Artificial Intelligence (AI) in STEM education

An NSTF/pro*SET* Discussion Forum

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Concept Document

"It is our job to teach students how to use AI"- Dr Shasta Looper

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Introduction:

Science, technology, engineering and mathematics (STEM) education is increasingly emphasised across educational levels for developing students' cross-disciplinary problem-solving skills, while artificial intelligence (AI) is gaining attention as a tool to automate aspects of human-like problem solving. Integrating AI into STEM education offers opportunities to cultivate AI literacy, engage students in learning STEM knowledge in a fun way, and create synergy between AI and STEM activities that connects school/academic learning to real-life applications. In STEM education, AI supports personalised learning, advanced data analysis, and automated instruction.

Although AI has strong potential to improve STEM learning, there is as yet, limited comprehensive research examining its real impact, implementation challenges, and effective

teaching approaches. While many studies highlight AI's transformative promise, clear plans for how to successfully implement it in schools remain underdeveloped. Most existing research focuses on general education or ICT (information and communication technologies) rather than STEM specifically and often lacks strong empirical evidence or discussion of practical limitations.

Large language models (LLMs) have proven to be extremely useful in finding and summarising information available on the internet or in databases, and chatbots can assist people with getting overviews on almost any topic, thereby simulating teaching of generally accepted knowledge. But what are the limitations in relation to education generally and STEM education in particular? Just because LLMs can imitate human reasoning, does it mean that they are capable of reasoning in the scientific and mathematical worlds?

Here follows a reference to one study. There have been many studies, with contradictory outcomes. AI may not lead to enhanced conceptual learning.

How much research has been done on AI in STEM education?

Triplett (2023) conducted a mixed-methods study on AI in STEM education with teachers and students from diverse public and private institutions. Data was collected via online questionnaires and semi-structured interviews, analysed statistically and thematically. The study found that AI enhances STEM learning by enabling personalised instruction, advanced analytics, and instructional automation, helping address challenges like varying learning speeds and limited hands-on access. While results may not generalise to all institutions and AI is rapidly evolving, the findings provide guidance for integrating AI into STEM education and highlight areas for future research.

If STEM education to develops cross-disciplinary problem-solving skills and AI literacy enables automated problem-solving in ways comparable to humans, does it make sense to. co-develop AI literacy and STEM skills? Curriculum development would need to address:

1. How best to foster AI literacy.
2. How AI elements can make STEM learning meaningful, engaging and fun, as well as promote conceptual understanding.
3. Synergy between AI and STEM activities to connect school learning with real-life applications, particularly through designing AI-enhanced STEM artifacts.

An international panel of various countries examined the use of AI in STEM through different applications and for each presentation the highlights were:

- **Data-Driven STEM Approaches (Hiroaki Ogata):** Pen-stroke analysis and group-learning support enhance student engagement and collaboration in STEM, with AI and data-driven methods offering future opportunities for improvement.

- **Robotic Inquiry Games (Ju-Ling Shih):** Interdisciplinary robotic games, like *Source of Sea*, allow students to explore real-world scientific phenomena, collect data, and build models, while AI can enhance interactivity and complexity.
- **AI/Machine Learning (ML) in Learning Analytics (Gautam Biswas):** Using AI/ML to analyse student behaviours enables **adaptive scaffolding**, transparency, and learning of AI concepts in STEM contexts.
- **Pedagogical Design for AI in STEM (Siu Cheung Kong):** Integrating the Five Big Ideas of AI into STEM activities develops both cognitive and ethical aspects of AI literacy, promoting creativity and responsible technology use.

Do AI and data-driven activities indeed have the potential to enhance STEM education, fostering creativity, problem-solving, collaboration, and real-world applications of knowledge?

Integration of AI in STEM Education:

AI in Education (AIEd) is a growing field that uses AI technologies to improve teaching, learning, and assessment. A specific area within this field, AI in STEM education (AI-STEM), focuses on applying AI tools to support STEM learning. AI tools such as intelligent tutoring systems (ITS), automated grading, data mining, and learning analytics have been used to improve the quality of STEM teaching and learning.

However, STEM education is a complex system made up of connected elements, including learners and teachers (subjects), content (information), tools and platforms (media), and learning settings (environment). Because of this complexity, AI must be carefully designed and integrated to effectively support STEM education.

The integration of AI into STEM education is reshaping teaching and learning. AI technologies, such as adaptive learning platforms**,** ITS**,** virtual and augmented reality (VR and AR)**,** and natural language processing tools, provide personalised learning experiences**,** real-time feedback**,** and data-driven insights into student performance. By tailoring instruction to individual learning styles and pacing, AI could possibly enhance critical thinking**,** problem-solving skills, and engagement, while supporting diverse learners, including those with disabilities or language barriers. AI-driven simulations and virtual labs enable experiential, risk-free learning of complex STEM concepts, making abstract principles more accessible and interactive.

AI's role extends beyond pedagogy to include administrative and decision-making support, allowing educators to track learning patterns, identify students at risk, and implement targeted interventions. Furthermore, AI prepares students for a technology-driven workforce by familiarizing them with AI tools, programming, and ethical considerations, aligning STEM education with the demands of the Fourth Industrial Revolution (4IR).

Despite these opportunities, challenges remain. Effective AI integration requires substantial investments in infrastructure, including reliable internet, computing devices, and cloud-based platforms, which are often lacking in underfunded or rural schools. Teachers require

training and professional development to integrate AI tools effectively into pedagogy, while curriculum design must balance new AI content with existing STEM requirements. Ethical concerns, including data privacy**,** algorithmic bias, and equitable access, must also be addressed to promote critical thinking about AI itself and retain human agency. Concerns related to the environmental costs of data centres should also be borne in mind. High costs of AI technologies further limit scalability, although partnerships with ed-tech companies, government initiatives, and open-source tools can mitigate financial barriers.

Current trends in AI applications for STEM education include:

- **Intelligent Tutoring Systems (ITS):** Provide individualised guidance and learning progression, e.g., Carnegie Learning's Cognitive Tutor.
- **Adaptive Learning Platforms:** Tailor content and exercises to students' needs, offering real-time feedback (DreamBox, Knewton).
- **Virtual and Augmented Reality:** Support immersive learning and visualization of complex systems (PhET, LabXchange).
- **AI-Powered Assessment Tools:** Automate grading and provide feedback (Gradescope, Turnitin Feedback Studio).

Opportunities from AI integration include personalised learning pathways, improved student engagement, support for diverse learning needs, and preparation for future careers in STEM fields.

Best practices from successful case studies include:

1. **Professional development:** Ensure teachers are equipped to use AI effectively.
2. **Equity and access:** Guarantee all students can benefit from AI technologies.
3. **Stakeholder involvement:** Engage students, parents, and communities to build trust in AI adoption.

Recommendations highlight that schools, policymakers, and researchers should collaborate to:

- Invest in **technology infrastructure** and **teacher training**.
- Use AI to create **personalised and inclusive learning experiences**.
- Monitor and address **ethical, privacy, and bias concerns**.
- Continue research on the **long-term impact of AI on learning outcomes**.

The case of South Africa

Over the past decade, AI has evolved from experimental applications to mainstream educational tools, transforming STEM education globally by enabling personalised learning, complex problem-solving, intelligent tutoring, and data-driven school management, while also raising concerns about bias, privacy, and equity. AI innovations such as intelligent labs and virtual simulations enhance conceptual understanding, engagement, and inquiry-based learning, and align with the idea of the 4IR which is knowledge- and skills-focused and the ideal of a (theoretical) human-centred 'Fifth Industrial Revolution (5IR).' Bibliometric studies

show a shift from technical algorithm development to pedagogical applications and ethical considerations, revealing research clusters, collaboration networks, and emerging gaps. In South Africa (SA), national strategies endorse AI as a lever for educational reform, supporting STEM education, addressing historical inequalities, and promoting inclusive learning. However, persistent challenges such as limited cross-institutional collaboration, scarce research on inclusive practices, teacher shortages, infrastructural constraints, and unequal access highlight the need for locally relevant pedagogical, ethical, and policy frameworks to effectively integrate AI into classrooms and improve learner outcomes.

To address this, a study conducted a bibliometric analysis of peer-reviewed publications to map trends, key contributors, collaboration patterns, and emerging research directions in AI for STEM education in SA, with the aim of guiding researchers, educators, and policymakers toward more inclusive and future-ready education aligned with 4IR goals. This bibliometric study examined how South African researchers have explored the use of AI in STEM education, analysing 286 peer-reviewed papers indexed in Scopus from 1990 to early 2025. The findings show that research activity was low before 2015 but increased noticeably after 2015, with a sharp rise following the COVID-19 pandemic, reflecting growing interest in digital learning and alignment with the 4IR. A few universities, including the University of Johannesburg (UJ), University of South Africa (UNISA), and University of KwaZulu-Natal (UKZN), dominate research output, while formerly black institutions lag, and collaboration remains limited both nationally and internationally. Dominant research themes include machine learning, robotics, and digital transformation, largely focused on higher education, with limited attention to basic education, classroom implementation, teacher training, and ethical considerations. Although some international partnerships exist, opportunities remain to expand collaboration, particularly with other Global South countries. The study highlighted the need for inclusive, practice-oriented, and ethically grounded research to ensure AI supports equitable and effective STEM education. Limitations include reliance on the Scopus database and English-language publications, suggesting future studies should use broader, multilingual datasets and incorporate qualitative insights to provide a more comprehensive understanding of AI in South African STEM education.

AI integration in South African basic education:

Global technological advancements are reshaping employment, with demand growing for computer-based competencies, particularly in data science. In response, SA's Department of Basic Education (DBE) introduced a Digital Skills Curriculum for Grades R–9, aiming to equip learners with skills to thrive in a rapidly evolving, technology-driven society and to foster future innovators and entrepreneurs. AI and machine learning are increasingly prevalent in everyday life from smart devices to drones and 3-D printing and even young children are exposed to AI-enabled technology, which influences their cognitive, emotional, and social development.

Currently, most AI education occurs at the university level, focusing on developing professional AI experts. However, primary and secondary schools are increasingly expected to promote AI literacy, aligning content with students' age-specific competencies. Block-based coding has emerged as a practical approach for younger learners, allowing them to create AI-enabled applications without mastering complex programming syntax. These platforms also help teachers facilitate technical learning at accessible levels, expanding educational opportunities.

SA's Curriculum and Assessment Policy Statements (CAPS) have begun integrating AI through coding and robotics, reflecting global trends. Experts recommend three strategies for school AI curricula: learning about AI, learning from AI, and learning with AI, though specifics on content and learning outcomes remain unclear. Challenges include fitting AI into an already dense curriculum, ensuring age-appropriate instruction, providing qualified teachers, adequate computing infrastructure, and responsive policy support. Students' mathematical foundations significantly impact their ability to understand AI concepts, creating disparities in learning outcomes. Non-programming activities are suggested to broaden access and understanding for students less proficient in coding.

The overall emphasis is on gradual, scaffolded AI learning, starting from simple concepts and progressing to more complex applications, with careful planning to overcome structural and pedagogical barriers. Without sufficient resources, guidance, and support, AI integration risks failing to achieve its intended educational impact.

Rationale for a discussion forum on AI in STEM Education:

The Committee of the Professional Bodies and Learned Societies of NSTF, known as pro*SET*, decided that this topic is a burning issue that would be of cross-cutting interest to professionals in STEM, and in STEM education. Representing more than 50 organisations (a third of the National Science and Technology Forum (NSTF) membership), pro*SET* is ideally positioned to lead such a discussion. The topic offers the opportunity for national policy engagement, sharing research findings, as well as case studies and best practice.

The rapid growth of AI and its integration into STEM education globally presents both opportunities and challenges that are particularly relevant to SA. AI technologies such as ITS, adaptive learning platforms, virtual labs, and data-driven analytics offer personalised learning, enhanced problem-solving, and real-world application of STEM knowledge, supporting 4IR skills development. Despite these benefits, evidence from bibliometric studies shows that research on AI in STEM within SA is concentrated in a few universities, mostly focused on higher education, with limited attention to basic education, teacher training, classroom implementation, and ethical considerations. Rural and under-resourced schools face infrastructural constraints, and disparities exist in access, teacher preparedness, and inclusive pedagogical practices.

Purpose:

The NSTF/pro*SET* discussion forum aims to bring together experts to discuss and share insights on the gaps and challenges in integrating AI into STEM education, with a focus not only on universities but on the education system, including basic education. The forum seeks to prepare academia for emerging developments, raise awareness of current practices, and highlight diverse perspectives on AI adoption and its impact on teaching and learning.

Objectives:

- **Bridge research and practice:** Connect policymakers, researchers, educators, and ed-tech developers to share insights on effective AI integration in STEM classrooms.
- **Promote inclusive and equitable AI-STEM education:** Address disparities in access, infrastructure, teacher training, and curriculum design to support diverse learners across urban, rural, and under-resourced schools.
- **Encourage context-specific strategies:** Promote age-appropriate, scaffolded approaches for AI literacy in primary and secondary education that align with South African curricula and socio-economic realities.
- **Examine ethical and policy considerations:** Foster discussions on data privacy, algorithmic bias, and responsible, trustworthy AI use in educational settings.
- **Discuss how to strengthen teacher preparation and professional development:** Educators' competence and confidence must be built to effectively adopt AI tools and pedagogical strategies in STEM teaching.
- **Encourage research collaboration and innovation:** Promote local and international partnerships, including with other Global South countries, to expand knowledge, share best practices, and advance AI-STEM research.

Themes:

- **AI literacy in STEM education**: How to integrate AI concepts, coding, robotics, and simulations effectively at all educational levels.
- **Pedagogical design and classroom practice**: Scaffolding AI learning, experiential learning with virtual labs, and strategies to engage diverse learners.
- **Equity, access, and inclusion**: Ensuring under-resourced and rural schools benefit from AI tools, and addressing disparities in teacher capacity and student readiness.
- **Teacher preparation and professional development**: Building educator competence to adopt AI tools effectively.
- **Research collaboration and innovation**: Encouraging local and international partnerships, especially with Global South countries, to expand knowledge and share best practices.

- **Ethics, privacy, and responsible AI**: Discussing frameworks to ensure safe, fair, and trustworthy AI integration in education.

Questions to investigate:

1. How does the use of AI contradict or impede, scientific thinking?
2. AI can be very useful when technical problems are to be solved. What are some examples and what can go wrong?
3. What best practice guidelines should be taught to students/learners for using AI to solve technical problems?
4. AI cannot do mathematical reasoning although it can solve mathematical problems. What are the implications for learning maths with AI?
5. It is very tempting to use AI for essay writing. How can students/learners be helped to develop their own skills – organising their knowledge, honing their debating skills, and formulating their arguments effectively?
6. How can assessment be done at university level to gauge with some accuracy what students are truly capable of?
7. How can it be ensured that learners master the basic skills of reading, writing and maths while AI is available to do everything for them?
8. How best can school learners' competencies be assessed given that AI can (e.g.) assist them with homework?
9. The wider context of the development of AI: the dependence of AI on vast quantities of (accurate) data, the environmental harm caused by data centres, and the use of AI in warfare: Where should this wider context be addressed in the school and university curricula?
10. Issues of access and the digital divide: does the integration of AI in curricula widen or narrow the digital divide?

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