ARTIFICIAL INTELLIGENCE, AN INNOVATION IN SCIENCE EDUCATION FOR SUSTAINABLE DEVELOPMENT

Bilshak Yakubu Gonchor
THE SCHOOL OF COMPUTING, COLLEGE OF SCIENCE, FEDERAL UNIVERSITY OF EDUCATION PANKSHIN bilshakyakubu@gmail.com,
Gokir Justne Ali
THE SCHOOL OF COMPUTING, COLLEGE OF SCIENCE, FEDERAL UNIVERSITY OF EDUCATION PANKSHIN
Jigokir1@fuep.edu.ng
AND
Nanim David Dandam
THE SCHOOL OF COMPUTING, COLLEGE OF SCIENCE, FEDERAL UNIVERSITY OF EDUCATION PANKSHIN
Dandamnanim125@fuep.edu.ng

Abstract

The internet has transformed human society, reshaping how we work, learn, and spend our free time. Artificial Intelligence (AI) is now driving a new frontier of innovation across education, business, corporate practice, security, and public policy. With deep learning and robotics, AI systems are creating both disruptive and enabling impacts on governments, industry, and global sustainability efforts. As the AI revolution unfolds, it presents dual possibilities: a utopian future of human-machine collaboration or a dystopian one marked by conflict, poverty, and social fragmentation. Against this backdrop, the present study examines AI and robotics as innovations in science for sustainable development, with particular emphasis on science education. Based on a review of recent literature, promising research across diverse fields highlights the potential of AI to address fundamental societal challenges, including climate change, economic resilience, poverty reduction, and social sustainability. However, a critical gap persists: while AI advances rapidly, science education curricula and teacher preparation lag in integrating real-world AI applications, datasets, and ethics needed to develop a workforce capable of steering AI toward sustainable outcomes. This study contributes by: providing a comprehensive overview of AI innovations that directly support the United Nations Sustainable Development Goals, analyzing how these innovations create new pedagogical demands for science education, and outlining future research avenues that align AI development with educational reform. The findings suggest that bridging AI and science education is essential to ensure technological progress translates into equitable, secure, and sustainable societies.

Keywords: Artificial Intelligence; Science Education; Sustainable Development; Robotics; Deep Learning; STEM Curriculum.

Introduction

The internet has changed human society, transforming how we interconnect with others, how we work, how we learn, and how we spend our free time. Artificial Intelligence is a rapidly growing technological domain capable of altering every aspect of life. The integration of AI into education is accelerating, driven by technological innovation and increasing emphasis on sustainability across its three pillars: economic, environmental, and social (Javkhedkar, Shrungarkar, & et al, 2023). In education, AI is producing new teaching and learning solutions that are being tested in diverse contexts. Teacher professional development and continuous learning are essential for advancement and sustainability in teaching and learning systems (Mula & Tilbury, 2023). The merging of AI with sustainable education practices presents both notable opportunities and significant challenges. AI requires advanced infrastructure and an ecosystem of thriving innovators, yet urgent questions remain for developing countries: (Q1) Should AI be a priority to reduce the digital and social divide? (Q2)How can equitable access be ensured? These questions guide this research paper.

To address them, this paper gathers examples of how AI has been introduced in education globally, particularly in developing countries. The discussion draws on debates from the 2019 Mobile Learning Week, which explored multiple pathways to achieve Sustainable Development Goal 4 on quality education. This document is intended for education policymakers and anticipates how AI affects the science education sector so that informed policy responses can be developed.

The first section analyzes how AI can improve learning outcomes. It presents examples of how AI technologies help education systems use data to improve educational equity and quality in the developing world. AI can make learning more engaging and tailored to individual student needs, potentially fostering deeper understanding of ecological and social problems. For teachers, AI can assist in designing experiments, collecting and analyzing data, highlighting new ideas for lessons, and expanding professional knowledge. For students, AI can help them grasp advanced concepts and promote self-directed learning, an essential 21st-century skill (Su & Yang, 2023). Key challenges include ensuring equitable access to AI technologies to avoid widening the digital divide (Directory, 2025).

Moreover, training educators and learners in the effective use of AI is essential to attaining sustainable development objectives (Isidori et al., 2024). AI is spreading worldwide, prompting strong claims: "[AI] is going to change the world more than anything in the history of mankind" and "it is more profound than even electricity or fire" (Toosi et al., 2021). Defining AI is not simple; no universally accepted definition exists, which can lead to uncertainty (Russell & Norvig, 2021).

The term Artificial Intelligence was coined by Stanford Professor John McCarthy in 1955 and defined as "the science and engineering of making intelligent machines." Early research focused on programming machines to act intelligently, for example playing chess. Today, the focus is on machines that can learn, at least somewhat like humans (Manning, 2020). Since the 1950s, AI has gained revolutionary momentum and is seen as a driver of the fourth industrial revolution (Qiang, 2018). Marvin Minsky defined AI as "the science of making machines do things that would require intelligence if done by men" (Minsky, 1969).

AI tools such as ChatGPT, Gemini, and Copilot, and technologies such as machine learning, robotics, and deep learning, contribute to enhanced educational outcomes by removing barriers to educational equity and supporting lifelong learning. They also align with the broader pillars of sustainability--economic, social, and environmental (AlSagri & Sohail, 2024). AI is recognized as a powerful catalyst for change in education, significantly altering methods of knowledge delivery and acquisition. The integration of AI by educators enables a shift from traditional one-size-fits-all approaches to personalized and interactive learning experiences (Bawaneh, 2025).

Organizations such as UNESCO (2019a, 2019b) and the World Economic Forum (2020) have highlighted the importance of using AI for sustainable development. In 2019, two UNESCO conferences addressed this theme: AI for Sustainable Development and International Conference on AI and Education: Planning Education in the AI

Era: Lead the Leap (Ally & Perris, 2022). The incorporation of AI in science education marks a turning point in addressing global challenges within the framework of the 17 Sustainable Development Goals adopted by the United Nations 2030 Agenda, specifically SDG 4 on Quality Education (AlSagri & Sohail, 2024; United Nations, 2015). SDG 4 aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (Tonegawa, 2022).

AI in education for sustainable development (ESD) extends beyond knowledge of society, environment, and economy. It incorporates training, awareness, skills, values, and ethics that inspire people to explore diverse viewpoints (Vinuesa et al., 2020). Elhajji et al. (2020) noted that ESD is transformative and examines learning content, outcomes, pedagogy, and environment to reform society. Education empowers citizens to address inequality, economic challenges, and cultural and natural heritage.

AI in education prepares individuals for the future and enables education for everyone, everywhere. It is based on four pillars: learning to know, learning to do, learning to live together, and learning to be. AI in education keeps pace with the evolving nature of sustainable development, addresses issues through collaboration, and enhances quality of life. AI technologies have the power to redefine communities and economies. They provide benefits such as improved efficiency and new career paths, but also pose risks including misinformation, job displacement, and ethical concerns. Balancing these benefits and harms requires attention to personal, societal, cultural, and ethical considerations that shape attitudes toward AI (Pokrivcakova, 2023).

In 2018, a study examined AI teaching systems and students' environmental knowledge but did not address science teachers' attitudes toward AI (Huang, 2018). The first article directly addressing science teachers' attitudes toward using AI in science education appeared in 2023 (Darayseh, 2023). Another 2023 study in Slovenia examined pre-service teachers' knowledge and attitudes toward AI integration in EFL teaching (Pokrivcakova, 2023). International surveys have found generally positive attitudes among science teachers toward AI in education and its role in sustainable development. In Lebanon, however, such research remains scarce and is concentrated in medical schools due to AI's perceived potential in healthcare (Kharroubi, Tannir, Abu El Hassan, & Ballout, 2024).

This paper aims to fill this gap in educational research. Understanding teachers' attitudes, knowledge, and practices regarding AI is a key factor in the successful application of AI in science education for sustainability, as recommended by UNESCO.

Brief History of Artificial Intelligence

Artificial Intelligence (AI) began as a quest to formalize human reasoning. In 1943, McCulloch and Pitts modeled neurons with logic, and in 1950 Alan Turing asked "Can machines think?" proposing the Turing Test. The field was formally named in 1956 at the Dartmouth Conference, where John McCarthy defined AI as "the science and engineering of making intelligent machines."

1950s-1960s: Early optimism. Researchers built symbolic AI programs like Logic Theorist (1956) and ELIZA (1966) that solved theorems and mimicked conversation in narrow "microworlds." Progress stalled when Minsky and Papert (1969) proved Perceptron could not learn non-linear problems, and the 1973 Lighthill Report cut UK funding. This triggered the first AI winter, 1974-1980.

1980s: Expert systems boom. AI revived with rule-based expert systems like XCON, which saved companies millions by encoding human expertise. Japan's Fifth Generation Project invested heavily. But systems became unmaintainable -- adding rules caused contradictions -- leading to the second AI winter, 1987-1993 as hardware markets collapsed.

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1990s-2000s: Shift to data. AI moved from hand-coded rules to statistical machine learning. IBM's Deep Blue beat Kasparov in 1997 using search, and Watson won Jeopardy! In 2011 using data-driven language processing. The internet and faster computers enabled real-world tasks like spam filtering and recommendations.

2012-Present: Deep learning and generative AI. Alex Net (2012) used GPUs and big data to crush image recognition benchmarks, launching the deep learning era. Transformers (2017) led to large language models like GPT-3 (2020). Chat GPT's 2022 release brought AI to 100M+ users, shifting focus to generative text, images, and code. Today's systems are powerful but still narrow AI -- excellent at specific tasks, not general reasoning.

Benefits of AI in Science Education

AI is beginning to reshape education in ways that could be transformative for a continent (Africa) where teacher shortages, large class sizes, and limited access to quality curriculum materials are pervasive challenges. Adaptive learning platforms use AI to assess each learner's current level, identify gaps in their understanding, and adjust the difficulty and sequencing of content in real time -- providing a degree of personalized instruction that would be impossible for a single teacher managing a classroom of forty students. Intelligent tutoring systems can provide immediate, detailed feedback on student work, guiding learners through their errors rather than simply marking them wrong. AI-powered translation and localization tools are making educational content available in local languages, addressing one of the most significant barriers to educational access in linguistically diverse African contexts.

(i). Personalized Learning: AI can tailor learning experiences to individual students' needs, abilities, and learning styles.

(ii). Intelligent Tutoring Systems: AI-powered systems can provide real-time feedback, guidance, and support to students.

(iii). Enhanced Accessibility: AI can make science education more accessible to students with disabilities and those in remote or underserved areas.

(iv). Data-Driven Instruction: AI can help teachers analyze student data, identify learning gaps, and adjust instruction accordingly.

AI personalizes learning, improving science understanding and skills.

(vi). Increased Accessibility: AI-powered tools make science education more accessible to diverse learners.

(vi). Improved Critical Thinking: AI-facilitated simulations and problem-solving enhance critical thinking.

The implications for Nigeria are significant. With over 250 distinct languages and a persistent shortage of qualified teachers in rural areas, AI-powered educational tools that can operate in local languages and adapt to individual learner needs represent a genuine opportunity to improve educational outcomes at scale. Challenges of AI in Science Education On the risk side:

Dangers of exclusion, the pace of AI development creates genuine dangers of exclusion. If AI systems are primarily trained on data from North America and Europe, they will perform poorly on African languages, contexts, and use cases.

Device access, if access to AI Device are expensive, the benefits of AI will accrue primarily to urban, educated populations and widen existing inequalities

(iii)Internet connectivity, If access to AI tools requires high-speed internet connections or expensive devices, the benefits of AI will accrue primarily to urban, educated populations and widen existing inequalities (iv)Access to power energy, If access to AI tools requires power connections, the benefits of AI will accrue primarily to urban, populations and widen existing inequalities

(v) Shortage of human capacity to deploy to deploy effectively, evaluate them critically, adapt them to local contexts, and govern them responsibly is the central challenge for Africa in the current AI moment.

Way Forward:

Addressing AI challenges in Africa and developing contexts the challenges of exclusion, infrastructure, and capacity must be addressed deliberately if AI is to support sustainable development and equitable science education rather than widen divides. Based on current literature and pilot projects, five targeted strategies are proposed: (i) Dangers of Exclusion:

Build Local Data and Models by invest in African data commons: Governments and universities should fund collection and open licensing of datasets for local languages, agriculture, health, and indigenous knowledge. Examples: Masakhane's NLP datasets for 30+ African languages; Lacuna Fund's agricultural datasets.

Mandate inclusion benchmarks that require AI vendors in education and public services to report performance metrics on African languages and rural contexts before procurement, similar to UNESCO's AI ethics guidelines.

Fine-tune, don't just import: Science education curricula should teach students how to fine-tune open-weight models like Llama, Gemma, or Aya on local data, reducing dependence on North American-trained systems.

(ii) Device Access: Low-Cost, Offline-First AI

Design for basic smartphones: Prioritize AI tools that run on Android Go devices with 2GB RAM using model quantization and distillation. Example: Google's Teachable Machine runs in-browser on low-end phones.

School-based device sharing: Leverage existing computer labs and TVET centers as community AI access points, with solar-powered Raspberry Pi kits running offline LLMs like phi-3-mini for science tutoring

Zero-rating for education: Partner with telcos to make AI education tools data-free, as done with Wikipedia Zero and e-learning platforms in Kenya and Nigeria.

Internet Connectivity: Edge AI and Asynchronous Design

Edge-first deployment: Deploy small language models and classifiers on-device for core tasks -- spelling, math tutoring, crop disease detection -- syncing only when connectivity exists. See: Plant Village Nuru app works offline.

SMS/USSD fallback: For regions with 2G only, build AI interfaces over SMS and USSD. Example: Arifu's learning chatbots in Kenya deliver entrepreneurship lessons via text.

Leverage LEO satellites: Integrate Starlink/OneWeb subsidies for schools into national broadband plans, with AI tools pre-cached locally to reduce bandwidth needs.

Access to Power/Energy: Solar + Low-Power Compute

Solar AI labs: Co-locate solar microgrids with school-based AI hubs. A 5kW system can power 20 Chrome books + edge server, with ROI from community charging fees.

Sub-5W inference: Prioritize ARM-based and NPU hardware. A Raspberry Pi 5 running Llama-3.2-1B uses <4W and can tutor science students offline for 8 hrs on a car battery.

Policy integration: Include AI compute in rural electrification programs. Nigeria's REA and Kenya's Last Mile Connectivity Project should budget for "digital load" alongside lighting.

(v) Human Capacity Shortage: Train Teachers First, Then ScaleWay Forward: AI literacy for science teachers: Make "AI for STEM pedagogy" a mandatory module in teacher training colleges. Focus on: prompt engineering for lesson plans, critical evaluation of AI output, and adapting AI to local examples. UNESCO's AI Competency Framework for Teachers provides a ready template.

Hub-and-spoke capacity building: Train 1 master teacher per LGA on AI tools, who then cascades to 20 others using step-down workshops. FMoE + NITDA can fund this via UBEC.

Youth-to-community model: Engage computer science students in Federal Universities of Education to deploy and maintain school AI labs as part of SIWES/IT, building local support capacity while training the next generation

Governance sandboxes: Create state-level AI-in-Education task forces with teachers, parents, and students to set local rules on data, plagiarism, and use -- building governance capacity from the ground up.

Findings

The research found that AI offers significant benefits for science education in Nigeria and Africa at large, including personalized learning, intelligent tutoring, enhanced accessibility through local languages, and data-driven instruction. These capabilities directly address teacher shortages, large class sizes, and limited curriculum materials that characterize Nigerian education.

However, five interlinked challenges threaten equitable adoption: (i) dangers of exclusion from foreign-trained models, (ii) expensive device access, (iii) unreliable internet connectivity, (iv) lack of power/energy, and (v) shortage of human capacity to deploy, adapt, and govern AI. The analysis shows these challenges are stacked -- without power and connectivity there is no device use; without local data the devices teach foreign contexts; without trained teachers no one adapts or governs

Summary:

AI-powered educational tools that can operate in local languages and adapt to individual learner needs represent a genuine opportunity to improve educational outcomes at scale. Challenges include device access, internet connectivity, and the need to ensure that AI educational tools reflect African cultural contexts and knowledge systems rather than simply replicating Western educational frameworks.

From Challenges to Opportunity. These five challenges are linked: without power and connectivity there is no device use; without local data the devices teach foreign contexts; without teachers no one adapts or governs. The way forward is therefore stacked: start with solar + edge devices + local datasets in teacher training colleges, then scale through teachers to schools. This turns AI from a driver of inequality into a tool for achieving SDG 4 and SDG 10 in science education.

Conclusion

AI is Necessary but Not Sufficient for SDG 4: AI-powered educational tools that operate in local languages and adapt to individual learners represent a genuine opportunity to improve educational outcomes at scale in Nigeria and Africa. Yet technology alone cannot close the digital divide. As the findings show, AI must be paired with deliberate investment in power, connectivity, devices, and teacher capacity to avoid widening inequalities.

Ultimately, AI in science education for sustainable development is more than a database of knowledge. It requires training, awareness, skills, values, and ethics that inspire people to explore diverse viewpoints. Understanding teachers' attitudes, knowledge, and practices regarding AI is the key factor in successful application, as recommended by UNESCO. With deliberate policy and pedagogy, AI can ensure technological progress translates into equitable, secure, and sustainable societies.

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