarcity of expensive laboratory equipment, and the challenge of presenting complex concepts simply to diverse learners. AI can bridge these gaps by creating immersive, flexible, and adaptable learning environments tailored to the needs of each individual student (Abdekhoda & Dehnad, 2024; Mariyono & Nur Alif Hd, 2025). This includes utilizing AI to create Virtual Labs, where students can conduct experiments without geographical or equipment constraints, or simulating unseen scientific phenomena, such as the movement of electrons in an atom, the functioning of nerve cells, or the interaction of molecules in chemical reactions, to help students visualize and grasp abstract concepts more easily and deeply. These simulations not only enhance understanding but also significantly reduce the risks associated with real experiments and save enormous resources. Furthermore, Intelligent Tutoring Systems (ITS) powered by AI can provide immediate feedback and guidance customized to each student's comprehension level, accurately identifying their strengths, weaknesses, and knowledge gaps. This makes learning more efficient and targeted. ITS can automatically adjust the difficulty of questions, explain additional concepts, or even suggest supplementary learning resources appropriate for each student, helping them progress at their own pace and receive necessary support at every step. AI also enables educators to conduct detailed analyses of student learning data, from classroom engagement patterns and time spent on exercises to frequently made errors and their potential causes (Kang, 2023; Payadnya et al., 2025). These insights empower teachers to identify students who may be struggling, design appropriate learning activities, and provide targeted support, such as grouping students for remedial activities, offering supplementary instruction, or recommending specific additional learning resources (Weinhandl et al., 2020). This leads to more significant and sustainable improvements in students' science and STEM learning outcomes. Moreover, AI-driven data analysis can help curriculum developers and educational administrators evaluate the effectiveness of curricula and learning materials to improve and adapt them to meet the changing needs of students and the educational context (Cook & Cook, 2024; Bilal et al., 2025).

Therefore, the strategy for leveraging AI to enhance science learning management within the STEM education framework must focus on integrating AI technology into every dimension of the learning process, from curriculum design and instructional management to assessment and continuous improvement (Mudkanna Gavhane & Pagare, 2024). The core idea is to view AI not merely as a supplementary tool, but as an integral part of a learning ecosystem that fosters higher-order thinking skills, creative problem-solving, and collaboration (Payadnya et al., 2025). Abdekhoda and Dehnad (2024) has conducted research and found that applying AI in STEM education will not only deepen students' understanding of scientific content but also cultivate essential skills for becoming innovative thinkers, creators, and qualified citizens in the digital education era, such as computational thinking, which is the foundation for understanding and solving

problems with computers and algorithms; data analysis skills, essential for interpreting quantitative and qualitative information in a data-rich world; and technological literacy, which includes understanding AI's potential and limitations, as well as its ethical and responsible use. Alsobeh and Woodward (2024) and Retno et al. (2025) have presented an AI integration also promotes project-based learning and inquiry-based learning, which are at the heart of STEM education, allowing students to engage in hands-on activities, create, and solve complex problems independently, working with AI as an intelligent assistant for data collection, analysis, or simulation. Furthermore, learning alongside AI helps foster adaptability and resilience, which are crucial in a rapidly changing world. Students will learn to work with new technologies and adapt to diverse tools and learning methods. Investing in the strategic development and systematic, thoughtful implementation of AI in STEM education is therefore a critical step in building a strong foundation for the nation's future, enabling youth to be leaders in science and technology and to apply their knowledge and skills to innovate and solve societal problems effectively and sustainably, thereby creating a truly knowledge-driven and innovative society in the AI era (Narayanan, 2023; Cook & Cook, 2024; Payadnya et al., 2025).

In summary, AI is transforming education, particularly in STEM fields, by providing essential tools for national development. Integrating AI into science learning is crucial to equip students with critical thinking, problem-solving, and collaboration skills. AI addresses traditional learning limitations, such as restricted access to resources, by creating immersive and flexible environments. It offers benefits like virtual labs for hands-on experience, intelligent tutoring systems for personalized feedback, and data analysis to help teachers provide targeted support. Ultimately, leveraging AI in STEM education helps prepare students for in-demand careers by fostering adaptability and technological literacy, paving the way for a knowledge-driven society.

LITERATURE REVIEW

In today's world, where digital technology plays a crucial role in every aspect of life, AI technology has emerged as one of the most influential innovations (Hannan & Liu, 2023; Abdekhoda & Dehnad, 2024). It has not only reshaped industries and economies but has also brought about a significant paradigm shift in education. This is particularly true in the fields of STEM education, which forms the vital foundation for driving national innovation and development. STEM education is an interdisciplinary approach to learning that integrates the four fields of Science, Technology, Engineering, and Mathematics. The core pedagogical goal is to move beyond traditional, siloed subject teaching to a more holistic, hands-on, and inquiry-based model. Instead of just memorizing facts, students learn to apply knowledge from multiple disciplines to solve real-world problems. This approach cultivates essential 21st century skills, including critical thinking, creativity, collaboration, and communication. It also fosters technological literacy and innovation. The ultimate aim is to empower students to become flexible thinkers and problem-solvers, prepared for a future workforce increasingly driven by technological advancements. Furthermore, STEM learning is not merely about transmitting knowledge; it's about nurturing essential 21st century skills such as critical thinking, complex problem-solving, creativity, and collaboration (Zhan et al., 2022). AI presents significant opportunities to revolutionize education by offering personalized learning experiences and automating administrative tasks for educators. It can create adaptive learning paths, provide instant feedback through intelligent tutoring systems, and automate grading, freeing up teachers to focus on student engagement. However, these benefits come with challenges. There are concerns about data privacy and security, as AI systems often collect vast amounts of sensitive student information. Additionally, the potential for algorithmic bias can lead to unfair assessments, and an over-reliance on AI might hinder the development of students' critical thinking and problem-solving skills. These qualities are crucial for driving future innovation and economic growth (Alsobeh & Woodward, 2024; Retno et al., 2025). Therefore, integrating AI into the management of science learning within a STEM framework is not just a passing trend but a strategic imperative. It must be systematically considered and implemented to equip learners with robust skills and competencies, preparing them to face the challenges and rapid, increasingly unpredictable changes of a technology-driven world. This literature review aims to explore and synthesize knowledge regarding strategies for using AI technology to enhance science learning management within a STEM education approach. It will highlight the benefits gained, the challenges faced, and feasible practical guidelines, ultimately

leading to the creation of effective, accessible, and responsive learning experiences for diverse learners in the AI era (Abdekhoda & Dehnad, 2024; Jafari & Keykha, 2024).

The literature related to AI integration in STEM education points to its immense potential to transform learning processes and student outcomes. Li and Wong (2023), Alsobeh and Woodward (2024), Marengo et al. (2024), and Ellikkal and Rajamohan (2025) has conducted research and found that one of the most significant benefits is AI's ability to facilitate Personalized Learning. AI can analyze individual student learning data, such as their learning speed, strengths, weaknesses, distinct learning styles, and knowledge gaps, to tailor content, instructional materials, and exercises to their specific needs. Bilal et al. (2025) has conducted research and found that the use of Intelligent Tutoring Systems (ITS) powered by AI has been extensively studied and found effective in providing instant feedback and specific guidance that helps students better understand complex concepts in science and mathematics (Hardaker & Glenn, 2025). Alsobeh and Woodward (2024) mentioned these ITS can detect student errors, pinpoint the causes of misconceptions, and offer targeted remediation or supplementary content. Additionally, AI plays a crucial role in creating realistic and safe learning environments through the development of Virtual Labs and Simulations (Payadnya et al., 2025). These allow students to conduct scientific experiments that might otherwise be dangerous, costly, or time-consuming in a controlled and risk-free environment. Such simulations not only increase access to practical learning experiences but also enable students to explore scientific concepts in deeper dimensions, such as simulating quantum physics phenomena or analyzing chemical reactions at a molecular level, which are otherwise imperceptible. Bilal et al. (2025) mentioned the application of AI in Learning Analytics is another valuable strategy. It helps educators analyze large amounts of student learning data to identify learning trends, predict academic success, or even detect students at risk of academic difficulties, allowing for timely and effective intervention and support. The insights gained from AI analysis are also beneficial for improving curricula, instructional materials, and teaching methodologies to be more effective and responsive to the needs of modern learners, including fostering Computational Thinking, a key skill for understanding and utilizing AI (Aad & Hardey, 2025; Mariyono & Nur Alif Hd, 2025; Payadnya et al., 2025).

While the potential of AI in enhancing science learning management within STEM is immense, its practical implementation still faces significant challenges and considerations (Abdekhoda & Dehnad, 2024; Payadnya et al., 2025). Alsobeh and Woodward (2024) have reported research results from finding, Firstly, data quality used to train AI is critical, as the effectiveness of AI systems depends on the quality and diversity of the data. If the data used is biased or incomplete, the AI system may produce inaccurate results or create learning inequities. Secondly, there's a shortage of specialized personnel—both in developing AI for education and among educators who understand how to effectively integrate AI into teaching and learning. Educators need continuous training and development to fully leverage AI tools and adapt them to their specific learning contexts. Additionally, the high investment costs in developing and widely implementing AI technology represent another significant barrier, especially for educational institutions with limited budgets. Ethical considerations and data security are also paramount (Gafni & Levy, 2024; Chen et al., 2025; Mariyono & Nur Alif Hd, 2025; Payadnya et al., 2025). Since AI systems in education collect vast amounts of personal student data, maintaining data privacy, ensuring transparent and responsible data usage, and preventing data breaches are of utmost importance. The literature also emphasizes the necessity of fostering AI literacy among both students and teachers (Hur, 2025). This goes beyond merely using AI tools; it includes understanding AI's working principles, limitations, and societal impacts (Asad & Ajaz, 2024; Sposato, 2025). AI education should not solely focus on being a user but should encourage students to be ethical and impactful creators and innovators with AI, considering its broader implications. Therefore, developing strategies for using AI in STEM education must balance the technology's potential with these critical considerations to ensure that AI adoption genuinely elevates educational quality and sustainably benefits all learners (Routray & Khandelwal, 2024; Aad & Hardey, 2025; Ronaghi & Ronaghi, 2025).

Based on the analysis of the provided abstract and literature review, here is a conceptual framework for implementing AI in STEM education as shown in Figure 1. This model is designed to be holistic, addressing not only the strategic use of AI but also the foundational prerequisites and continuous evaluation necessary for sustainable and ethical integration.

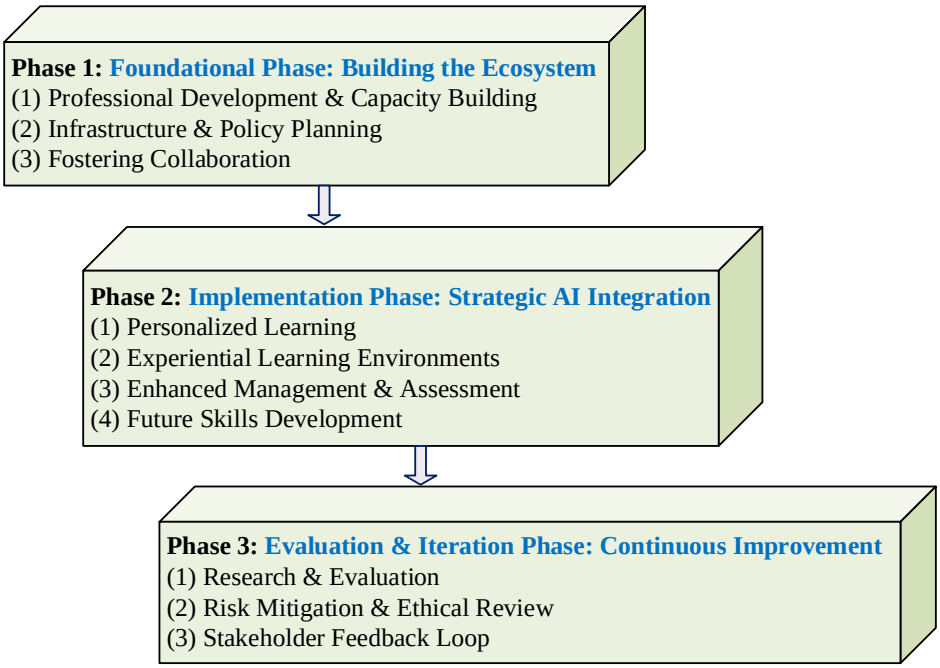

Figure 1: Conceptual framework for implementing AI in STEM education approach

This framework provides a holistic approach for implementing AI in STEM education, addressing the strategic use of AI alongside the foundational requirements and ongoing evaluation necessary for sustainable and ethical integration. The model is divided into three interconnected phases: Foundation, Implementation, and Evaluation & Iteration. The details were as follows:

1. Foundational Phase: Building the Ecosystem. This initial phase establishes the essential groundwork before any technology is deployed. It is designed to create a robust and ethical environment for AI integration by addressing key challenges.

(1) Professional Development & Capacity Building: Continuous training is crucial for educators to develop AI literacy, master AI-powered teaching tools, and understand the ethical implications of AI use.

(2) Infrastructure & Policy Planning: Careful planning is required for technological infrastructure and budgetary allocation. Clear policies on data privacy, security, and ethical AI usage must be developed to mitigate risks.

(3) Fostering Collaboration: Success depends on promoting collaboration among all stakeholders—teachers, administrators, parents, and industry experts—to ensure a shared vision and collective support.

2. Implementation Phase: Strategic AI Integration. This phase puts the strategies into practice, leveraging AI directly to enhance the learning process. It forms the core of the framework, built on the solid foundation established in the previous phase.

(1) Personalized Learning: Utilize AI-powered intelligent tutoring systems and adaptive platforms to tailor content to individual student needs, providing customized learning paths and targeted feedback.

(2) Experiential Learning Environments: Implement AI-powered virtual labs and simulations to offer realistic, hands-on learning experiences that transcend the limitations of cost and physical space.

(3) Enhanced Management & Assessment: Employ AI to automate repetitive administrative tasks, such as grading and data analytics, which reduces the teacher's burden and offers deeper insights into student performance.

(4) Future Skills Development: Integrate AI tools and curricula to actively develop students' computational thinking, data literacy, and AI literacy, preparing them for 21st century demands.

3. Evaluation & Iteration Phase: Continuous Improvement

(1) This final phase is a continuous loop of monitoring, refining, and adapting to new insights and technologies, ensuring the long-term sustainability and effectiveness of the framework.

(2) Research & Evaluation: Ongoing research and data-driven evaluation are essential to assess the effectiveness of AI implementation, measure its impact on learning outcomes, and identify areas for improvement.

(3) Risk Mitigation & Ethical Review: Policies must be regularly reviewed and updated to address emerging ethical issues, such as algorithmic bias and educational inequality, while ensuring human judgment remains the ultimate authority.

(4) Stakeholder Feedback Loop: A mechanism for gathering feedback from all stakeholders is vital to inform future iterations of the framework, ensuring it remains relevant and effective.

In summary, this framework represents a comprehensive and holistic approach that aims to fully harness AI's potential while proactively addressing its challenges, moving beyond simple tool use to a strategic, well-governed integration.

THE ROLE OF AI TECHNOLOGY IN MANAGING SCIENCE LEARNING WITHIN THE STEM EDUCATION APPROACH

In the current context of managing science learning within the STEM framework, AI has taken on an increasingly crucial role in transforming how we learn and develop essential 21st century skills (Ebekozien et al., 2023). AI is not merely a supplementary technology; it's a powerful tool capable of creating entirely new learning environments, making science education more engaging, accessible, and responsive to the diverse needs of learners. Kang (2023), Alsobeh and Woodward (2024), Mariyono and Nur Alif Hd (2025), and Payadnya et al. (2025) have given the primary roles of AI in managing science learning within STEM can be categorized into several dimensions:

1. Personalized Learning. AI excels at analyzing and adapting learning to each individual student, which is at the core of digital-era STEM education. Using Machine Learning Algorithms, AI can collect and process vast amounts of data about a student's learning behavior, including their comprehension speed, strengths, weaknesses, preferred learning styles, or even their emotional state during learning (Li & Wong, 2023). Based on this data, AI can precisely tailor content, instructional materials, exercises, and various activities to each student's unique needs. A clear example is Intelligent Tutoring Systems (ITS), which are powered by AI. These systems can provide immediate feedback when students make mistakes, identify the root causes of misunderstandings, and offer targeted remediation or supplementary content (Ellikkal & Rajamohan, 2025). This enables students to learn at their own pace and receive the necessary support to effectively develop their understanding of complex scientific and mathematical concepts.

2. Creating Realistic and Safe Learning Environments. Science and STEM learning often involves hands-on experiments and practical application, which can sometimes be limited by safety concerns, high costs, or equipment accessibility. AI addresses these challenges by developing highly realistic Virtual Labs and Simulations. Students can conduct potentially hazardous experiments, such as those involving dangerous chemicals or simulating nuclear reactions, in a controlled and risk-free virtual environment. Furthermore, simulations allow students to explore complex scientific phenomena invisible to the naked eye, like electron movement, molecular changes, or astronomical events. Students can repeat experiments, change variables, and observe results an unlimited number of times, thereby increasing access to practical experience and fostering deep inquiry-based learning (Cook & Cook, 2024).

3. Learning Analytics and Automated Assessment. AI plays a crucial role in collecting, analyzing, and interpreting vast amounts of student learning data, known as Learning Analytics. This data enables educators to quickly and accurately identify student learning trends, predict success, or even identify students at risk of academic difficulties. This allows for timely and effective intervention and support. Additionally, AI assists with Automated Assessment (Mudkanna Gavhane & Pagare, 2024), from grading multiple-choice questions and essay responses to analyzing programming code or scientific project designs. AI-powered assessment reduces the workload for teachers, giving them more time to focus on instruction, mentoring, and designing creative learning activities. Moreover, AI can provide detailed and systematic feedback to students, helping them understand their mistakes and continuously improve their work. It also helps reduce grading bias, leading to more fair and consistent evaluations.

4. Developing Computational Thinking and Future Skills. Directly integrating AI into STEM science learning also promotes the development of Computational Thinking, a fundamental skill for

the digital education era (Kang, 2023). Students learn the principles of AI operation, basic programming, data analysis, and model creation, all of which are components of computational thinking. Furthermore, working with AI helps students develop other critical skills such as critical thinking (by evaluating AI-generated information), problem-solving (by using AI as a tool to find solutions), creativity (by designing new innovations collaboratively with AI), and technological literacy (which includes understanding AI's limitations and ethical considerations) (Bilal et al., 2025; Chen et al., 2025). These skills are essential for preparing students for future careers where AI will play an increasingly prominent role.

In conclusion, the role of AI in managing science learning within STEM education encompasses improving personalized and engaging learning experiences, increasing access to resources and practical experiences, assisting teachers with administration and assessment, and fostering essential future skills. Strategically and thoughtfully implementing AI in STEM is therefore a crucial step in creating high-quality education and preparing young people to be key contributors to society and the economy in the digital education era.

STRATEGIES FOR UTILIZING AI TECHNOLOGY TO ENHANCE SCIENCE LEARNING MANAGEMENT WITHIN THE STEM EDUCATION APPROACH

In the 21st century, with its relentless technological advancements, AI has become a crucial driving force transforming every aspect of life, including the education sector. This is particularly true in the fields of STEM education is paramount for nurturing essential future skills such as critical thinking, problem-solving, creativity, and collaboration, which form the bedrock of national development. The integration of AI into science learning management within the STEM framework is, therefore, more than just an option; it is a strategic imperative that demands serious consideration (Narayanan, 2023). This integration aims to cultivate a knowledgeable and capable citizenry prepared to tackle the challenges of a rapidly evolving, technology-driven world. This article will present key strategies for utilizing AI technology to enhance science learning management within the STEM education approach, focusing on creating effective, accessible, and responsive learning experiences for diverse learners (Alsobeh & Woodward, 2024; Aad & Hardey, 2025; Payadnya et al., 2025; Ronaghi & Ronaghi, 2025).

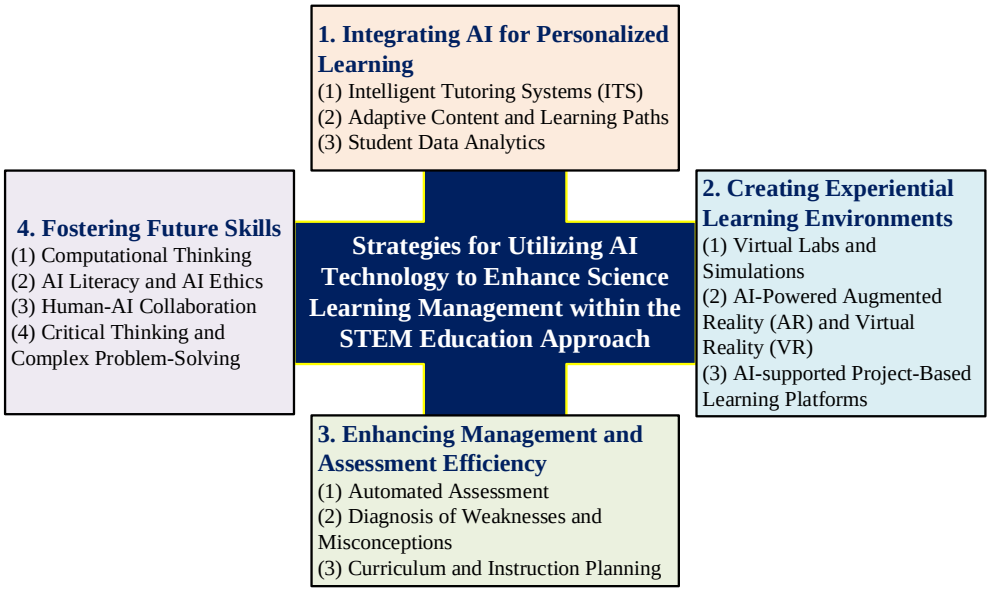

Figure 2: Strategies for utilizing AI technology to enhance science learning management within the stem education approach

Strategies for utilizing AI technology to enhance science learning management within the STEM education approach as shown in Figure 2, The details were as follows:

1. Integrating AI for Personalized Learning. One of the most powerful strategies for using AI in STEM education is its unprecedented ability to facilitate Personalized Learning (Li & Wong,

2023). Ellikkal and Rajamohan (2025) have given the core idea is that AI acts as an “intelligent teaching assistant” that deeply understands the unique differences among individual learners and tailors the learning experience to their specific needs. This strategy can be implemented in several ways:

(1) Intelligent Tutoring Systems (ITS), AI-powered ITS can analyze student learning data, such as their comprehension speed, common errors, and response patterns, to provide immediate feedback and guidance adapted to the student’s level of understanding (Hardaker & Glenn, 2025). For example, if a student struggles with the concept of gravity, the ITS might present an additional explanatory video, simpler exercises, or even a relevant simulation game, allowing the student to learn at their own pace and receive targeted support.

(2) Adaptive Content and Learning Paths: AI can recommend real-time content, instructional materials, or supplementary resources appropriate for each student's knowledge level and learning style (Bilal et al., 2025). For instance, if AI detects that a student learns best through visuals, it might suggest infographic videos or virtual simulations, whereas a hands-on learner might be advised to engage in virtual laboratory projects. This makes learning more effective and engaging for everyone.

(3) Student Data Analytics: AI can analyze vast amounts of Big Data generated from student interactions with learning platforms to provide educators with insights into overall and individual student learning performance (Alsobeh & Woodward, 2024). This data helps teachers identify students who may be struggling, plan appropriate interventions, or adjust teaching strategies to better align with the class’s needs.

2. Creating Experiential Learning Environments. True science and STEM learning necessitate hands-on practice and exploration, but often faces limitations due to equipment, cost, or safety. AI plays a crucial role in overcoming these obstacles through the following strategies:

(1) Virtual Labs and Simulations: AI can create highly realistic virtual laboratories where students can conduct complex or even dangerous scientific experiments safely and without limitations (Alsobeh & Woodward, 2024). For example, students can mix hazardous chemicals, simulate nuclear reactions, or experiment under conditions difficult to replicate in reality (e.g., in space or deep underwater) without any risk. Moreover, simulations allow students to explore abstract scientific concepts invisible to the naked eye, such as electron movement within atoms, molecular interactions in chemical reactions, or the functioning of the nervous system. These simulations help students visualize and understand concepts more profoundly.

(2) AI-Powered Augmented Reality (AR) and Virtual Reality (VR), Integrating AI with AR/VR technologies enables students to “step into” realistic scientific scenarios (Phakamach et al., 2022). This could involve exploring the human body at a cellular level, virtually navigating the solar system, or assembling virtual mechanical components. These experiences not only make learning enjoyable and engaging but also help develop spatial reasoning and empirical understanding.

(3) AI-supported Project-Based Learning Platforms: AI can act as an assistant in science and STEM projects, helping students collect data, analyze experimental results, propose ideas, or even assist in report writing (Retno et al., 2025). For instance, AI can help search for relevant information from large databases, assist in processing complex experimental data, or suggest problem-solving approaches that students might overlook. This fosters inquiry-based learning and real-world problem-solving skills.

3. Enhancing Management and Assessment Efficiency. AI benefits not only learners but also significantly reduces the workload for teachers and educators, allowing them to focus more on strategic roles:

(1) Automated Assessment: AI can assist teachers in quickly and accurately checking and grading various assignments, including multiple-choice questions, essay responses, programming code, or data analysis from experiments (Narayanan, 2023). This substantially reduces the time teachers spend on grading, freeing them up to provide in-depth feedback to individual students or design more complex and creative learning activities.

(2) Diagnosis of Weaknesses and Misconceptions: AI can analyze student answers or learning behaviors to identify systematic weaknesses or misconceptions (Narayanan, 2023). For example, if AI detects that many students misunderstand the same concept, it can alert the teacher to revisit that concept or organize supplementary activities for specific groups of struggling learners.

(3) Curriculum and Instruction Planning: AI can help teachers analyze learning data to improve curriculum and teaching methods more effectively (Narayanan, 2023). This includes identifying content areas where most students struggle, optimizing the sequence of instruction, or recommending diverse teaching materials to meet the needs of students in the classroom.

4. Fostering Future Skills. Using AI in STEM learning is not just about utilizing tools; it's about cultivating crucial 21st century skills that will empower students to be capable citizens in an AI-driven world:

(1) Computational Thinking: Interacting with AI systems or learning directly about how AI works helps students develop computational thinking skills, including decomposing large problems into smaller parts, creating models, thinking systematically, and applying logical reasoning (Kang, 2023). These are fundamental for solving complex problems in the future.

(2) AI Literacy and AI Ethics: Learning about AI within the STEM context will help students understand AI's potential, limitations, and societal impacts (Hur, 2025; Sposato, 2025). This includes ethical considerations such as data privacy, AI bias, and responsible use. This is crucial for fostering responsible citizens in the AI era (Chen et al., 2025).

(3) Human-AI Collaboration: Students will learn to work collaboratively with AI as a tool to aid in problem-solving, creation, and analysis. This is an increasingly vital skill in the future job market. Students will understand how AI can augment human capabilities and how to leverage AI for maximum efficiency.

(4) Critical Thinking and Complex Problem-Solving: Even though AI assists with analysis and processing, students will still need to apply critical thinking to evaluate AI-generated results and use problem-solving skills to formulate appropriate questions and interpret data logically.

Challenges and Considerations

While AI plays a vital role in enhancing science learning management within STEM, there are also challenges and important considerations that must be taken into account:

(1) Professional Development: Teachers need continuous training and professional development to acquire the knowledge and understanding to effectively use AI and integrate it into their teaching and learning practices.

(2) Infrastructure and Budget: Widespread AI implementation requires robust technological infrastructure and sufficient financial resources, which can be a barrier for some educational institutions (Aad & Hardey, 2025).

(3) Ethics and Data Privacy: The use of AI in education must prioritize ethical considerations and the security of students' personal data (Kang, 2023; Gafni & Levy, 2024).

(4) Flexible Curriculum Design: Curricula must be adapted to be flexible and effectively accommodate AI integration, including emphasizing future skills that AI cannot replace.

The utilization of AI technology to enhance science learning management within the STEM education approach is a crucial and necessary strategy in the current era. AI has the potential to transform learning to be personalized, create realistic experiences, enhance administrative efficiency, and foster essential 21st century skills (Kang, 2023; Gafni & Levy, 2024; Chen et al., 2025). However, the implementation of AI requires careful planning, investment in personnel and infrastructure, and strict adherence to ethical considerations. If implemented appropriately, AI will be a powerful force in creating a bright future for STEM education and preparing youth to be leaders in science and technology in the new world.

GUIDELINES FOR IMPLEMENTING AI TECHNOLOGY TO ENHANCE SCIENCE LEARNING WITHIN THE STEM EDUCATION APPROACH

Alsobeh and Woodward (2024), Payadnya et al. (2025), and Sposato (2025) argued that implementing AI technology in science learning management under the STEM approach is more than just adopting new tools; it's a paradigm shift in learning to meet the challenges and demands of the digital world. To effectively utilize the AI strategies mentioned earlier, a clear and systematic approach is essential. This approach must cover planning, professional development, technology selection, content creation, and continuous evaluation. These guidelines aim to create a learning ecosystem that fosters AI as an integral part of high-quality and sustainable STEM learning management. The details are as follows:

1. Clear Vision and Strategic Planning. Before introducing AI in any context, the most crucial step is to establish a clear vision and specific goals for how AI will enhance STEM learning and what the expected outcomes are. Sound strategic planning ensures that investments and operations are directed effectively. Clear vision and strategic planning can be achieved through the following methods:

(1) Assess Institutional Readiness: Conduct a SWOT Analysis (Strengths, Weaknesses, Opportunities, Threats) of the educational institution's current state. This includes technological infrastructure (e.g., high-speed internet, AI-compatible devices), budget, skilled personnel, and an organizational culture open to innovation (Narayanan, 2023).

(2) Define AI Integration Goals: Clearly state what problems AI will solve or what strengths it will augment. For example, the goals might be to enhance personalized learning, reduce teacher workload, develop computational thinking skills, or increase access to experimental experiences. Clear objectives will guide the selection of appropriate strategies and technologies (Li & Wong, 2023; Ellikkal & Rajamohan, 2025).

(3) Establish a Driving Team: Form a working committee or a driving team to lead the adoption of AI in STEM learning. This team should comprise administrators, teachers, educational technology specialists, and AI experts to ensure collaboration and leverage diverse expertise (Routray & Khandelwal, 2024).

(4) Develop an Action Plan: Create a concrete action plan, defining timelines, budget, necessary resources, responsible parties, and clear Key Performance Indicators (KPIs). It may be beneficial to start with a pilot program in specific subjects or with a select group of learners to learn and refine the approach (Narayanan, 2023).

2. Continuous Professional Development for Educators. Teachers are at the heart of successful AI implementation in education. Investing in professional development is therefore indispensable. Teachers must not only know how to use AI but also understand their role as facilitators of learning in the AI era. Continuous professional development can be achieved through the following methods:

(1) Build Awareness and Understanding of AI's Potential: Organize initial training workshops to help teachers grasp the fundamental concepts of AI, the benefits AI can bring to STEM learning management, and see examples of successful applications (Narayanan, 2023).

(2) Provide Training on AI Tools: Conduct practical workshops focusing on hands-on experience with the AI tools and platforms to be used in the institution. Examples include using intelligent tutoring systems, creating virtual labs, utilizing learning analytics tools, or employing AI to assist in creating instructional content.

(3) Promote the Development of AI-Driven Teaching Skills: Train teachers to effectively design learning activities that integrate AI. This could involve designing projects where students use AI as a problem-solving tool, fostering critical thinking about how AI works, or creating environments that promote human-AI collaboration (Mariyono & Nur Alif Hd, 2025).

(4) Foster Learning Communities and Experience Sharing: Establish Professional Learning Communities (PLCs) or teacher networks to allow educators to exchange experiences, share best practices, discuss challenges, and collectively develop innovative uses of AI in STEM learning (Phakamach et al., 2025).

3. Selection and Adaptation of Appropriate AI Technologies. Choosing AI technologies that align with the educational institution's context and needs is crucial; not every platform is suitable for every setting. The selection and adaptation of appropriate AI technologies can be achieved through the following methods:

(1) Consider Curriculum and Goal Compatibility: Select AI platforms or tools that align with the institution's established STEM curriculum and meet the defined goals for AI integration.

(2) Account for Customization and Scalability: Choose technology that allows for content customization to suit student knowledge levels and can be scaled for use with a large number of learners in the future.

(3) Evaluate User-Friendliness: Prioritize tools that are easy for both teachers and students to use, which helps them adopt new technologies quickly.

(4) Consider Budget and Infrastructure Issues: Assess initial investment costs, maintenance expenses, and technological infrastructure requirements (e.g., servers, internet bandwidth) (Narayanan, 2023).

(5) Prioritize Data Security and Ethics: Choose AI platform providers with high data security standards and data usage policies that adhere to ethical principles and relevant laws (Gafni & Levy, 2024; Bilal et al., 2025).

4. AI-Powered Content Development and Management. Having an excellent platform without quality content is futile. Creating and managing content that aligns with AI's functionality is essential. AI-powered content development and management can be achieved through the following methods:

(1) Create Adaptive Content: Develop STEM science learning content that can be dynamically adjusted by AI in terms of difficulty, depth, and presentation format, based on individual student learning data.

(2) Leverage AI for Content Creation: Consider using AI tools to assist in generating initial content, such as creating quizzes, summarizing material, generating questions, setting up simulated scenarios, or even creating interactive lessons (Kang, 2023). However, teachers must still review, refine, and infuse human creativity into the content.

(3) Systematize Content Databases: Establish a well-organized database system for content management to enable AI to access and utilize it efficiently, and for teachers to manage content easily.

Integrate External Resources: Connect AI platforms with reliable external science and STEM resources to broaden the scope of student knowledge and experience.

5. Continuous Evaluation and Improvement. Implementing AI in STEM learning management is an ongoing process that requires continuous learning and refinement, not just a one-time system installation. Continuous evaluation and improvement can be achieved through the following methods:

(1) Define Key Performance Indicators (KPIs), Regularly measure performance against established initial KPIs, such as average student scores, engagement rates, teacher and student satisfaction, time spent learning, or the development of specific STEM skills.

(2) Collect Data and Feedback: Utilize AI's Learning Analytics to gather quantitative data on student learning behaviors (Alsobeh & Woodward, 2024), and simultaneously collect qualitative feedback from teachers, students, and other stakeholders through surveys, interviews, or focus groups.

(3) Analyze and Interpret Results: Analyze the collected data to understand the effectiveness of the implemented AI strategies, identify areas for improvement, or pinpoint any emerging problems.

(4) Refine and Develop Plans: Use evaluation results to refine AI strategies, action plans, instructional content, or staff training methods to ensure that AI usage is maximally effective and responsive to evolving student needs and contexts.

(5) Promote Research and Development: Encourage teachers and educators to conduct research on AI's use in STEM learning to generate new knowledge and drive continuous innovation in education.

6. Fostering a Culture of Learning and Technology Acceptance. Last but not least, creating an environment where people embrace and recognize the benefits of AI is crucial for long-term success. Fostering a culture of learning and technology acceptance can be achieved through the following methods:

(1) Consistently Communicate AI's Value and Benefits: Highlight the value and benefits that AI brings to STEM learning for students, teachers, and the institution as a whole to build motivation and confidence.

(2) Promote Experimentation and Learning from Mistakes: Create an atmosphere that encourages teachers and students to experiment with AI without fear of failure, viewing mistakes as opportunities for learning and improvement.

(3) Emphasize the Human Role: Clarify that AI is a tool that augments human capabilities, not replaces them. Teachers retain their vital role in guiding, inspiring, and developing students' social and emotional skills.

(4) Encourage Multi-Stakeholder Engagement: Provide opportunities for parents, the community, and industry sectors to participate in and support the use of AI in STEM learning to foster sustainable collaboration.

In summary, effectively implementing AI technology strategies to enhance science learning management within the STEM education approach requires a comprehensive and holistic approach. This encompasses strategic planning, professional development, selecting appropriate technologies, content development, and continuous evaluation and improvement. Most importantly, it involves fostering an open and technology-accepting culture. If all stakeholders collaborate systematically and with dedication, AI integration will not only elevate the quality of STEM education but also truly prepare youth to be innovators and users of innovation in the future AI-driven world.

CHALLENGES AND OPPORTUNITIES

Cook and Cook (2024), Jafari and Keykha (2024), Routray and Khandelwal (2024), Ronaghi and Ronaghi (2025), and Payadnya et al. (2025) gave a perspective on the integration of AI into science learning management under the STEM approach represents a significant advancement with the potential to revolutionize education. However, like any major innovation, the adoption of AI in education comes with both challenges that must be overcome and vast opportunities waiting to be seized. A deep understanding of both these aspects is crucial for successful planning and implementation

Challenges

Implementing AI technology to enhance science learning management within the STEM education approach faces several obstacles that require careful handling. These challenges include:

1. Lack of Knowledge and Skills among Personnel

(1) Teachers: One of the biggest challenges is that many teachers still lack fundamental knowledge about AI, how it works, and how to apply it in teaching. Shifting from the role of knowledge transmitter to a learning facilitator who uses AI as a tool is not easy and requires time for adaptation (Alsobeh & Woodward, 2024).

(2) School Administrators: Administrators may lack a deep understanding of AI's potential and the necessary infrastructure requirements to support its implementation, which affects budget allocation and appropriate policy setting (Kang, 2023).

(3) Students: While Gen Z is familiar with technology, AI literacy and a deep understanding of its underlying principles are still necessary and must be systematically taught (Hur, 2025).

2. Infrastructure and Budgetary Constraints

(1) High Costs: Investing in AI platforms, compatible hardware, high-speed network systems, and maintenance involves significant costs (Jafari & Keykha, 2024). This can be a barrier for educational institutions with limited budgets, especially in developing countries.

(2) Unequal Access to Technology: The digital divide remains a significant issue. Students in remote areas or from low-income families may lack adequate devices or internet access, preventing them from fully utilizing AI (Assefa et al., 2025).

(3) Connectivity and Maintenance: AI systems require stable internet connections with high bandwidth, as well as regular maintenance and updates, which can be a technical and managerial burden for educational institutions.

3. Ethics, Privacy, and Data Security Issues

(1) Data Privacy: AI systems in education must collect large amounts of personal and learning data from students. Protecting this data from leaks or misuse is a significant challenge (Gafni & Levy, 2024).

(2) AI Bias: If the data used to train AI is biased or not diverse, it may lead to AI providing inappropriate recommendations or creating learning disparities for certain groups of students.

(3) Transparency and Auditability: Understanding how AI makes decisions or provides recommendations is crucial for users and administrators to be able to explain and correct errors (explainable AI).

(4) Over-reliance on AI: There are concerns that excessive reliance on AI systems might diminish essential human skills such as critical thinking, self-problem-solving abilities, or social interaction.

4. Curriculum Adaptation and Integration

(1) Curriculum Flexibility: Current curricula may not be designed to fully support AI integration, making it difficult to naturally incorporate AI into teaching and learning (Jafari & Keykha, 2024).

(2) Developing Appropriate Content: Developing STEM science learning content that can adapt to AI's capabilities and respond to personalized learning styles remains a challenge that requires resources and expertise (Li & Wong, 2023).

Opportunities

Despite the challenges, the potential of AI to enhance science learning management within the STEM education approach is immense, presenting opportunities we should seize. These opportunities include:

1. Personalized and Adaptive Learning

(1) Addressing Learner Diversity: AI can analyze each student's strengths, weaknesses, learning styles, and learning pace to adapt content, exercises, and activities accordingly. This maximizes learning effectiveness for everyone, regardless of their ability level (Li & Wong, 2023; Alsobeh & Woodward, 2024 Ellikkal & Rajamohan, 2025).

(2) Intelligent Tutoring Systems (ITS), AI can provide immediate and targeted guidance and feedback, helping students better understand complex scientific and mathematical concepts. This level of learning support is difficult to achieve in large classrooms (Ellikkal & Rajamohan, 2025)

2. Access to Realistic Learning Experiences

(1) Virtual Labs and Simulations: AI enables the creation of complex and expensive virtual laboratories and simulated scenarios where students can conduct potentially dangerous or difficult-to-access experiments safely and without limitations in a real classroom setting. This helps bridge the gap in access to practical STEM education.

(2) Exploring Beyond-Reality Scientific Worlds: AI can simulate phenomena invisible to the naked eye, such as the movement of atoms or molecules, or universal simulations, allowing learners to explore abstract concepts deeply and excitingly (Jafari & Keykha, 2024).

3. Enhanced Management and Assessment Efficiency

(1) Automated and Accurate Assessment: AI can help teachers quickly and impartially evaluate assignments and provide grades, whether by checking exams, analyzing programming code, or giving feedback on science projects. This significantly reduces teachers' workload (Mudkanna Gavhane & Pagare, 2024).

(2) Insights for Development: AI-driven Learning Analytics can provide insights into student learning behavior, helping teachers and administrators identify trends, emerging problems, and improve curriculum or teaching methods for greater effectiveness (Alsobeh & Woodward, 2024).

(3) Identifying At-Risk Learners: AI can help identify students who are likely to struggle early on, allowing for timely support and intervention.

4. Development of Future Skills

(1) Computational Thinking Skills: Directly using AI in STEM learning fosters computational thinking skills, which are crucial for problem-solving in a data- and technology-driven world (Bilal et al., 2025).

(2) AI Literacy and Collaboration with AI: Students will learn to work with AI as a tool and understand its potential, limitations, and ethical implications, which is essential for becoming responsible citizens in the digital education era (Cook & Cook, 2024; Hur, 2025).

(3) Critical Thinking and Complex Problem-Solving: Although AI assists in data processing, learners must still use critical thinking to ask questions, evaluate results, and apply creativity to utilize AI for solving complex problems.

In summary, implementing AI strategies to enhance science learning management within the STEM education approach is a journey filled with both challenges that must be overcome through good planning, investment in personnel and infrastructure, ethical considerations, and curriculum refinement, and immense opportunities to revolutionize learning to be personalized, accessible, efficient, and future-ready for students. Recognizing both these challenges and opportunities will enable stakeholders to plan and execute wisely, allowing AI to become a true force in driving the quality of STEM education and creating a bright future for our youth.

EXAMPLES OF SUITABLE AI TOOLS FOR ENHANCING SCIENCE LEARNING MANAGEMENT WITHIN THE STEM EDUCATION APPROACH

Integrating AI technology to enhance science learning management within the STEM education approach requires considering a diverse range of tools. These tools should address the four core strategies: personalized learning, creating experiential learning environments, enhancing management and assessment efficiency, and fostering future skills. Omran Zailuddin et al. (2024), Oyelude (2024), Ellikkal and Rajamohan (2025), Hardaker and Glenn (2025), and Williamson and Fernandez (2025) have presented an examples of suitable AI tools that could be applied:

1. AI Tools for Personalized Learning

1.1 Intelligent Tutoring Systems (ITS), These systems use AI to analyze each student's progress, strengths, weaknesses, and learning style. They then adapt content, explanations, exercises, and feedback in real-time. Examples include:

(1) Khanmigo (by Khan Academy), An AI-driven tool that helps teachers in the US create lessons and exercises tailored to students. It also acts as a personal tutor, answering questions and providing guidance to students.

(2) Century Tech: This platform uses AI to create personalized learning paths, incorporating gamification, scoring, and real-time data analysis to adapt the path to the learner.

(3) DreamBox Learning: Focuses on adapting math lessons based on student performance in real-time, providing appropriate support and challenges.

1.2 Adaptive Learning Platforms: These platforms adjust the difficulty of content and questions based on student comprehension, making learning efficient and challenging at the right level. An example is ALEKS (Assessment and Learning in Knowledge Spaces), An adaptive learning system that uses AI to assess student knowledge in math and science, then provides content directly addressing individual knowledge gaps.

2. AI Tools for Creating Experiential Learning Environments

2.1 Virtual Labs and Simulations (VR/AR with AI), Integrating AI with virtual reality (VR) and augmented reality (AR) technologies allows students to conduct complex, dangerous, or expensive experiments in a safe and realistic environment. Examples include:

(1) Labster: Offers virtual science labs where students can conduct biology, chemistry, and physics experiments in interactive simulated environments.

(2) VRLab Academy: Provides over 240 simulated science experiments aligned with international curricula, usable on desktops, tablets, and VR headsets.

(3) BodyViz / zSpace: Utilizes VR/AR to allow students to explore anatomy or scientific models in interactive 3D.

2.2 AI-powered Gamification Platforms: Using AI to add gaming elements to learning makes the experience more engaging and enjoyable. An example is Minecraft Education Edition (with AI integrations), While not directly AI, Minecraft can be integrated with AI to create complex STEM missions or scenarios where students solve problems and create in a virtual world.

3. AI Tools for Enhanced Management and Assessment Efficiency

3.1 Automated Assessment Tools: AI can help teachers grade assignments and provide feedback quickly and impartially, reducing workload and offering timely responses. Examples include:

(1) Turnitin: Uses AI to detect plagiarism and provide feedback on grammar and writing style, which is especially useful for science reports and projects.

(2) Gradescope: Leverages AI to streamline the grading process, making it faster and providing deeper insights, capable of reading both text and mathematical equations.

(3) SchoolAI: An AI platform that can rapidly process large volumes of student work, providing consistent and timely feedback to help students correct errors immediately.

3.2 Learning Analytics Platforms (AI-driven), These platforms use AI to analyze student learning data to identify trends, pinpoint areas where students struggle, and provide insights to teachers and administrators for instructional decision-making. Examples include LMS (Learning Management Systems) with AI features: Many LMS platforms, such as Disco, Docebo, Canvas, Moodle (with AI plugins), are integrating AI to provide deeper learner analytics and assist in course management.

4. AI Tools for Fostering Future Skills

4.1 Generative AI Tools (LLMs), Generative AI tools, especially Large Language Models (LLMs), can assist students with research, brainstorming ideas, writing scientific reports, and problem-solving. Examples include:

(1) ChatGPT / Google Gemini / Claude: Students can use these AIs to ask complex scientific questions, brainstorm project ideas, get explanations for difficult concepts, or even help with coding for STEM projects (Baber et al., 2024; Elbanna & Armstrong, 2024).

(2) Perplexity AI: Focuses on being a research-oriented AI chatbot, providing quick access to information with references, making it suitable for inquiry-based learning and fact-checking.

(3) Wolfram Alpha: More than just an advanced calculator, it's an AI-powered tool for computing, answering scientific and mathematical questions, and providing various data insights.

4.2 AI for Programming and Data Analysis:

(1) GitHub Copilot: An AI-powered code completion tool that helps students write code faster, learn language structures, and debug programming issues, which are essential STEM skills.

(2) AI-powered data visualization tools: Enable students to analyze and present complex scientific data in an easy-to-understand format.

The selection of appropriate AI tools should consider the educational institution's context, budget, staff readiness, and clear learning objectives. Implementing AI in STEM is not just about adopting technology; it's about using technology to transform the learning experience and prepare students for a future driven by science and technology.

POTENTIAL IMPACTS OF IMPLEMENTING AI STRATEGIES IN STEM SCIENCE LEARNING MANAGEMENT

Asad and Ajaz (2024), Alsobeh and Woodward (2024), Ronaghi and Ronaghi (2025), Aad and Hardey (2025), Bilal et al. (2025), Hur (2025), and Sposato (2025) gave a perspective on the implementing AI technology to enhance science learning management within the STEM education approach is not merely about adapting teaching methods; it's a profound transformation with wide-ranging impacts. These impacts include both positive outcomes that bring new opportunities and negative ones that require careful management. Understanding these impacts is crucial for judicious planning and execution, ensuring that AI integration maximizes benefits and mitigates potential risks.

Potential Positive Impacts

Integrating AI into STEM learning has the potential to generate numerous beneficial outcomes:

1. More Effective and Accessible Learning

(1) Personalized Learning: AI genuinely helps create learning experiences tailored to each student's individual needs (Li & Wong, 2023). This includes learning speed, learning styles, and strengths/weaknesses, allowing learners to achieve maximum efficiency and reduce educational disparities.

(2) Access to Learning Resources: AI can make complex scientific learning resources, such as Virtual Labs or simulations of dangerous/hard-to-access phenomena, more easily accessible to all students, regardless of their location (Cook & Cook, 2024).

(3) Increased Learning Motivation: AI's ability to present content in engaging and interactive formats, along with timely and specific feedback, will boost students' motivation and enthusiasm for learning science and STEM (Kang, 2023; Cook & Cook, 2024).

2. More Strategic Role for Teachers

(1) Reduced Administrative Burden: AI can assist with Automated Assessment and Learning Analytics, which will significantly reduce teachers' administrative workload.

(2) Emphasis on Coaching and Mentoring: With more time available, teachers can dedicate themselves to more crucial roles, such as coaching and mentoring students, designing complex learning activities, instilling ethics and morals, and developing social and emotional skills—tasks that AI cannot yet perform as well as humans (Kang, 2023; Cook & Cook, 2024).

(3) Data-Driven Decisions: Insights from AI enable teachers and administrators to make data-driven instructional and management decisions, making learning management more efficient and targeted.

3. Development of Essential Future Skills

(1) Computational Thinking and AI Literacy: Direct learning with AI will help develop Computational Thinking skills and AI Literacy in students, which are fundamental skills crucial in the digital world (Kang, 2023; Cook & Cook, 2024).

(2) Problem-Solving and Critical Thinking: Using AI as a tool to solve scientific and STEM problems will encourage students to develop complex problem-solving skills and critical thinking in evaluating AI-generated results (Kang, 2023; Cook & Cook, 2024).

(3) Workforce Preparedness: Students who are familiar with using AI in learning will be better prepared for a future job market where AI will play a significant role across all industries.

Potential Negative Impacts

Despite its immense benefits, implementing AI without careful consideration can lead to negative consequences:

1. Increased Educational Inequality

(1) Digital Divide: If access to AI technology and the internet remains unequal, educational institutions with limited resources or unable to invest in AI will further widen the gap and inequality in education between students with access to technology and those without (Assefa et al., 2025).

(2) Bias and Fairness: If the AI used is trained with biased data, it may lead to AI providing unfair recommendations or assessments to certain student groups, such as those from different socioeconomic backgrounds or diverse ethnic/gender identities.

2. Impact on Teacher Roles and Expertise

(1) Role Diminishment: If teachers do not receive adequate skill development, they may feel that AI diminishes their role and importance, leading to resistance or unwillingness to adopt AI.

(2) Lack of Interpersonal Interaction: Over-reliance on AI systems may reduce opportunities for students to receive direct interaction from teachers and peers, potentially impacting the development of social and emotional skills.

3. Ethical, Privacy, and Security Risks

(1) Privacy Violations: The collection of large amounts of personal and learning data from students by AI, without robust security measures, could lead to privacy violations or misuse of data.

(2) Over-reliance on AI and Lack of Critical Thinking: If learners rely on AI for answers without engaging in their own critical analysis, it may diminish their critical thinking and problem-solving skills.

(3) AI Errors: AI systems are not flawless; errors or glitches may occur. If used for learning assessment, this could impact students' educational futures.

4. Adaptation and Maintenance Challenges

(1) Technical Complexity: Implementing and maintaining AI systems in educational institutions can be highly technically complex and requires specialized personnel, which may be a burden for institutions.

(2) Rapid Change: AI technology evolves rapidly, requiring educational institutions to continuously adapt and update their systems, which can be a strain on both budget and human resources.

In summary, the impacts of implementing AI strategies in STEM science learning management include significant positive aspects, such as enhancing learning efficiency, making teachers' roles more valuable, and developing future-ready skills (Alsobeh & Woodward, 2024; Lytras & Ordonez De Pablos, 2024; Ronaghi & Ronaghi, 2025; Aad & Hardey, 2025; Chen et al., 2025; Bilal et al., 2025; Hur, 2025; Sposato, 2025). However, potential negative impacts must also be acknowledged and prepared for, particularly concerning the digital divide, ethical and data privacy issues, and challenges in professional development and infrastructure. Careful planning, supportive policy creation, and continuous investment will be key to mitigating negative impacts and leveraging AI's full potential for STEM education in the digital era (Assefa et al., 2025).

CONCLUSION AND DISCUSSION

Integrating AI technology into science learning management under the STEM education approach is a significant strategic advancement in the 21st century with the potential to revolutionize learning paradigms. This article presented four key strategies for leveraging AI to enhance STEM learning: 1) Personalized Learning, 2) Creating Experiential Learning Environments, 3) Enhanced Management and Assessment Efficiency, and 4) Fostering Future Skills. Furthermore, it discussed the systematic guidelines for implementation and the potential impacts, both positive outcomes bringing new opportunities and negative ones requiring careful management. A deep understanding

of these dimensions is crucial for successful and sustainable planning and implementation. Based on all the information presented, a conclusion and discussion can be provided, divided into the following three key points.

Summary of Key Strategies and Implementation Guidelines

AI has the potential to revolutionize STEM learning, particularly in delivering personalized learning experiences. AI can analyze student learning data, such as learning speed, styles, and strengths/weaknesses, to adapt content, exercises, and activities to each student's specific needs (Li & Wong, 2023; Alsobeh & Woodward, 2024; Aad & Hardey, 2025; Ellikkal & Rajamohan, 2025). Through ITS and adaptive content, this allows learners to study at their own pace and according to their aptitude, significantly increasing learning efficiency and reducing educational gaps caused by individual differences.

Moreover, AI plays a crucial role in creating realistic experiential learning environments. AI enables the development of virtual labs and complex or dangerous simulations, offering learners hands-on experience with intricate scientific concepts like simulating hazardous chemical reactions or exploring hard-to-access cosmic phenomena, all without spatial or equipment limitations (Cahyono et al., 2024; Mariyono & Nur Alif Hd, 2025; Hardaker & Glenn, 2025). This expands the boundaries of traditional learning and enhances practical understanding.

In terms of management and assessment, AI significantly helps reduce teachers' administrative burden through automated assessment for tasks such as grading exams, analyzing code, or providing initial feedback on projects. Crucially, AI-driven Learning Analytics tools ((Mudkanna Gavhane & Pagare, 2024; Bilal et al., 2025) provide detailed insights into student learning behaviors, pinpointing areas where students struggle and overall trends. This allows teachers and administrators to make data-driven instructional and management decisions and plan curriculum improvements effectively.

Finally, adopting AI also fosters essential future skills for the digital education era and an AI-driven world. Students will develop computational thinking skills through interacting with AI systems and learning about AI's working principles (Bilal et al., 2025). This also includes developing AI literacy and understanding AI's ethical implications, which is crucial for becoming responsible citizens (Hur, 2025). Additionally, using AI as a tool to solve scientific and STEM problems cultivates complex problem-solving skills and critical thinking in evaluating AI-generated results, vital for preparing youth for the future workforce.

Discussion on Challenges and Impacts

While AI strategies offer immense opportunities, their implementation faces several significant challenges that need careful management. Firstly, there's a lack of knowledge and skills among personnel; both teachers and school administrators require continuous professional development to effectively and creatively use and integrate AI into teaching and learning. Secondly, infrastructure and budgetary constraints pose a hurdle. Investing in AI platforms, compatible hardware, high-speed networks, and maintenance is costly, which can be an obstacle for resource-limited institutions, especially in developing countries. This could lead to a digital divide if access to AI technology and the internet remains unequal. Thirdly, ethical, privacy, and data security issues are critical. Collecting large amounts of student personal and learning data via AI, without robust and transparent security measures, risks privacy violations or AI bias stemming from non-diverse training data.

Significant positive impacts include students gaining more effective and accessible learning experiences tailored to individual needs, increased motivation, and teachers shifting to more strategic and creative coaching and mentoring roles. However, potential negative impacts must be acknowledged and prepared for. There's a risk of AI diminishing teachers' roles or causing resistance if teachers aren't adequately upskilled. Over-reliance on AI systems, without engaging in critical analysis, could reduce students' critical thinking and problem-solving skills. Most importantly, the digital divide could widen if technology access isn't comprehensive and equitable.

Conclusion and Suggestions

Implementing AI strategies in STEM science learning management offers a golden opportunity to revolutionize education. However, this must be pursued with a deep understanding of its potential and inherent challenges. Prudent planning, investing in skilled personnel, and strengthening

technological infrastructure are all crucial steps. We also need to develop robust policies that address ethical considerations, data privacy, and equity to ensure AI benefits all students. To truly unlock AI's potential and create a sustainable, beneficial future for STEM education, collaboration is key. The government, educational institutions, the private sector, and AI experts must work together. This collective effort will ensure successful AI integration, fostering innovations that not only prepare our youth for the digital era but also benefit society as a whole. By carefully navigating both the promises and pitfalls, we can create an educational system that empowers the next generation to be leaders in science and technology.

RECOMMENDATIONS

To leverage AI for enhancing science learning management within the STEM education approach, both now and in the near future, a comprehensive, systematic, and highly flexible approach is essential. This ensures the maximum potential of AI to transform education while mitigating potential challenges and negative impacts.

The first key recommendation focuses on visionary personnel development and infrastructure, starting with a serious investment in training and upskilling teachers. This training should equip them with a deep understanding of AI principles and the ability to apply AI tools to design complex, analytical learning activities, rather than just using off-the-shelf software. The training should also emphasize transitioning teachers' roles from knowledge transmitters to facilitators, coaches, and mentors. They should be able to use AI for administrative tasks, automated assessments, and extracting deep insights into student learning behaviors to effectively refine their teaching.

Alongside personnel development, educational institutions must prioritize planning and allocating budgets for appropriate and sustainable technological infrastructure. This includes AI-compatible devices, stable high-speed internet networks, and reliable AI platforms with high security standards. Furthermore, clear policies regarding the collection, use, and protection of student data, as well as measures to prevent potential AI algorithm biases, are absolutely crucial. This builds trust and ensures safety for users and parents.

The second recommendation emphasizes creating a supportive and dynamic learning ecosystem. This begins with promoting systematic and continuous research and evaluation. Educational institutions should regularly assess the use of AI in STEM learning, utilizing data from AI-generated Learning Analytics alongside qualitative feedback from teachers, students, and other stakeholders. This data should then be analyzed to continuously refine strategies, tools, and teaching methods. Supporting teachers and educators in conducting research on AI use in STEM contexts to generate new knowledge and disseminate best practices will drive innovation and overall educational development.

Moreover, fostering strong partnerships with all stakeholders is paramount. This includes collaborating with AI experts from universities and research institutions, industry sectors, and other educational bodies to exchange knowledge, experiences, and resources, as well as jointly funding and developing innovations. Last but not least, establishing an open organizational culture that encourages creative AI experimentation in the classroom, viewing mistakes as part of the learning process (Culture of Experimentation), will reduce technophobia and stimulate the full potential application of AI. By diligently and systematically implementing these recommendations, educational institutions can effectively leverage AI to enhance science learning management within the STEM approach, preparing students to be future-ready citizens and fostering innovations that genuinely benefit society in the digital education era.

ACKNOWLEDGEMENTS

The authors are grateful to acknowledge the support of Advanced Future Talent Academy (AFTA), Thailand.

REFERENCES

Aad, S., & Hardey, M. (2025). Generative AI: hopes, controversies and the future of faculty roles in education. *Quality Assurance in Education*, 33(2), 267-282. https://doi.org/10.1108/QAE-02-2024-0043

Abdekhoda, M., & Dehnad, A. (2024). Adopting artificial intelligence driven technology in medical education. *Interactive Technology and Smart Education*, 21(4), 535-545. https://doi.org/10.1108/ITSE-12-2023-0240

Alsobeh, A., & Woodward, B. (2024). An Integrative Review of AI-Powered STEM Education. *International Journal of AI in Education and Applied Research*, 7(1), 1-15. http://ijeais.org/wp-content/uploads/2024/4/IJAPR240420.pdf

Arslan, N., Haj Youssef, M., & Ghandour, R. (2025). AI and learning experiences of international students studying in the UK: an exploratory case study. *Artificial Intelligence in Education*, 1(1), 1-23. https://doi.org/10.1108/AIIE-10-2024-0019

Asad, M.M., & Ajaz, A. (2024). Impact of ChatGPT and generative AI on lifelong learning and upskilling learners in higher education: unveiling the challenges and opportunities globally. *International Journal of Information and Learning Technology*, 41(5), 507-523. https://doi.org/10.1108/IJILT-06-2024-0103

Assefa, Y., Gebremeskel, M.M., Moges, B.T., Tilwani, S.A., & Azmera, Y.A. (2025). Rethinking the digital divide and associated educational in(equity) in higher education in the context of developing countries: the social justice perspective. *International Journal of Information and Learning Technology*, 42(1), 15-32. https://doi.org/10.1108/IJILT-03-2024-0058

Baber, H., Nair, K., Gupta, R., & Gurjar, K. (2024). The beginning of ChatGPT – a systematic and bibliometric review of the literature. Information and Learning Sciences, 125(7/8), 587-614. https://doi.org/10.1108/ILS-04-2023-0035

Bilal, D., He, J., & Liu, J. (2025). Guest editorial: AI in education: transforming teaching and learning. *Information and Learning Sciences*, 126(1/2), 1-7. https://doi.org/10.1108/ILS-01-2025-268

Cahyono, S., Ardianto, A., & Nasih, M. (2024). Breaking barriers: CEOs STEM educational background and corporate climate change disclosure. International Journal of Accounting & Information Management, 32(4), 651-684. https://doi.org/10.1108/IJAIM-10-2023-0268

Chen, K., Tallant, A.C., & Selig, I. (2025). Exploring generative AI literacy in higher education: student adoption, interaction, evaluation and ethical perceptions. *Information and Learning Sciences*, 126(1/2), 132-148. https://doi.org/10.1108/ILS-10-2023-0160

Cook, J.S., & Cook, J. (2024). Artificial intelligence in management education: transformative potential and challenges. *SAM Advanced Management Journal*, 89(4), 340-355. https://doi.org/10.1108/SAMAMJ-05-2024-0026

Ebekozien, A., Aigbavboa, C., & Aliu, J. (2023). Built environment academics for 21st-century world of teaching: stakeholders' perspective. *International Journal of Building Pathology and Adaptation*, 41(6), 119-138. https://doi.org/10.1108/IJBPA-04-2022-0062

Ellikkal, A., & Rajamohan, S. (2025). AI-enabled personalized learning: empowering management students for improving engagement and academic performance. *Vilakshan - XIMB Journal of Management*, 22(1), 28-44. https://doi.org/10.1108/XJM-02-2024-0023

Elbanna, S., & Armstrong, L. (2024). Exploring the integration of ChatGPT in education: adapting for the future. *Management & Sustainability: An Arab Review*, 3(1), 16-29. https://doi.org/10.1108/MSAR-03-2023-0016

Gafni, R., & Levy, Y. (2024). The role of artificial intelligence (AI) in improving technical and managerial cybersecurity tasks' efficiency. *Information and Computer Security*, 32(5), 711-728. https://doi.org/10.1108/ICS-04-2024-0102

Hannan, E., & Liu, S. (2023). AI: new source of competitiveness in higher education. *Competitiveness Review*, 33(2), 265-279. https://doi.org/10.1108/CR-03-2021-0045

Hardaker, G., & Glenn, L.E. (2025). Artificial intelligence for personalized learning: a systematic literature review. *International Journal of Information and Learning Technology*, 42(1), 1-14. https://doi.org/10.1108/IJILT-07-2024-0160

Hur, J.W. (2025). Fostering AI literacy: overcoming concerns and nurturing confidence among preservice teachers. *Information and Learning Sciences*, 126(1/2), 56-74. https://doi.org/10.1108/ILS-11-2023-0170

Jafari, F., & Keykha, A. (2024). Identifying the opportunities and challenges of artificial intelligence in higher education: a qualitative study. *Journal of Applied Research in Higher Education*, 16(4), 1228-1245.

Kang, H. (2023). Artificial intelligence and its influence in adult learning in China. *Higher Education, Skills and Work-Based Learning*, 13(3), 450-464. https://doi.org/10.1108/HESWBL-01-2023-0017

Li, K.C., & Wong, B.T.-M. (2023). Artificial intelligence in personalised learning: a bibliometric analysis. *Interactive Technology and Smart Education*, 20(3), 422-445. https://doi.org/10.1108/ITSE-01-2023-0007

Lytras, M.D., & Ordonez De Pablos, P. (2024). Guest editorial: Active and transformative learning in higher education in times of artificial intelligence and ChatGPT. *Interactive Technology and Smart Education*, 21(4), 489-498. https://doi.org/10.1108/ITSE-11-2024-252

Marengo, A., Pagano, A., Pange, J., & Soomro, K.A. (2024). The educational value of artificial intelligence in higher education: a 10-year systematic literature review. *Interactive Technology and Smart Education*, 21(4), 625-644. https://doi.org/10.1108/ITSE-11-2023-0218

Mariyono, D., & Nur Alif Hd, A. (2025). AI's role in transforming learning environments: a review of collaborative approaches and innovations. *Quality Education for All*, 2(1), 265-288. https://doi.org/10.1108/QEA-08-2024-0071

Mudkanna Gavhane, J., & Pagare, R. (2024). Artificial intelligence for education and its emphasis on assessment and adversity quotient: a review. *Education + Training*, 66(6), 609-645. https://doi.org/10.1108/ET-04-2023-0117

Narayanan, V. (2023). The transformative AI initiative: from process digitization to AI strategic digitalization. *Strategy & Leadership*, 51(2), 24-30. https://doi.org/10.1108/SL-01-2023-0009

Omran Zailuddin, M.F.N., Nik Harun, N.A., Abdul Rahim, H.A., Kamaruzaman, A.F., Berahim, M.H., Harun, M.H., & Ibrahim, Y. (2024). Redefining creative education: a case study analysis of AI in design courses. *Journal of Research in Innovative Teaching & Learning*, 17(2), 282-296. https://doi.org/10.1108/JRIT-01-2024-0019

Oyelude, A.A. (2024). Artificial intelligence (AI) tools for academic research. *Library Hi Tech News*, 41(8), 18-20. https://doi.org/10.1108/LHTN-08-2024-0131

Payadnya, I.P.A.A., Putri, G.A.M.A., Suwija, I.K., Saelee, S., & Jayantika, I.G.A.N.T. (2025). Cultural integration in AI-enhanced mathematics education: insights from Southeast Asian educators. Journal for Multicultural Education, 19(1), 58-72. https://doi.org/10.1108/JME-09-2024-0119

Phakamach, P. (2023). Educational innovation: elements and mechanisms for the development of Thai educational institutions towards internationalization. *Journal of Education and Innovative Learning*, 3(2), 161-179. https://so06.tci-thaijo.org/index.php/jeil/article/view/261444

Phakamach, P., Panjarattanakorn, D., & Seenonlee, A. (2025). Innovative leadership for professional education administrators in the digital age. *Journal of Education and Learning Reviews*, 2(3), 153–170. https://doi.org/10.60027/jelr.2025.1765

Phakamach, P., Senarith, P., & Wachirawongpaisarn, S. (2022). The metaverse in education: The future of immersive teaching & learning. *RICE Journal of Creative Entrepreneurship and Management*, 3(2), 75-88. https://doi.org/10.14456/rjcm.2022.12

Retno, R.S., Purnomo, P., Hidayat, A., & Mashfufah, A. (2025). Conceptual framework design for STEM-integrated project-based learning (PjBL-STEM) for elementary schools. *Asian Education and Development Studies*, 14(3), 579-604. https://doi.org/10.1108/AEDS-08-2024-0188

Ronaghi, M.H., & Ronaghi, M. (2025). How does the use of artificial intelligence affect sustainability rating in Middle Eastern universities?. *Asian Education and Development Studies*, 14(2), 152-172. https://doi.org/10.1108/AEDS-08-2024-0182

Routray, R., & Khandelwal, K. (2024). Artificial intelligence (AI) adoption: do Generation Z students feel technostress in deploying AI for completing courses of study at universities?. *Asian Education and Development Studies*, 13(5), 534-545. https://doi.org/10.1108/AEDS-06-2024-0115

Sposato, M. (2025). A call for caution and evidence–based research on the impact of artificial intelligence in education. *Quality Education for All*, 2(1), 158-170. https://doi.org/10.1108/QEA-09-2024-0087

Vodenko, K.V., & Lyausheva, S.A. (2020). Science and education in the form 4.0: public policy and organization based on human and artificial intellectual capital. *Journal of Intellectual Capital*, 21(4), 549-564. https://doi.org/10.1108/JIC-11-2019-0274

Weinhandl, R., Lavicza, Z., & Houghton, T. (2020). Mathematics and STEM teacher development for flipped education. *Journal of Research in Innovative Teaching & Learning*, 13(1), 3-25. https://doi.org/10.1108/JRIT-01-2020-0006

Williamson, J.M., & Fernandez, P. (2025). "Through the looking glass: envisioning new library technologies" academic search using artificial intelligence tools. *Library Hi Tech News*, 42(2), 1-5. https://doi.org/10.1108/LHTN-01-2025-0014

Zhan, Z., Shen, W., Xu, Z., Niu, S., & You, G. (2022). A bibliometric analysis of the global landscape on STEM education (2004-2021), towards global distribution, subject integration, and research trends. *Asia Pacific Journal of Innovation and Entrepreneurship*, 16(2), 171-203. https://doi.org/10.1108/APJIE-08-2022-0090