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Integrating AI in STEM Education in Africa: A Systematic Review of Best Practices and Perspectives

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Abstract:

The integration of Artificial Intelligence (AI) in higher education is gaining global momentum, particularly within STEM (Science, Technology, Engineering, and Mathematics) disciplines. In Africa, however, the adoption of AI in STEM education remains fragmented and underexplored. This systematic review offers a novel and comprehensive synthesis of 46 peer-reviewed studies to assess how AI is being integrated into STEM education across African higher education institutions. Using the PRISMA framework, the review applies both thematic analysis and a PESTEL (Political, Economic, Social, Technological, Environmental, and Legal) lens to discover patterns, regional disparities, and systemic barriers. The study reveals three key innovations: first, it integrates a wide range of theoretical perspectives including Diffusion of Innovations, Constructivist Learning Theory, Cognitive Load Theory, and Postcolonial Theory to interpret the socio-technical and pedagogical dynamics of AI adoption. Second, it develops a strategic, context-sensitive framework to guide the equitable and sustainable implementation of AI in STEM education, aligned with the UN Sustainable Development Goals (SDGs 4 and 9). Third, it critiques Eurocentric approaches to AI adoption and calls for a decolonized, locally adaptive model of AI integration. Major findings include infrastructure deficits, insufficient lecturer training, ethical and policy gaps, and the digital divide all of which hinder AI's transformative potential in African STEM education. Yet, the increasing use of AI tools like ChatGPT, Intelligent Tutoring Systems, and LMS platforms post-2020 signals a turning point. This review advances a nuanced, Africa-centered roadmap for AI in STEM education and contributes original theoretical and strategic insights to the global discourse on educational innovation.

Keywords: *AI Integration in STEM Education, Artificial Intelligence in Africa, STEM Education in Africa, Best Practices in AI Adoption, Higher Education in Africa.*

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Introduction

In recent years, Artificial Intelligence (AI) has become increasingly prominent in educational discourse, offering new possibilities for reshaping learning and teaching practices. Its potential to disrupt conventional classroom models has been widely acknowledged (Chisom, Unachukwu, & Osawaru, 2024). Within the African context, however, the integration of AI into education particularly STEM (Science, Technology, Engineering, and Mathematics) remains uneven. Many institutions face longstanding barriers, such as limited digital infrastructure, inadequate staff training, and significant digital divides that hinder broad-scale adoption (Hlongwane, Shava, Mangena, & Muzari, 2024; Chisom et al., 2024). While studies suggest that AI technologies may improve educational delivery through personalization, assessment adaptation, and learner support, it remains uncertain whether such benefits can be realized uniformly across Africa's diverse higher education systems (Chisom et al., 2024).

Research on AI in education has emphasized the importance of context-sensitive implementation, especially in developing countries where technological disparities persist (Saputro & Fitriawan, 2023; Mahendra et al., 2022). Progress in adopting AI for education in Africa is still developing. Although the use of AI tools ranging from adaptive

learning systems to conversational agents has been linked to better learning experiences and increased student engagement (Hlongwane et al., 2024), many countries are still in exploratory or pilot phases of implementation (Rangavittal, 2024; Kim & Kim, 2022). Educators often recognize the value of these technologies, especially for STEM disciplines, but their effective use is constrained by a lack of training and institutional readiness. In addition, concerns persist about the implications of AI for instructional roles and the transparency of algorithmic decision-making, which adds further complexity to integration efforts.

Some Barriers to AI Adoption

Data Availability

Although efforts to introduce AI into African education systems are underway, these initiatives often face structural limitations. One major obstacle is the scarcity of robust, individualized student data, which forms the backbone of most AI-driven learning systems (Roshan et al., 2023). Without access to detailed datasets, it becomes challenging to offer personalized or adaptive learning experiences, particularly for students with special needs or non-traditional learning profiles (Santos et al., 2024; Lampou, 2023). This shortfall limits the ability of institutions to design inclusive AI applications tailored to diverse learner populations.

Limited Access to STEM

This review takes a systematic approach to analysing how AI is currently being integrated into STEM education within African universities. It explores institutional practices, highlights challenges, and identifies promising strategies for fostering more inclusive and sustainable implementation of AI in higher education. In doing so, the study addresses three guiding research questions:

1. In what ways is AI being adopted within African higher education STEM programs?
2. What challenges and successful strategies are reported in the literature regarding AI integration?
3. What kinds of frameworks could support equitable, long-term adoption of AI tools across the continent?

By investigating these questions, this study contributes to a growing body of work that seeks to localize AI innovations in ways that are practical, context-sensitive, and aligned with Africa's diverse educational realities.

Research Method

To gather a broad perspective on how AI is being introduced into STEM education across Africa, we conducted a systematic literature search using both Google Scholar and Scopus. These databases were selected to ensure a diverse and reliable set of peer-reviewed academic sources. The search was guided by specific keywords such as "AI in STEM education," "Artificial Intelligence in Africa," "STEM education in Africa," and "Higher Education and AI," among others. Our time frame spanned from 2013 to 2024, which allowed us to capture both early developments and more recent trends in AI integration within African higher education systems.

The review process followed the PRISMA 2020 framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). This framework provided a clear structure for identifying, screening, and synthesizing studies. By adhering to PRISMA, we aimed to maintain transparency and rigor throughout the review, from article selection to the interpretation of findings. This approach enabled us to compile a balanced synthesis that reflects the current state of knowledge, while also being sensitive to regional differences and methodological diversity.

Inclusion/Exclusion Criteria

We applied specific criteria to decide which studies to include in the review. Articles were considered eligible if they were peer-reviewed, published in academic journals, and focused on AI use in higher education settings within African countries. In particular, we selected research that assessed AI's impact on teaching practices, learning outcomes, or instructional innovation.

We excluded articles that lacked empirical data, such as conceptual discussions, editorials, and commentary pieces. Studies conducted outside Africa or those addressing AI applications in non-educational contexts were also left out. Our intention was to maintain a clear and focused scope that directly addresses the research questions guiding this review.

Data Extraction Process

Following the initial screening, we performed a detailed review of each selected study using a standardized data collection form. This form helped ensure that we captured consistent information across sources. Each study was examined for several core elements: its research objectives, the type of methodology used (qualitative, quantitative, or mixed methods), and relevant details about the educational context, such as country, institutional setting, and participant demographics.

From each study, we extracted insights related to the adoption of AI tools in STEM education. We noted reported outcomes, such as student engagement, academic performance, and instructor feedback. We also recorded challenges mentioned by the authors and considered their recommendations for improving AI integration in similar contexts. The purpose of this phase was not only to summarize existing evidence but also to understand how it might inform future educational strategies in Africa.

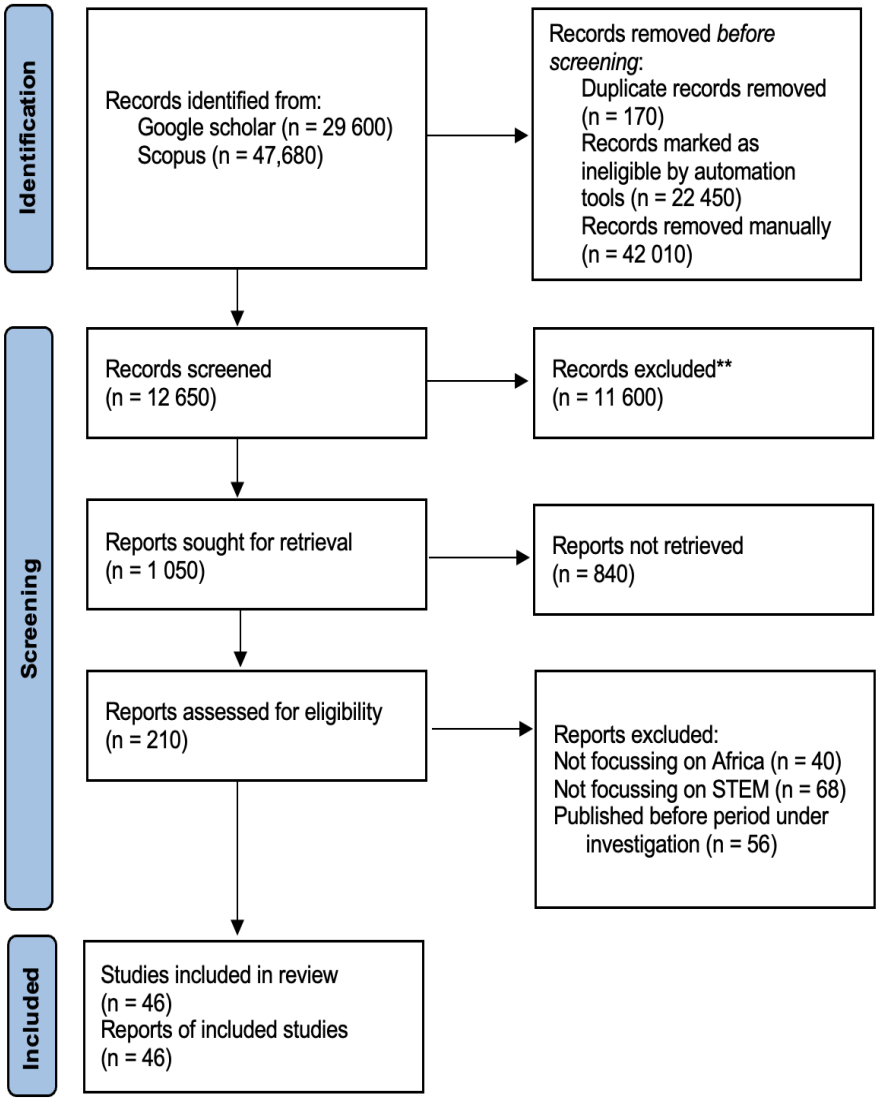

Figure 1. PRISMA Flowchart

Result

Distribution of Publications of AI in HE per Country

The publication distribution on AI in higher education in Africa shows that South Africa is the dominant contributor, accounting for 37.84% of the total publications. Nigeria follows with 10.81%, reflecting its significant role in AI

research within the continent. Ghana, Zambia, and Morocco each contribute 8.11%, representing a notable share of the total publications. Tanzania and Kenya each contribute 5.41%, highlighting emerging contributions from East Africa. Meanwhile, Lesotho, Botswana, Senegal, Cameroon, Madagascar, and Rwanda each account for 2.70%, with one publication each, collectively representing a smaller portion of the total. This breakdown illustrates that while South Africa leads the field, other African nations are beginning to make important strides in AI research within higher education. Figure 2 illustrates this distribution.

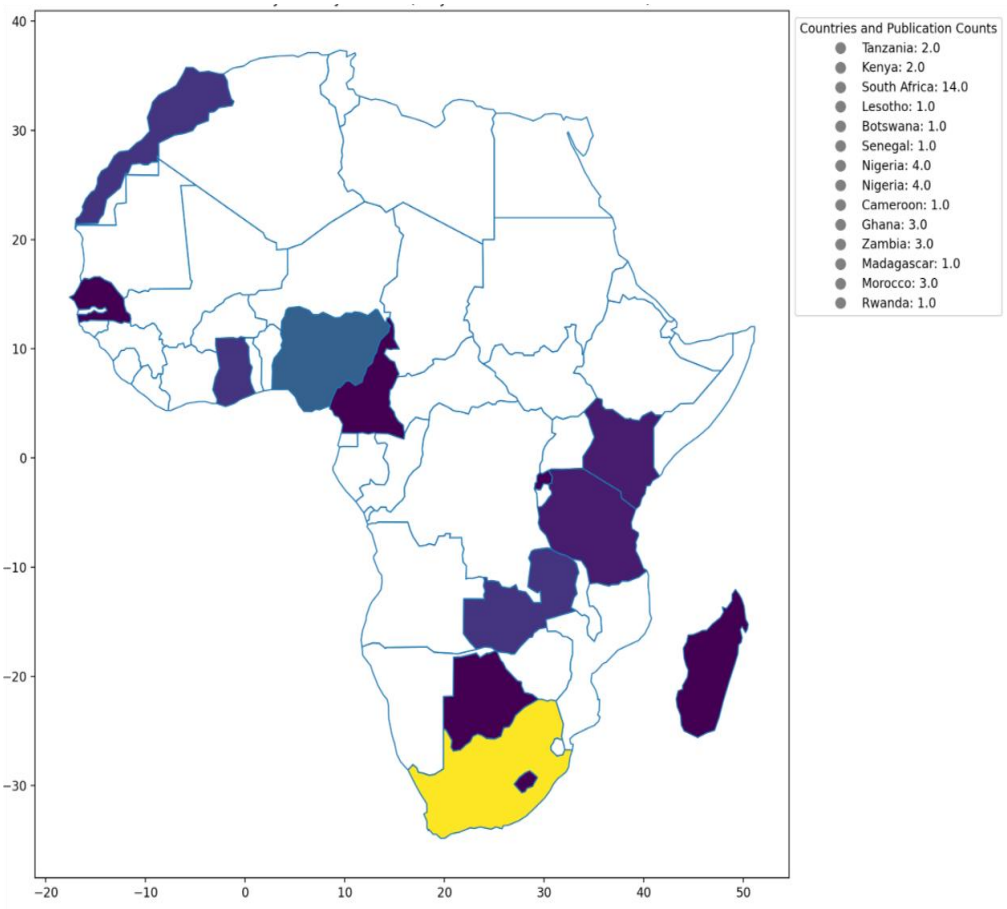

Figure 2. Distribution of AI-related publications in African higher education by country

Distribution of AI Tools and Technologies in Education

Machine Learning & AI leads the list with the highest percentage of 23.91%, followed by Learning Management Systems (LMS) & E-Learning (17.39%) and Virtual Reality (VR) & Augmented Reality (AR) (13.04%). Other notable categories include ChatGPT & Language Models and Intelligent Tutoring Systems (ITS) & Adaptive Learning, each at 10.87%.

The bar graph illustrated in Figure 3 highlights the diverse ways AI is being integrated into educational technologies, ranging from virtual learning environments to intelligent tutoring systems and personalized learning platforms. Lesser-represented categories, such as Robotics & Smart Classrooms and Visualization & Geospatial Tools, each account for 4.35% of the studies.

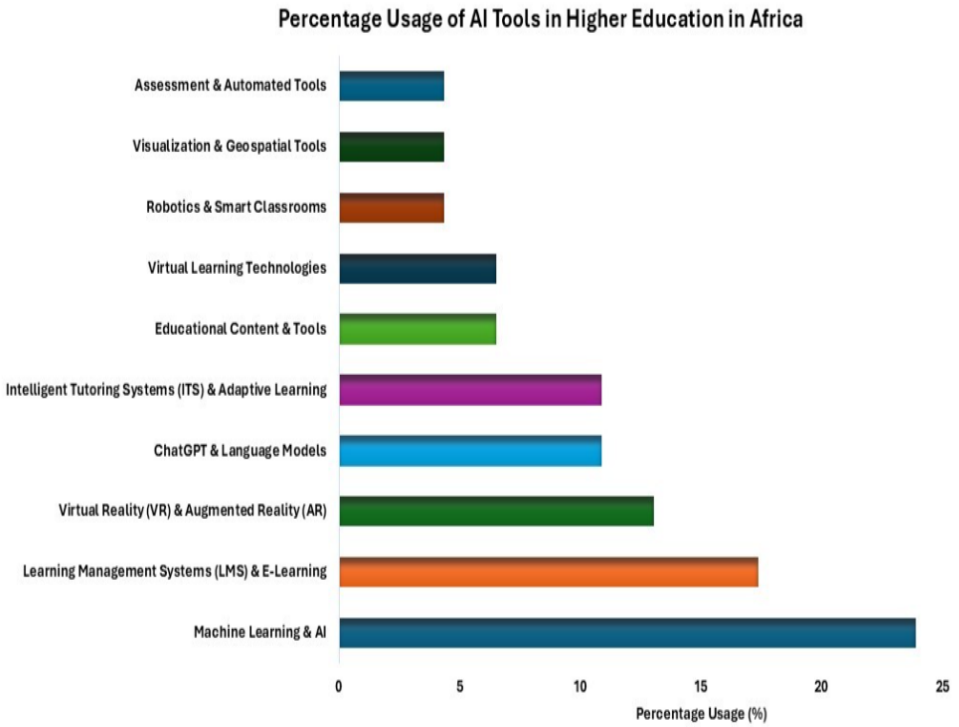

Figure 3. Percentage distribution of various AI tools and technologies across 46 studies

Trends in the Publication of Studies (2013-2024)

In 2024, most studies (41.3%) were published, reflecting a growing interest in the role of technology, particularly AI, in education. The years 2022 and 2017 also saw notable contributions, accounting for 10.87% and 6.52% of the total studies, respectively. Publications from 2012 to 2020 were less frequent, with most years representing under 7% of the total. This trend, which illustrated in Figure 4, highlights a surge in research activity from 2020 onwards, particularly in the wake of the COVID-19 pandemic, which accelerated the adoption of digital and AI technologies in higher education.

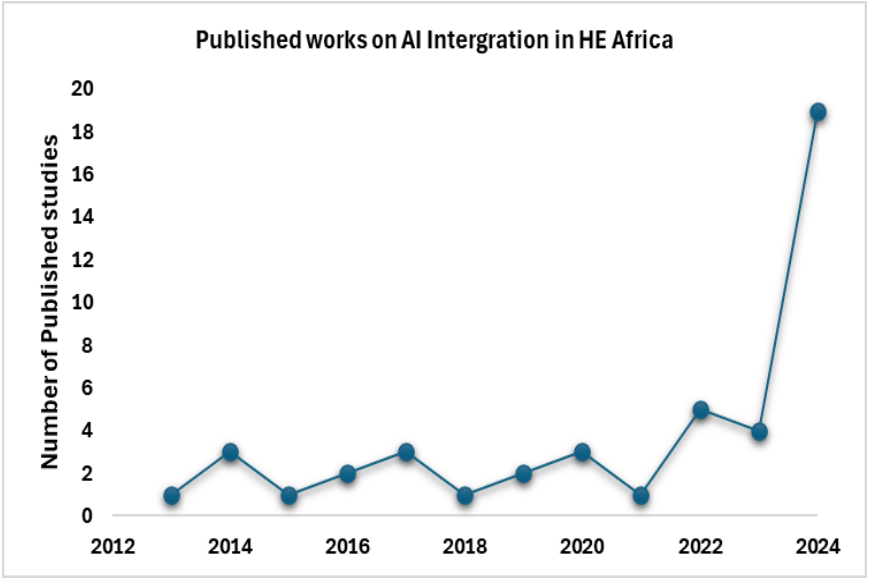

Figure 4. Distribution of the publication years of 46 studies

Overview of AI Integration into STEM Curriculum in African Higher Education

Table 1 provides a summary of key findings related to the integration of Artificial Intelligence (AI) into STEM curricula across African higher education institutions. It highlights the main AI technologies being utilized, such as machine learning, data analytics, and robotics, and presents common challenges faced by institutions, including limited infrastructure, lack of trained personnel, and resistance to change.

Table 1. Key findings summary

Country	AI Technology	Key Findings	Challenges	References
Nigeria	Machine Learning	AI and machine learning can revolutionize STEM education by personalizing learning, automating administrative tasks, and offering data-driven insights, creating adaptive environments that boost engagement and mastery of subjects.	The digital divide, inadequate infrastructure, insufficient teacher training on AI/ML tools, and data privacy concerns	(Joseph & Uzondu, 2024)
Rwanda	ChatGPT	ChatGPT enhanced productivity for academic tasks, with strengths in literature reviews but weaknesses in advanced technical tasks.	Risks of overreliance reduced critical thinking, ethical concerns, and lack of AI policies.	(Numviyumukiza et al., 2024)
Ethiopia	Artificial Intelligence and Machine Learning	AI helps enhance STEM education by promoting coding, math skills, and innovation in Ethiopian schools.	Lack of ICT infrastructure, shortage of qualified teachers, and insufficient government support hinder AI integration.	(Shumiye , 2024)
Multiple African countries (South Africa, Nigeria, Kenya, Ghana)	Intelligent Tutoring System (ITS)	An ITS-based AAC curriculum was developed, positively received by students, showing significant knowledge gains.	Need for further modifications to the ITS for improved effectiveness.	(Dada et al., 2024)
South Africa	AI Chatbots	AI chatbots improve student support in distance learning, offering real-time assistance and engagement.	Implementation challenges include infrastructure limitations, digital literacy, and integration of AI into traditional support systems.	(Mashilo & Shekgola, 2024)
South Africa	Adaptive learning platform - Wiley Plus ORION	The adaptive learning platform improved physics learning outcomes, with a positive correlation between proficiency test scores and paper-based midterm results.	Need for further investigation into long-term effectiveness and user experiences.	(Basitere & Ivala, 2017)
South Africa	Robotics	Robotics in Grade 5 classrooms foster critical thinking, creativity, and collaboration among students.	Limited infrastructure, insufficient teacher training, and challenges integrating robotics into the curriculum.	(Mathebula et al., 2024)
East Africa (Tanzania)	Learning Management System	Four factors significantly influenced students' intention to adopt mobile learning: performance expectancy, effort expectancy, social influence, and facilitating conditions, with performance expectancy as the strongest predictor.	Limited research on mobile learning adoption in the region.	(Mtebe & Raisamo, 2014)
Multiple (Africa Focus)	Adaptive Learning platforms	Adaptive learning platforms enhance personalized education by tailoring content to individual students' needs.	Ethical concerns regarding data privacy, limited digital infrastructure, and the need for teacher training.	(Nyathi & Sisimayi, 2024)

Country	AI Technology	Key Findings	Challenges	References
Africa (Focus on SSA)	Computer Adaptive-Based Learning	Adaptive learning enhances STEM education by providing personalized learning experiences for students.	Key challenges include lack of infrastructure, limited teacher training, and insufficient policy support for technology integration.	(Oladele et al., 2022)
South Africa	E-assessment (Blackboard LMS)	Students experienced anxiety and concentration issues during e-assessments but recognized their value in enhancing higher education.	Limited understanding of factors influencing effective e-assessment implementation	(Thembane, 2024)
South Africa	Virtual Learning Technologies	Virtual classrooms helped sustain learning during COVID-19 but faced accessibility and engagement challenges.	Limited internet access, digital literacy gaps, and difficulties in maintaining student engagement.	(Skhephe, 2022)
Zimbabwe	Virtual Learning Technologies	Virtual learning sustained education during the pandemic but exposed deep inequalities in access and engagement.	Limited access to reliable internet, inadequate infrastructure, and a lack of digital literacy among students and teachers.	(Muchabaiwa & Gondo, 2022)
South Africa	Virtual Reality (VR)	VR enhances engagement and immersive learning experiences, particularly in technology-rich disciplines.	High costs of implementation, limited access to VR equipment, and the need for educator training.	(Matome & Jantjies, 2021)
Multiple (South Africa, Nigeria)	Virtual Reality (VR)	VR is effective in reinforcing engineering concepts, enhancing student engagement and understanding of complex ideas.	High costs of VR implementation and the need for proper infrastructure and instructor training.	(Laseinde et al., 2015)
South Africa	Virtual and Augmented Reality (VR/AR)	VR and AR enhance experiential learning by offering immersive environments for practical education.	High costs of implementation and the need for extensive training for both educators and students.	(Jantjies et al., 2018)
Nigeria	Virtual Reality (VR)	Desktop VR enhances learning experiences by simulating real-world scenarios in higher education classrooms.	High cost of VR implementation, limited access to necessary equipment, and a lack of technical support for educators.	(Onyesolu et al., 2012)
Zambia	Automated Assessment	Automated assessment in learning management systems enhances efficiency and accuracy in evaluating student performance.	Lack of infrastructure limited technical expertise, and the high cost of implementing automated systems.	(Mumbi & Nyirenda, 2024)
Uganda and Nigeria	E-learning Platforms	E-learning adoption is influenced by technological infrastructure, internet access, and students' familiarity with ICT.	Key challenges include inadequate infrastructure, limited digital literacy, high implementation costs, and resistance to change among students and educators in adopting new technologies.	(Hamiza et al., 2014)
Kenya	Plagiarism Detection (Turnitin)	High awareness of plagiarism and Turnitin, but low usage due to negative perceptions and limited licenses.	Negative perceptions; insufficient licenses.	(Rop, 2017)
Uganda	E-learning systems	The adoption of e-learning in Ugandan institutions is influenced by factors such as perceived benefits, complexity, and organizational support. The study emphasizes the importance of top management support and infrastructure.	The key challenges include high complexity in using e-learning systems, lack of sufficient IT resources, inadequate training, and the need for regulatory support to foster smoother adoption of these technologies.	(Nyeko & Ogenmungu, 2017)

Country	AI Technology	Key Findings	Challenges	References
South Africa	AI-based Speech-to-Text Translator	Proposed a real-time AI solution for translating speech to sign language for the hearing impaired. Found limited evidence of AI adoption for this purpose in Africa.	Lack of evidence on AI/ML adoption in healthcare; limited research in the African context.	(Madahana et al., 2022)
Ghana	E-learning systems (Extended TAM Model)	The study identified that self-efficacy, perceived usefulness, and perceived ease of use are significant factors influencing the behavioural intention to use e-learning systems. Self-efficacy is the most influential factor.	Challenges include ensuring proper training and improving technological infrastructure to support the adoption and effective use of e-learning systems in Ghana's tertiary education institutions.	(Budu et al., 2018)
Sub-Saharan Africa	Big Data	The study highlights the potential of big data in improving decision-making and educational outcomes in Sub-Saharan Africa. It emphasizes the importance of data integration and quality in education.	Challenges include poor data integration, issues with data quality, lack of technological infrastructure, and privacy concerns, which all hinder the successful adoption of big data technologies in educational systems.	(Umezuruike & Ngugi, 2020)
Tanzania	Learning Analytics Tool	Developed a tool to analyse LMS data, finding significant factors like discussion posts and peer interaction impacting student performance, while time spent, and login frequency showed no effect.	Reliance on user opinions and subjective data in previous studies; ensuring data reliability.	(Mwalumbwe & Mtebe, 2017)
Africa (Sub-Saharan)	Geospatial visualization tool for NRENs	The tool visualizes network topologies of African NRENs, improving insights into network performance and identifying routing inefficiencies, especially traffic routing through Europe.	Challenges include high latency due to inefficient routing paths and limited infrastructure within Africa, leading to a dependence on external traffic routing through European networks.	(Yang et al., 2016)
South Africa	Podcasts for Learning	Podcasts enhance student learning when tightly integrated into the curriculum, promoting flexibility, reflection, and self-paced learning. Students were generally confident in using them.	Institutional policies on limited Internet quota; challenges in integration into learning design.	(Ng'ambi, Brown, Bozalek , Gachago , 2016)
Egypt	Tableau Big Data Visualization Tool	Tableau helps higher education institutions visualize large datasets to support decision-making related to the United Nations' Sustainable Development Goals (SDGs). It enhances data analysis for educational improvements.	Key challenges included ensuring the technical skills to implement and manage Tableau, the complexity of integrating different data formats, and the need for adequate infrastructure and support for smooth adoption.	(Amer & El-Hadi, 2019)
Egypt	Mobile Learning System ("Easy-Edu")	The mobile learning system enhances communication between educators and students, adjusts curriculum to fit learners' needs, and reduces costs by providing online access to materials.	Large student enrollment challenges in universities; need for effective implementation and adoption.	(Elkhateeb et al., 2019)
Morocco	Interactive animation and ICT in education	The use of interactive 3D animation enhances students' understanding of complex biological concepts, such as cell biology, and improves their engagement and attitudes towards ICT in education.	Key challenges include the need for technological infrastructure, teacher training on effective integration of animation tools, and addressing varying levels of students' access to ICT resources in Moroccan universities.	(El Hammoumi et al., 2022)

Country	AI Technology	Key Findings	Challenges	References
Senegal	AI Chatbot ("Saytù Hemophilie")	The chatbot effectively enhances knowledge and self-management for people with haemophilia, with a high usability score (SUS: 81.7). Preference for Wolof language support was noted.	Variability in users' proficiency in Wolof; ensuring cultural adaptation for broader impact.	(Babington-Ashaye et al., 2023)
Madagascar	Educational videos for health education	The use of culturally appropriate educational videos significantly improved tuberculosis (TB) knowledge in remote, low-literacy populations. Of the participants, 58.9% improved their scores after viewing the videos.	Challenges include addressing the varying levels of literacy among the target population and ensuring sustained use of these videos in remote areas with limited access to healthcare resources.	(Reeves et al., 2020)
Namibia	AI-Powered Chatbot	The chatbot improves efficiency in handling student queries, offering a scalable and accessible alternative to traditional communication methods. User retention is expected to increase over time.	Limitations in the chatbot's capabilities; ongoing user feedback necessary for improvement.	(Hashiyana & Kamati ,2025)
Botswana, Zambia	4IR Technologies (AI, VR, AR)	Higher institutions are integrating 4IR technologies (e.g., LMS, video conferencing) but need to incorporate advanced technologies like blockchain and AI teaching assistants.	Limited adoption of advanced technologies; need for further integration.	(Shonhe et al., 2023)
Rwanda	Smart Classroom Model (SCM)	The smart classroom program positively impacted student performance in subjects like physics, biology, and geography, especially in government-aided schools, among girls, and younger students. The effects were small but significant.	Challenges include the need for long-term exposure to technology to realize significant learning outcomes, and the lack of impact on mathematics and chemistry scores. Additionally, resource limitations in some schools can hinder widespread adoption.	(Nsabimana, et al., 2024)
Cameroon	Learning Management Systems (LMS)	Content delivery has a negligible impact on self-directed learning skills; learning assessments and teacher-student interactions significantly enhance self-directed learning.	Lack of teacher training in LMS usage; potential for monotonous content delivery; need for increased student engagement.	(Kacha et al., 2024)
Africa (General)	AI for Development (AI4D)	AI has the potential to accelerate Africa's development, particularly in areas such as education, healthcare, and energy distribution, with efforts to localize AI models for African languages and contexts.	Challenges include limited infrastructure, dependence on multinational corporations, and a lack of meaningful engagement with the local political and social needs of communities. There is also a gap in the sustainable development impact of AI initiatives.	(Censrehurd & Nyugha, 2024)
South Africa	AI-powered learning management systems (LMS) and intelligent tutoring systems (ITS).	AI enhances student learning, engagement, and motivation by improving personalized learning experiences, making education more inclusive, and fostering a collaborative and supportive learning environment.	The integration of AI in higher education faces challenges related to regulation and policy, including the lack of comprehensive national AI education policies to guide and harmonize its use.	(Opesemowo, Adekomaya ,2024)
Ghana	Virtual Teaching Assistant (Chatbot)	Students using the chatbot performed better academically than those interacting with the instructor. The experimental group	Limited resources for developing and integrating AI tools like chatbots. Technical challenges in implementing AI	(Essel et al., 2022)

Country	AI Technology	Key Findings	Challenges	References
		expressed confidence in the chatbot's effectiveness.	in resource-constrained educational environments.	
Morrocco	ChatGPT	ChatGPT use enhances student learning outcomes by improving perceived usefulness, student satisfaction, and engagement, with output quality, social influence, and perceived ease of use significantly influencing its effectiveness.	The study does not explicitly identify specific challenges, but the implications suggest a need for HEIs to integrate AI effectively into teaching practices and adapt to the digital age.	(Boubker, 2024)
South Africa	ChatBot	Students' intention to adopt chatbots is strongly influenced by their perceived benefits, compatibility, and trialability. Perceived usefulness and ease of use did not directly affect adoption intention, suggesting other factors may play a role.	The study did not identify specific challenges but highlights the need for further exploration into other influencing factors beyond perceived usefulness and ease of use.	(Ayanwale & Ndlovu, 2024)
Morocco	AI-Driven Personalized Learning Platform: Langchain, Pinecone, and the LLM Model.	The AI-powered mobile learning system significantly increased student engagement, understanding, and academic achievement compared to the control group. The system effectively supports mobile learners through personalized, real-time feedback.	The study suggests the need for continuous innovation to improve the system's usefulness and effectiveness in higher education. Some challenges may arise in maintaining the platform's mobile usability across diverse devices and contexts.	(Baba et al., 2024)
Zambia	Turnitin, ChatGPT, Google Cloud AI, Grammarly, Word tune, MATLAB, and DALL-E.	Most used AI tools: Faculty: Turnitin (40.6%), ChatGPT (25%), Google Cloud AI (25%); Students: ChatGPT (45.5%), Google Cloud (41.8%).	The challenges identified in the study include the lack of an AI policy, inadequate ICT infrastructure, erratic internet connectivity, low AI skills, high subscription fees for some tools, and insufficient training on AI.	(Kanyemba et al., 2023)
South Africa	ChatGPT (GPT-4)	The study found that AI tools like ChatGPT can effectively personalize learning, enhance content creation, improve media literacy, and save time for educators, contributing to more engaged and responsible learning experiences.	Concerns about academic integrity due to students using AI tools for assignments. Issues related to data privacy, copyright, manipulation, and ethical use of AI in higher education.	(Bosch et al., 2023)
Lesotho	Chatbot	The study found that students' intention to adopt chatbots for educational purposes is influenced by perceived benefits, compatibility, and trialability, while no direct relationship was found between perceived usefulness, ease of use, and adoption intention.	Other unidentified factors may influence chatbot adoption beyond the tested variables.	(Ayanwale & Molefi, 2024)

The Emerging Themes in AI Integration for STEM Education in Africa

Figure 5 depicts the emerging themes in AI integration for STEM education in Africa, which outlines key areas of focus. Artificial Intelligence (AI) is proving to be a valuable tool in education by enabling more personalized learning experiences. Technologies such as Intelligent Tutoring Systems help students progress at their own pace, while AI-driven platforms also introduce learners to skills like coding and technical problem-solving skills that are increasingly important in today's innovation-driven world. In many African contexts, AI has supported continuity in teaching during crises, such as the COVID-19 pandemic, when traditional learning methods were disrupted.

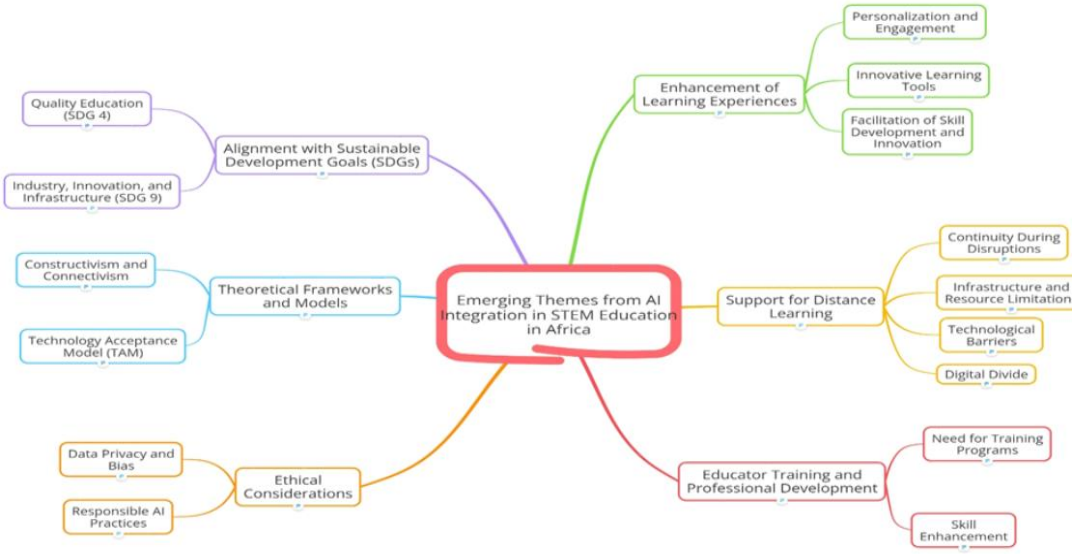

Figure 5. Emerging themes in AI integration for STEM education in Africa

Despite these benefits, the rollout of AI in education is far from straightforward. Many institutions still struggle with issues like poor internet access, lack of infrastructure, and limited availability of trained educators. For AI tools to be used effectively, educators must be equipped with the necessary training and support. Moreover, as AI use grows, it raises important ethical questions, especially concerning data privacy and potential biases in algorithms. To address these concerns and support meaningful adoption, theories such as constructivism and the Technology Acceptance Model (TAM) provide useful guidance for aligning technology use with pedagogical goals. Ultimately, integrating AI into education also contributes to broader developmental priorities, particularly by advancing the United Nations' Sustainable Development Goals specifically SDG 4 (quality education) and SDG 9 (industry and innovation).

Discussion

In this discussion section, we explore the implications of the findings from the systematic review on AI integration in STEM education across African higher education institutions.

Geographic Distribution and Regional Disparities in AI Research in African Higher Education

The development of Artificial Intelligence (AI) in African higher education is progressing at different rates across the continent. Southern and Western Africa, in particular, have made more notable strides likely due to stronger research institutions and comparatively better infrastructure (Kondo & Diwani, 2023; Gikunda, 2023). South Africa has emerged as a leader in this space, with universities such as the University of the Witwatersrand contributing significantly to AI-related scholarship (Kondo & Diwani, 2023). Our review echoes these patterns, showing that South Africa alone accounts for 37.84% of AI publications in the region. Nigeria follows with 10.81%, while Ghana, Zambia, and Morocco each contribute 8.11%. Tanzania and Kenya, representing East Africa, each hold 5.41% of the share, with other countries such as Lesotho, Botswana, Senegal, Cameroon, Madagascar, and Rwanda contributing modestly at 2.70% each.

These variations are consistent with broader theories of innovation diffusion. According to the Diffusion of Innovations (DOI) framework (Rogers et al., 2014), the uptake of new technologies depends heavily on contextual factors, including infrastructure, institutional support, and societal readiness. Countries like South Africa, often seen as early adopters, benefit from better funding and policy alignment. In contrast, other regions face delays in implementation due to weaker infrastructure, limited human capacity, and less cohesive governance strategies (Ndlovu et al., 2025; Arakpogun et al., 2021). Compared to parts of South and Southeast Asia, many African nations still lack the technical expertise and regulatory support needed for full-scale AI deployment (Abanga & Dotse, 2024).

Nevertheless, the potential for transformative AI applications remains significant. Scholars highlight promising opportunities in sectors such as agriculture and financial inclusion, which, if strategically harnessed, could contribute

to the continent's broader socio-economic development (Abanga & Dotse, 2024; Gikunda, 2023). However, such potential can only be realized through enhanced governance, capacity-building, and problem-driven approaches tailored to African contexts. Furthermore, ethical considerations particularly those concerning data privacy, algorithmic bias, and the protection of marginalized groups, must underpin all efforts to create a sustainable and responsible AI ecosystem (Gikunda, 2023). Together, these findings provide a critical backdrop against which the diversity of AI tools and applications used across African higher education institutions (see Section 4.2) should be interpreted.

AI Tools and Technologies in African Higher Education: Trends and Adoption in Educational Applications

Building on the analysis of regional disparities in AI research, this section examines the tools and technologies currently driving AI integration in African higher education. As shown in Figure 3, machine learning and AI systems dominate, appearing in 23.91% of publications, followed by Learning Management Systems (17.39%), AR/VR technologies (13.04%), and emerging interest in tools like ChatGPT, language models, and intelligent tutoring systems (10.87%).

Recent literature confirms these findings: global and African trends are converging around these technologies, with machine learning, AI systems, and LMS at the forefront, and growing experimentation with AR/VR and ITS (Chisom et al., 2024). AI adoption has been shown to enhance personalized learning, educational outcomes, and administrative efficiency, even as it raises ethical and data privacy concerns (Azimova et al., 2025).

Despite growing enthusiasm, practical implementation remains uneven. Many institutions lack the foundational infrastructure or staff training to use these tools effectively, particularly in rural or underfunded settings (Reina-Parrado et al., 2025). Nonetheless, there has been a sharp uptick in AI-related educational research, focusing on adaptive learning environments, automated assessments, and the practical deployment of ChatGPT (Guettala et al., 2024). This suggests a shift from theory to action but success depends on context-sensitive strategies and professional development that supports educators at all levels.

The Technology Acceptance Model (Davis, 1989) helps explain much of this variance: educators are more likely to adopt AI tools when they perceive them as practical and easy to use, and when institutions provide proper infrastructure. Similarly, the slow adoption of immersive technologies like VR and AR can be understood through the socio-technical systems lens (Ray et al., 2025), which emphasizes that technologies must be compatible with institutional culture, not just technically advanced. In short, while AI is steadily gaining ground in African education, its full potential will only be realized when both the human and technical ecosystems are prepared to support it.

Trends in AI Research Publications: Surge in Activity Post-2020 and Impact of the COVID-19 Pandemic on African Higher Education

The rise in AI adoption is not just technological it is also temporal. Figure 4 of our study illustrates a sharp increase in publications after 2020, with 41.3% of the total output appearing in 2024. Smaller peaks occurred in 2022 and 2017, but the most dramatic growth clearly aligns with the COVID-19 pandemic. The forced pivot to remote learning pushed many institutions to test and implement digital solutions, with AI often playing a supporting role.

Recent studies reinforce this narrative. Scholars have observed a post-pandemic surge in AI-related research across domains like personalized instruction, smart assessment systems, and digital learning support (Afzaal et al., 2024; Crompton & Burke, 2023; Rangavittal, 2024). At the same time, however, longstanding limitations such as outdated infrastructure, limited broadband access, and lack of training have continued to constrain uptake in many African universities (Maina & Kuria, 2024).

Crisis-Driven Innovation Theory (Garud et al., 2016) provides a helpful lens here. According to this model, emergencies such as pandemics create pressure points that can accelerate innovation. In Africa, this meant adopting AI tools not just out of interest but necessity. As Fordjour et al. (2020) note, this reactive phase saw digital technologies move from the margins to the mainstream. Yet the unevenness of the shift remains concerning. While some institutions quickly adjusted, others lagged due to deeper systemic inequalities.

The Equity of Access framework (Selwyn, 2017) reminds us that new technologies do not inherently resolve inequality they may in fact reinforce it unless paired with proactive measures. Addressing these disparities requires targeted policies and investments, particularly in underserved regions. The result is a mixed picture: a clear uptick in AI use and research, but one that is fragmented and shaped by resource distribution. The challenge moving forward is to ensure that AI becomes a tool for equity, not just efficiency.

Overview of AI Integration into STEM Curriculum in African Higher Education: Key Findings, Challenges, and AI Technologies Used

The growing integration of AI into STEM education across Africa signals a shift toward more technology-enhanced, future-focused learning environments. Many of these efforts also align with global development agendas, particularly SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure).

Drawing on the findings in this review, we observe that AI is not just being introduced as a tool, but as a means to cultivate 21st-century skills such as critical thinking, coding, and data literacy. It is also supporting more responsive teaching, enabling educators to adjust their approaches based on real-time student feedback and performance data.

This transformation is being analysed through multiple theoretical lenses. Constructivist Learning Theory, for instance, supports the use of adaptive tools that respond to learners' contexts. Meanwhile, Human Capital Theory frames AI as an investment that enhances individual and national productivity. The Technology Acceptance Model continues to be central in understanding how educators perceive and use these technologies.

Yet, serious challenges persist. Many universities still operate with limited connectivity, insufficient hardware, and staff who have had little formal training in educational technologies. Countries like South Africa and Nigeria are showing progress, but disparities remain especially in smaller or more rural institutions. A key takeaway is that local adaptation matters. Technologies must be introduced in ways that consider not only the technical context but also cultural, linguistic, and pedagogical realities. When done right, AI can help bridge existing educational gaps but only if implemented with care and inclusion in mind.

Enhancing Learning Experiences through AI Technologies

One of the notable developments in African STEM education is the use of AI to create more engaging and tailored learning environments. For instance, in Nigeria, machine learning applications have been used to adjust instruction to the needs of individual learners, leading to better subject mastery and increased participation in STEM fields (Joseph & Uzondu, 2024). Similarly, Rwanda's exploration of ChatGPT tools has shown potential for improving academic productivity. Yet, these gains are not without caveats. There are emerging concerns that overreliance on generative AI may hinder students' critical thinking, particularly when tools are used beyond their intended scope (Numviyumukiza et al., 2024).

Such concerns are echoed in recent scholarship, which questions the depth of cognition supported by AI writing tools. While systems like ChatGPT can assist with basic tasks, their role in higher-order thinking is still debated (Essien et al., 2024). Beyond personalization, AI is also being applied to streamline routine academic tasks, such as marking and communication. In doing so, it helps students and educators focus more on meaningful learning and develop the digital fluency required in the evolving job market (Zouhaier, 2023).

However, the value of these systems depends heavily on how they are introduced. Promoting AI literacy and training both educators and learners in prompt engineering and ethical usage has emerged as a core need (Walter, 2024). Encouragingly, some research points to improved learner confidence and critical thinking among non-native English speakers when AI tools are well-integrated (Muthmainnah et al., 2022). That said, institutions must not overlook concerns around algorithmic fairness, data privacy, and the potential for misuse especially in high-stakes academic contexts (Walter, 2024; Muthmainnah et al., 2022).

These observations resonate with Constructivist Learning Theory, which sees AI not as a replacement but as a scaffold that supports learners in constructing their own knowledge (DeVries, 2000). The adaptability of AI learning environments also reflects Vygotsky's idea of the Zone of Proximal Development, where guided assistance can help students move beyond their current skill level (Yousif, 2025). At the same time, Cognitive Load Theory reminds us of that excessive reliance on automation may impair deep learning, especially if it diminishes learner engagement (Abdullah et al., 2025; Sweller, 2011).

There is growing consensus that AI should serve to amplify, rather than replace, students' reflective and metacognitive abilities (Chen et al., 2023; da Silva, 2024; Kundu & Bej, 2024). Meta-analyses back this up, with findings showing that over 70% of reviewed studies noted improvements in self-regulated learning and more than 60% reported gains in critical thinking (Sardi et al., 2025). Even so, the literature continues to stress the importance of maintaining student autonomy and academic integrity through robust policies and training (Mariyono & Hidayatullah, 2025). Ultimately, while the outlook is promising, responsible design and governance are essential to realize AI's full benefits in STEM education.

Advancing Innovation and Skill Development through AI

In addition to improving classroom experiences, AI is playing a growing role in fostering innovation and workforce readiness across African education systems. Ethiopia offers one example, where AI-driven learning programs have been used to boost learners' coding and mathematics abilities two areas critical to emerging STEM careers (Shumiye, 2024). Similarly, the deployment of Intelligent Tutoring Systems (ITS) in countries like South Africa and Nigeria demonstrates how adaptive instruction can help students build deeper understanding by aligning content with individual learning paths (Dada et al., 2024). This type of experiential learning supports Kolb's theory, which emphasizes that knowledge is best retained when actively applied (Kolb, 2014).

These developments are not just educational they are economic. Human Capital Theory (Becker, 1964) suggests that strategic investments in education and digital skills lead to long-term gains in national productivity. By equipping students with skills in data analysis, digital collaboration, and AI-assisted problem-solving, education systems are preparing them for participation in fast-evolving global markets. Self-Determination Theory also comes into play here: when students feel competent and autonomous, they are more motivated to engage and persist in learning (Deci & Ryan, 2012; Xu et al., 2025).

At the policy level, AI contributes directly to the advancement of SDG 9 by encouraging technological innovation and sustainable infrastructure. It also supports SDG 4 by improving access to quality education and optimizing resource use to reduce inequality (Alsagri & Sohail, 2024; Singh et al., 2024). That said, scaling these benefits requires thoughtful implementation. While AI tools have shown they can enhance student confidence and efficiency, ethical issues around privacy, surveillance, and academic misconduct must be addressed (Singh et al., 2024).

Recent reports highlight AI's role in developing key 21st-century skills problem-solving, adaptability, and digital literacy among them. These are seen as essential for strengthening Africa's STEM workforce (Chasokela, 2025). However, the success of AI in this domain depends as much on human factors training, ethics, motivation as it does on technical sophistication. In this way, the value of AI rests not only in its innovative capacity but also in its alignment with inclusive educational practices and sound pedagogical theory.

Enhancing Learning Outcomes and Instructional Efficiency through AI Integration

Building on the earlier discussion of learning experiences, additional evidence from African higher education illustrates how AI technologies can support both improved academic outcomes and more efficient teaching practices. For instance, in Cameroon, the introduction of Learning Management Systems (LMS) revealed that while content delivery is important, it is the interactive elements such as assessments and meaningful teacher-student exchanges that foster self-directed learning (Kacha et al., 2024). This insight aligns well with Constructivist Learning Theory and Self-Regulated Learning Theory, both of which highlight the need for active participation and timely feedback to develop autonomy and metacognitive awareness (Zimmerman, 2002).

In the South African context, AI-enhanced platforms, including LMS and Intelligent Tutoring Systems (ITS), have been associated with greater student motivation, better personalization, and improved inclusivity in diverse classrooms (Opesemowo & Adekomaya, 2024). These outcomes can be viewed through Vygotsky's concept of the Zone of Proximal Development, where technology acts as a scaffold to support learning progression (Yousif, 2025). Ghana's experience with virtual teaching assistants (chatbots) also stands out students reported both academic improvement and increased confidence in using these tools (Essel et al., 2022). This kind of learner trust speaks to Self-Determination Theory, where competence and relatedness help foster deeper engagement (Deci & Ryan, 2012).

In Morocco, AI tools such as ChatGPT have improved student satisfaction and perceived ease of learning key drivers in the Technology Acceptance Model (Boubker, 2024). Similarly, when personalized platforms using Langchain and Pinecone were introduced, students demonstrated stronger academic outcomes, although issues related to cross-device usability underscored the need for ongoing technical refinement (Baba et al., 2024). In South Africa, GPT-4-based applications helped educators craft flexible learning spaces while boosting media literacy and streamlining instruction showing how AI can support both teaching and learning efficiency (Bosch et al., 2023).

Taken together, these findings reinforce the value of strategic AI use. Tools that are contextually implemented and pedagogically sound can contribute to equity, engagement, and improved academic performance (Onyebuchi et al., 2024; Saifullah et al., 2024). These applications echo Experiential Learning Theory, which emphasizes the importance of active and personalized cycles of learning (Kolb, 2014). However, their effectiveness ultimately depends on thoughtful integration rooted in theory and tailored to specific learning environments.

Challenges of AI Integration in STEM Education

While the benefits of AI in STEM education are compelling, several constraints limit its effective use particularly in resource-limited environments. Infrastructure challenges remain among the most critical. In countries like South Africa and Ethiopia, consistent access to reliable internet, electricity, and adequate computing resources continues to hinder widespread AI adoption (Shumiye, 2024; Mashilo & Shekgola, 2024).

These limitations affect both students and educators. Without stable platforms and high-performing devices, even well-designed AI systems fail to deliver meaningful impact. Personalized learning, adaptive testing, and real-time feedback hallmarks of AI-enhanced education are difficult to implement in environments lacking the technological foundation to support them. Therefore, bridging the infrastructure gap must be prioritized if the full promise of AI in African STEM education is to be realized.

Challenges in AI Integration: Lecturer Training, Infrastructure, and Local Adaptations

The case of Cameroon highlights how successful AI integration depends not only on having the right tools but also on the readiness of those who use them. The introduction of LMS platforms faced barriers due to insufficient lecturer training and the frequent use of monotonous, non-interactive content formats both of which undermined student engagement (Kacha et al., 2024). These micro-level issues reflect broader systemic challenges faced by institutions across the continent.

More broadly, Africa's involvement in global AI for Development (AI4D) initiatives has exposed structural dependencies, particularly on multinational tech providers. These partnerships often overlook local needs and knowledge systems, leading to solutions that may not align with regional realities (Censrehurd & Nyugha, 2024). This lack of contextual adaptation can result in a mismatch between imported technologies and classroom dynamics.

These concerns are supported by the Socio-Technical Systems perspective (Emery & Trist, 1960), which argues that technology must be integrated in harmony with local social and institutional frameworks. Postcolonial Theory also offers valuable critique here, highlighting the risks of adopting Western-centric educational models without critical adaptation to African contexts (Chaaban et al., 2024; Waghid, 2022).

Recent literature has stressed the importance of co-designing educational technologies with local stakeholders, to ensure cultural relevance and long-term sustainability (Mhlanga & Moloi, 2023; Mhlanga, 2025). While AI and LMS systems hold immense potential to personalize learning and improve outcomes, their impact is often constrained by underdeveloped infrastructure, lack of professional development for faculty, and insufficient institutional support (Maina & Kuria, 2024; Bervell & Umar, 2017).

When used well, LMS platforms can assist with learning analytics, instructional planning, and personalized feedback (Maluleke, 2024). But to get there, institutions must address the underlying issues such as funding, equity, and training and commit to collaborative implementation. Only by grounding technology in local realities and empowering educators can African universities fully benefit from AI-enhanced learning systems (Maina & Kuria, 2024; Chisom et al., 2024; Maluleke, 2024).

Regulatory and Policy Challenges in AI Integration

Incorporating Artificial Intelligence (AI) into tertiary education across Africa particularly in countries such as South Africa and Ghana offers significant promise but also raises complex regulatory and policy-related concerns. For instance, South Africa lacks a unified national framework guiding AI use in education, resulting in fragmented adoption efforts across institutions (Opesemowo & Adekomaya, 2024). The absence of consistent regulations impedes long-term planning and creates gaps in ethical oversight, data protection protocols, and implementation standards. In Ghana, the situation is further complicated by limited access to technical infrastructure and financial resources, which pose challenges for deploying tools like chatbots effectively in academic settings (Essel et al., 2022). These constraints disproportionately impact less-resourced institutions and exacerbate inequality in digital learning opportunities.

Additionally, the growing use of AI-generated content has introduced new intellectual property dilemmas. Uncertainty around authorship and ownership of AI-assisted outputs raises concerns about academic recognition and creative accountability (Ayandibu, 2024). In the absence of clear legal protections, both faculty and students may be hesitant to fully engage with AI-driven platforms, potentially stalling innovation in research and teaching.

Despite the benefits of AI such as streamlining assessments and enabling adaptive instruction structural issues persist. These include a lack of technical capacity, uneven distribution of skilled professionals, and ongoing socio-economic disparities (Patel & Ragolane, 2024). Without adequate safeguards, the integration of AI may widen the digital divide

instead of closing it. Maina and Kuria (2024) emphasize that the lack of governance mechanisms limits the ability of institutions to address ethical challenges such as data privacy, algorithmic fairness, and bias mitigation.

The urgency of these issues is particularly evident in South Africa, where current education policies rarely address AI's ethical dimensions (Ayandibu et al., 2024). This regulatory silence risks enabling unchecked use of AI, with implications for academic integrity and institutional credibility. As Funda and Mbangeleli (2024) suggest, future policies must prioritize technical training, ethical awareness, and equitable access to ensure AI tools genuinely enhance learning outcomes rather than reproducing existing disparities.

Ultimately, to harness AI's full potential in African higher education, governments and institutions must craft policies that support both innovation and accountability. These frameworks should be locally relevant, ethically sound, and aligned with broader goals for inclusive educational development.

Infrastructure and Resource Challenges in AI Adoption

In Zambia, the rollout of AI technologies ranging from Turnitin and ChatGPT to MATLAB and DALL·E has exposed a set of recurring challenges that limit their educational impact. These include the lack of a comprehensive AI strategy, poor ICT infrastructure, unreliable internet connectivity, limited digital literacy among staff and students, and high subscription costs for certain platforms (Kanyemba et al., 2023). Without significant improvements in infrastructure particularly in underserved rural areas many learners remain excluded from the benefits of AI-enhanced instruction.

While AI applications have shown promise in improving classroom engagement and operational efficiency (Maina & Kuria, 2024), their adoption is slowed by persistent issues like under-resourced facilities and shortages of qualified educators. This is particularly problematic in rural settings, where connectivity and hardware access are minimal (Boateng, 2024; Kamarullah et al., 2024). In response, educators in some institutions have implemented creative workarounds, such as rotating computer access and encouraging group-based problem solving, to make the most of limited tools (Kamarullah et al., 2024).

AI has been applied across various domains of education from automated grading and science simulations to coding instruction and research assistance (Boateng, 2024). For example, when used in postgraduate research assessments, AI systems can speed up feedback and improve consistency. However, questions around fairness, transparency, and accountability continue to surface (Juma et al., 2025).

Addressing these structural constraints requires more than just adopting new tools. It demands comprehensive investment in digital infrastructure, expanded professional development programs for lecturers, and coherent policy interventions that encourage ethical and effective AI use (Maina & Kuria, 2024; Juma et al., 2025). Without this foundation, the digital transformation of African higher education will remain uneven and limited in scope.

The Need for Lecturer Training and Professional Development

Effective integration of Artificial Intelligence (AI) into African higher education systems depends heavily on the preparedness of lecturers. A lack of sufficient training in AI tools particularly in emerging areas like robotics has been identified as a major barrier to successful adoption (Mathebula et al., 2024). This gap is evident in contexts such as Cameroon, where many educators remain unfamiliar with how to leverage Learning Management Systems (LMS), leading to underutilization and poor instructional outcomes (Kacha et al., 2024). Similarly, educators in Zambia often lack foundational AI literacy and access to training, further limiting the impact of AI in teaching and learning (Kanyemba et al., 2023).

This challenge directly connects to Sustainable Development Goal 4, which calls for improving teaching quality and educational outcomes (Baba et al., 2024). Without targeted professional development, the transformative potential of AI remains out of reach. Building lecturers' capacity to integrate these tools into pedagogical practices is not only a technological necessity but a strategic imperative for educational advancement.

Recent studies highlight just how urgent this need is. Roshan et al. (2024) found that while 40% of educators report moderate familiarity with AI technologies, only 5% feel confident using them, and the vast majority around 70% have never received any formal training in AI. Bekdemir (2024) argues that bridging this gap requires embedding AI competencies into pre-service and in-service teacher education, alongside ethical instruction. Mission et al. (2024) also point out a disconnect between AI content in university IT curricula and actual industry needs, largely due to inadequate lecturer training and unequal access to resources.

Together, these findings underline the importance of structured, continuous professional development initiatives. Empowering lecturers with both technical and ethical AI competencies is essential not only for improving teaching

quality but also for supporting broader development goals, including decent work and lifelong learning as outlined in SDG 8 (Roshan et al., 2024; Mission et al., 2024).

Ethical Considerations in AI Integration

As AI technologies become increasingly embedded in African higher education, ethical issues have moved to the forefront of academic and policy discussions. Concerns include data privacy, the risk of algorithmic bias, and the potential for misuse in institutional decision-making (Numviyumukiza et al., 2024; Nyathi & Sisimayi, 2024). In countries like South Africa, the use of tools such as ChatGPT (GPT-4) has prompted scrutiny around academic integrity, intellectual property, manipulation, and responsible data handling (Bosch et al., 2023).

Establishing clear ethical frameworks is therefore essential to ensure that AI is implemented in a way that builds trust, protects users, and supports equitable learning. These frameworks must be sensitive to the socio-political realities of African education systems. For instance, many AI for Development (AI4D) efforts struggle with both infrastructural limitations and the failure to meaningfully engage local cultural contexts factors critical to equitable implementation (Victor, 2025).

The ethical challenges extend beyond technical concerns to broader structural and ideological questions. Scholars warn that poorly contextualized AI deployment risks reinforcing systemic inequalities and fostering a form of digital colonialism, where external technologies dominate local practices and marginalize indigenous epistemologies (Mubangizi, 2024).

In response, growing academic consensus calls for the decolonization of AI in African education. This involves reimagining technology use in ways that prioritize inclusion, cultural relevance, and empowerment of marginalized communities (Hlatshwayo, 2023). Promoting such a shift requires not only ethical safeguards but also pedagogical strategies that recognize learners' social and cultural identities.

While AI holds significant promise for personalized learning, greater access, and administrative support—it also introduces risks that must be addressed head-on. Farooqi et al. (2024) emphasize the need to preserve meaningful human engagement in education, even as automation expands. Likewise, generative tools like ChatGPT offer both opportunities and challenges, including threats to learner autonomy and increased potential for academic dishonesty (Mariyono & Hidayatullah, 2025).

To manage these complexities, institutions must adopt a balanced strategy that includes ethical policy development, educator training, and equitable access to resources (Mishara, 2024). Only through such intentional, inclusive approaches can AI be integrated in a manner that is both transformative and responsible across African higher education.

Strategic Management of AI in Education

Looking to the future, the successful integration of Artificial Intelligence (AI) into higher education demands deliberate application of change management principles. These principles emphasize the need to reshape organizational structures and cultivate institutional cultures that support innovation, collaboration, and adaptability. A cornerstone of this process is engaging key stakeholders from the outset building trust, fostering shared ownership, and minimizing resistance to change are all vital to ensuring the sustainability of AI-driven reforms (Zembylas, 2023; Chan, 2023).

Strategic planning also benefits from employing established management tools such as the PESTEL framework, which facilitates a holistic analysis of the Political, Economic, Social, Technological, Environmental, and Legal dimensions affecting AI adoption. Politically, case studies from countries like South Korea show how strong policy direction and government backing have accelerated the implementation of AI in educational systems. Economically, disparities in public and private funding influence how effectively institutions can deploy AI tools, with well-resourced systems typically achieving more robust outcomes.

Social factors including graduation rates, job readiness, and levels of inclusion offer insight into how AI impacts educational equity and access. On the technological front, AI introduces capabilities such as adaptive learning, automated assessments, and real-time analytics that can enhance both teaching and institutional management. Environmental considerations are increasingly relevant, as AI curricula should not only reflect global sustainability goals but also raise awareness about the ecological impacts of digital technologies.

On the legal side, institutions must navigate a complex regulatory landscape. Effective AI implementation requires clear frameworks addressing data protection, authorship, and algorithmic transparency. These safeguards are essential to protect the rights of students and educators while maintaining institutional integrity. In this context, a coordinated,

policy-driven approach grounded in change management theory and supported by contextualized strategic tools like PESTEL can guide higher education institutions in Africa toward responsible and effective AI integration.

The integration of AI in higher education holds transformative potential, enhancing personalized learning, streamlining administrative functions, and preparing graduates for a rapidly evolving digital economy (Fayziyeva, 2025; Sidorkin, 2025). Realizing this potential, however, necessitates a multidimensional strategy that addresses pedagogical, operational, and governance challenges (Chan, 2023). Key approaches include curriculum restructuring to focus on meta-AI competencies, differentiating between temporary and long-term AI pedagogical supports, and leveraging AI to strengthen academic support services (Sidorkin, 2025).

Nonetheless, persistent challenges such as infrastructure deficits, ethical dilemmas, and concerns over data security must be addressed to ensure sustainable AI integration (Patel & Ragolane, 2024). Strategic planning and institutional roadmaps are needed, supported by reliable funding mechanisms and a clear vision. Additionally, cross-sector collaboration among policymakers, educators, technology developers, and civil society is critical for navigating the complexities of AI adoption and maximizing its impact in African higher education contexts (Patel & Ragolane, 2024; Fayziyeva, 2025).

Aligning AI Integration with Broader Development Goals: Future Directions for AI in STEM Education

To ensure long-term impact, the integration of Artificial Intelligence (AI) into African higher education systems must align closely with national development priorities and global goals. Rather than being implemented in isolation, AI strategies should be embedded within strong conceptual frameworks that promote equity, coherence, and relevance to local educational needs. Without such alignment, there is a risk that AI could widen existing educational disparities. Policies must actively promote equal access to AI tools, training, and digital infrastructure so that learners across rural and urban, rich and poor regions benefit equally from AI-enhanced instruction.

For AI to fulfill its potential in advancing STEM education, several key priorities need to be addressed. As noted earlier (see Sections 4.4, 4.6, and 4.12), professional development remains foundational. Educators require targeted training in AI literacy, prompt engineering, and digital pedagogy to use these tools effectively. Infrastructure development (refer to Sections 4.8 and 4.11) is also essential, especially in under-resourced communities where lack of connectivity and equipment continues to limit access.

Equally important are strong ethical guidelines (see Section 4.13). These must address issues such as data privacy, algorithmic fairness, and responsible use. Ethical frameworks should reflect local cultural values while also drawing from global best practices. Integrating AI initiatives into broader policy efforts, such as the United Nations Sustainable Development Goals (SDGs) particularly SDG 4 (quality education) and SDG 9 (industry and innovation) ensures that the pursuit of technological advancement also supports social equity and sustainable growth.

Theoretical Synthesis and Conceptual Integration of Findings

This review highlights the complex and uneven adoption of AI in STEM education across African universities. When analysed through key theoretical lenses, these variations reveal underlying systemic patterns and offer insights for future planning.

Diffusion of Innovations (DOI) theory (Rogers, 2003) helps explain why some countries are further ahead. South Africa, for example, benefits from stronger infrastructure and research capacity, positioning it as an “early adopter,” while others lag due to limited resources and institutional readiness.

The Technology Acceptance Model (TAM) (Davis, 1989) is useful for understanding educator and student engagement with AI tools like ChatGPT or VR learning platforms. Perceptions of usefulness and ease of use significantly shape adoption outcomes, as evidenced in studies from Ghana and Morocco (e.g., Boubker, 2024; Alalwan et al., 2023).

Sections 4.4, 4.5, and 4.7 show how AI supports personalized learning, aligning with Constructivist Learning Theory (DeVries, 2000) and Vygotsky’s Zone of Proximal Development (ZPD). These frameworks explain how intelligent systems can adapt to learners’ needs. However, Cognitive Load Theory (Sweller, 2011) reminds us that poorly designed systems may undermine deep learning, especially if automation replaces critical thinking tasks (Muthmainnah et al., 2022; Essien et al., 2024).

When used in skill-based learning, Human Capital Theory (Becker, 1964) frames AI as an investment in the workforce of tomorrow. At the same time, Self-Determination Theory (Deci & Ryan, 2012) offers insight into how adaptive AI tools support motivation, autonomy, and student engagement (Xu et al., 2025).

Challenges like infrastructure gaps and policy limitations (Sections 4.8–4.11) are best understood through a Socio-Technical Systems perspective (Emery & Trist, 1960; Baxter & Sommerville, 2011). This model emphasizes the need for technological tools to be aligned with social, institutional, and cultural realities.

The concern about foreign dominance in educational technologies (Section 4.13) is critically addressed through Postcolonial Theory (Waghid, 2022; Chaaban et al., 2024). This lens warns against overreliance on Eurocentric tools and calls for locally relevant, participatory approaches to AI design and adoption.

Finally, the increased adoption of AI following the COVID-19 pandemic (Section 4.3) can be viewed through Crisis-Driven Innovation theory (Garud et al., 2016), which shows how emergencies accelerate change. However, frameworks focused on Equity of Access (Selwyn, 2017) caution that such advances must be inclusive—otherwise, they risk reinforcing social divides.

In summary, these overlapping theories offer a rich conceptual foundation for understanding AI's opportunities and pitfalls in African higher education. They highlight the importance of aligning technological innovation with ethical principles, infrastructure development, educator readiness, and cultural responsiveness. The strategic roadmap (Figure 6) synthesizes these insights, offering practical guidance for institutions seeking to implement AI in ways that are both effective and equitable.

Proposed Framework for Strategic AI Integration in STEM Education in Africa

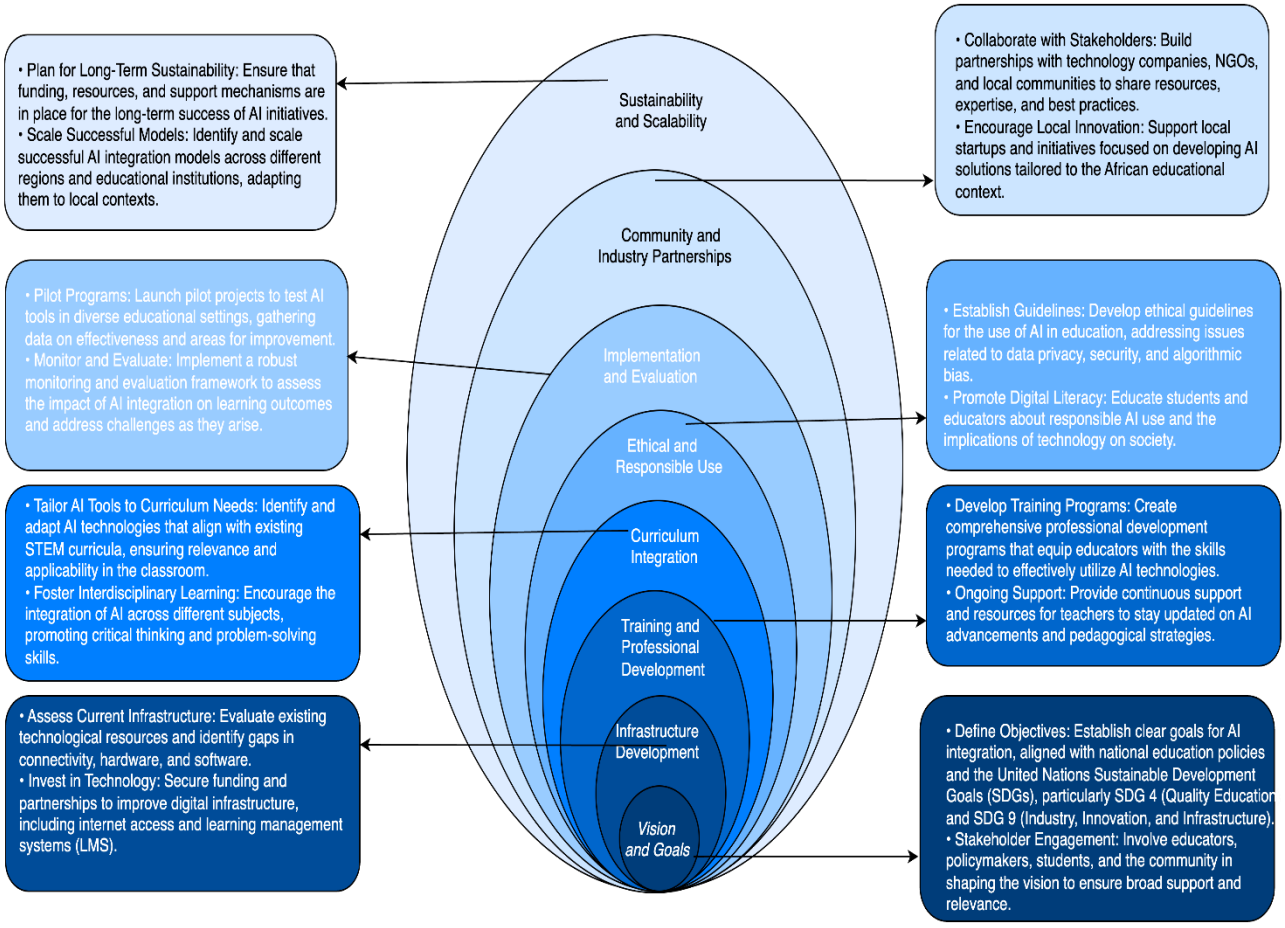

Figure 6. Proposed Framework for Strategic Implementation of AI in STEM Education

Figure 6 illustrate the proposed framework, which serves as a guide to fostering equitable access and improved learning outcomes in African higher education, aligned with the United Nations Sustainable Development Goals (SDGs) for sustainable education development.

Key Themes and Theoretical Underpinnings for AI Integration in STEM Education in Africa

Figure 5 presents emerging themes shaping the adoption of Artificial Intelligence (AI) in STEM education across Africa. A major trend is the personalization of learning through AI-enabled platforms such as Intelligent Tutoring Systems (ITS), which allow for individualized learning pathways based on student performance and needs (Yakubu et al., 2025). These systems enhance student engagement by adapting content and pace, ultimately improving learning outcomes. AI also plays a growing role in building digital competencies, particularly coding and technical skills that are increasingly essential for participation in today's global workforce (Massaty et al., 2024). Moreover, during periods of disruption such as the COVID-19 pandemic AI-supported distance learning platforms provided continuity and access to education when traditional classroom settings were unavailable (Ndlovu et al., 2025). Despite these promising developments, several barriers continue to impede the widespread and equitable adoption of AI. Poor infrastructure, limited digital access, and stark urban–rural divides remain critical challenges in many parts of the continent (Revesai et al., 2024). These disparities often result in unequal access to AI-enhanced learning, particularly for students in rural or under-resourced environments.

To maximize the benefits of AI, educator training must be prioritized. Teachers and lecturers need support not only in using AI tools but also in effectively integrating them into pedagogical practice (Ansori et al., 2024). Without adequate training, the transformative potential of AI in the classroom may remain unrealized. In parallel, ethical concerns surrounding AI use in education require urgent attention. Issues such as data privacy, algorithmic bias, and fairness must be addressed through clear, enforceable guidelines to ensure that AI enhances, rather than undermines, equity and trust in education systems. Theoretical models such as Constructivism and the Technology Acceptance Model (TAM) offer valuable perspectives for understanding how AI can be effectively embedded in teaching and learning. Constructivism emphasizes learner-centred approaches where AI can support scaffolding and adaptive instruction, while TAM highlights the role of perceived usefulness and ease of use in determining technology adoption among educators and students (Massaty et al., 2024). Aligning AI integration with broader development goals is also vital. Specifically, efforts should support Sustainable Development Goal 4 (quality education) and Goal 9 (innovation and infrastructure). AI, when implemented responsibly and inclusively, can contribute to more effective education systems while also spurring innovation and capacity-building across the continent.

Vision, Goals, and Strategic Framework for AI Integration in STEM Education in Africa

This section outlines a structured strategic framework for integrating Artificial Intelligence (AI) into STEM education across Africa. Building on key insights identified in earlier sections, the framework seeks to address both the opportunities and systemic barriers unique to African higher education environments.

Vision and Goals

A clearly articulated vision is essential for successful AI integration. Numerous studies affirm that AI has the potential to transform education in ways that directly support global development targets, notably Sustainable Development Goals (SDG) 4 and 9, which promote quality education and technological innovation. However, realizing this potential depends on local ownership and alignment with national education strategies. Active involvement of key stakeholders including educators, policymakers, students, and communities is vital for ensuring relevance and long-term support. Prior research cautions against externally imposed, top-down approaches that neglect regional realities and cultural contexts (Censrehurd & Nyugha, 2024). Therefore, stakeholder engagement is positioned as a foundational principle within this framework.

Infrastructure Development

One of the most pressing challenges in AI adoption is the lack of adequate infrastructure across many African countries. Effective implementation of AI in STEM education depends on foundational elements such as high-speed internet access, reliable electricity, modern hardware, and functional Learning Management Systems (LMSs). This framework emphasizes the importance of conducting systematic infrastructure audits to identify deficits and establish partnerships aimed at improving digital access. As documented by Kanyemba et al. (2023), addressing infrastructural disparities especially in under-resourced communities is crucial to enable AI-supported learning.

Training and Professional Development

Educator readiness plays a pivotal role in determining the success of AI integration. Research consistently shows that limited digital skills and lack of exposure to AI technologies among teachers hinder effective implementation (Mathebula et al., 2024). The proposed framework prioritizes long-term investment in professional development programs that cover AI literacy, prompt engineering, and pedagogically sound integration strategies. Given the rapidly evolving nature of AI tools, these training programs must be continuous and responsive to emerging trends, ensuring that educators remain equipped to adapt and innovate within their teaching practices.

Curriculum Integration

For AI to have lasting impact, it must be seamlessly woven into the existing STEM curriculum. The framework advocates for a curriculum-responsive approach, where AI tools enhance rather than replace core instructional goals. Aligning AI applications with curriculum objectives supports interdisciplinary learning and encourages students to apply critical thinking and problem-solving skills in real-world contexts. Shumiye (2024) underscores that embedding AI across subject areas prepares students for participation in the digital economy and future STEM careers.

Ethical and Responsible Use of AI

Ethical considerations are fundamental to responsible AI deployment. Concerns around data protection, algorithmic fairness, and misuse of AI systems are particularly acute in educational settings (Numviyumukiza et al., 2024). This framework promotes the establishment of context-specific ethical guidelines that are both culturally grounded and aligned with international best practices. In addition, the framework calls for deliberate efforts to decolonize AI by questioning Eurocentric design assumptions and fostering inclusive, locally relevant technology solutions (Thembane, 2023). Educators and learners must be empowered with digital ethics education to foster safe and equitable AI use.

Implementation and Evaluation

Pilot initiatives serve as critical testing grounds for evaluating the applicability and impact of AI technologies in diverse learning environments. The framework proposes a phased implementation strategy that begins with small-scale pilots, followed by systematic evaluation and refinement. Drawing on lessons from Bosch et al. (2023), the approach emphasizes iterative learning, using real-time data to inform improvements and to tailor implementation to institutional needs. A robust monitoring and evaluation mechanism is essential to track progress, assess learning outcomes, and guide decision-making.

Community and Industry Partnerships

The long-term success of AI in African education hinges on collaboration across sectors. This framework encourages partnerships among governments, universities, NGOs, and private technology firms. Effective collaboration helps pool resources, share expertise, and scale best practices. Furthermore, fostering local innovation ecosystems is essential. Encouraging homegrown solutions that reflect African educational priorities will ensure sustainability and cultural relevance (Opesemowo & Adekomaya, 2024).

Sustainability and Scalability

Finally, for AI integration to be sustainable and impactful, it must be adaptable to different educational contexts across the continent. This requires forward-thinking strategies that prioritize cost-effectiveness, environmental sustainability, and long-term policy alignment. The framework promotes scalable models of AI adoption that can expand gradually across institutions, supported by local capacity-building and continuous evaluation. This structured, holistic approach offers both a practical roadmap for stakeholders and a scholarly contribution to the discourse on educational innovation in Africa.

Future Research

As AI technologies become more prevalent in educational systems, future research must adopt a broader lens moving beyond STEM-focused applications to encompass other disciplines. Expanding the scope in this way will offer a more inclusive and comprehensive picture of how AI is reshaping learning environments in African contexts.

There is also a pressing need for longitudinal research that monitors the sustained impact of AI on teaching and learning outcomes. Such studies could shed light on the long-term benefits, potential risks, and unintended consequences associated with AI integration. Furthermore, comparative analyses across different African countries or regions could illuminate context-specific drivers of success and barriers, helping to tailor best practices more effectively.

Another valuable avenue lies in implementation-focused research, particularly studies that examine effective lecturer training models, community-driven deployment strategies, and the factors that promote or inhibit institutional adoption. In addition, incorporating student voices and lived experiences into future studies will help uncover how AI affects learner motivation, engagement, and achievement in real-world settings.

Policy-oriented research is also needed to evaluate the adequacy of current national education strategies in addressing the demands of AI-enhanced teaching and learning. This includes identifying policy gaps and providing evidence-based recommendations to inform reform and advocacy efforts. Lastly, ethical dimensions especially those related to data security, surveillance, bias, and equitable access must remain central to future research agendas. Ethical scrutiny will ensure that AI tools are implemented in ways that uphold fairness, transparency, and social responsibility within education systems.

Conclusion

This systematic review set out to explore the integration of Artificial Intelligence (AI) in STEM education within African higher education institutions, with a focus on three guiding research questions: 1. How is AI currently being applied within African STEM higher education? 2. What are the key challenges and emerging best practices related to this integration? 3. How can strategic frameworks support equitable and sustainable AI adoption?

Three central conclusions emerge from the analysis of 46 peer-reviewed studies. First, AI is increasingly being integrated into African higher education with considerable momentum, particularly in STEM disciplines. This integration is evident through the adoption of tools such as ChatGPT, Learning Management Systems, Intelligent Tutoring Systems, and machine learning applications. These tools enhance personalized learning, facilitate adaptive assessments, and support skill development core features that align with the goals of inclusive, quality education as outlined in SDG 4. However, the review also highlights that this integration is uneven across the continent, shaped by significant disparities in research capacity, digital infrastructure, and institutional readiness.

Second, the study identifies six recurring and interlinked factors that shape AI integration: (a) the geographic and political dynamics of regional leadership in AI research, (b) uneven access to AI tools, (c) insufficient lecturer training and professional development, (d) infrastructural limitations including unreliable internet and electricity, (e) the digital divide between urban and rural learners, and (f) the emerging potential of AI to personalize and adapt learning experiences. While South Africa and Nigeria lead in AI research and deployment, other nations such as Zambia, Cameroon, and Rwanda are navigating structural and pedagogical challenges that constrain effective implementation.

Third, the study highlights the critical need for strategic and context-sensitive frameworks that address these challenges holistically. Drawing on theories such as the Diffusion of Innovations (Rogers, 2014), Technology Acceptance Model (Davis, 1989), Constructivist Learning Theory, and Socio-Technical Systems Theory, the review demonstrates that successful AI integration requires more than technological availability. It necessitates alignment with local cultural, institutional, and policy contexts. The Crisis-Driven Innovation framework further explains how the COVID-19 pandemic acted as a catalyst for AI adoption, accelerating digital transformation in higher education across the continent. However, without deliberate policy design and ethical governance, such progress risks reproducing existing inequalities, a concern echoed in the Equity of Access framework (Selwyn, 2017) and Postcolonial Theory (Waghid, 2022).

Educationally, AI's transformative potential is emphasized by its capacity to scaffold learning within the Zone of Proximal Development (ZPD), promote self-directed learning, and enhance student engagement when integrated thoughtfully. Yet, concerns about overreliance, critical thinking, and academic integrity require balanced pedagogical strategies, as highlighted by Cognitive Load Theory and recent empirical studies. Furthermore, Human Capital and Self-Determination theories affirm AI's role in developing 21st-century skills and fostering learner autonomy, competence, and motivation. In sum, this review affirms that AI can play a pivotal role in reshaping STEM education in Africa, contributing not only to improved learning outcomes but also to broader socio-economic development. However, to realize this potential, stakeholders must invest in digital infrastructure, educator training, ethical guidelines, and inclusive policies that ensure equitable access across diverse educational contexts. The strategic alignment of AI integration with national development plans and the Sustainable Development Goals (SDGs 4 and 9) is imperative. Only through such multidimensional and locally grounded approaches can AI serve as a truly transformative force in African higher education.

Limitation

The study reviewed 45 papers, but the diversity of contexts may not fully represent the educational landscapes across all African countries, leaving some regional challenges unaddressed. The quality of the studies varied, with some

lacking rigorous methodology or comprehensive data, potentially affecting the reliability of the findings. The focus on AI in STEM education may have overlooked its contributions to other fields. Additionally, the rapid evolution of AI technology may make earlier studies less relevant. The literature also shows geographic concentration, with certain regions overrepresented, which could skew the findings. Finally, research in local languages or inaccessible formats may limit the review's comprehensiveness.

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References

Abanga, E. A., & Dotse, S. (2024). AI and digital economies: A comparative analysis of South and Southeast Asia and Africa. *Asian Journal of Research in Computer Science, 17*(10), 12–25. https://doi.org/10.9734/ajrcos/2024/v17i10506

Abdullah, Q., Rehman, H., Shehzad, M., Attique, H., & Zaki, S. (2025). Relationship between cognitive load and AI dependence among university teachers: Moderating role of decision-making styles. *Research Journal of Psychology, 3*(3), 26–35. https://doi.org/10.59075/rjs.v3i3.166

Adeniyi, I. S., Al Hamad, N. M., Adewusi, O. E., Unachukwu, C. C., Osawaru, B., Onyebuchi, C. N., & David, I. O. (2024). E-learning platforms in higher education: A comparative review of the USA and Africa. *International Journal of Science and Research Archive, 11*(1), 1686–1697. https://doi.org/10.30574/ijsra.2024.11.1.0283

Afzaal, M., Shanshan, X., Yan, D., & Younas, M. (2024). Mapping artificial intelligence integration in education: a decade of innovation and impact (2013-2023)-a bibliometric analysis. *IEEE Access*. https://doi.org/10.1109/ACCESS.2024.3443313

AlSagri, H. S., & Sohail, S. S. (2024). Evaluating the role of artificial intelligence in sustainable development goals with an emphasis on "quality education". *Discover Sustainability, 5*(1), 458. https://doi.org/10.1007/s43621-024-00682-9

Amer, A. M., & El-Hadi, M. M. (2019). Tableau big data visualization tool in the higher education institutions for sustainable development goals. *International Journal of Computer Science and Mobile Computing (IJCSMC)*.

Ansori, A., Damyati, F., & Dhestyani, S. A. (2024). Assessing AI integration in Islamic higher education: A mixed-methods fishbone diagram analysis. *International Journal on Informatics for Development, Article 4862*.

Arakpogun, E. O., Elsahn, Z., Olan, F., & Elsahn, F. (2021). Artificial intelligence in Africa: Challenges and opportunities. In *The fourth industrial revolution: Implementation of artificial intelligence for growing business success* (pp. 375-388). https://doi.org/10.1007/978-3-030-62796-6_22

Asy'ari, M., & Sharov, S. (2024). Transforming education with ChatGPT: Advancing personalized learning, accessibility, and ethical AI integration. *International Journal of Essential Competencies in Education, 3*(2), 119–157. https://doi.org/10.36312/ijece.v3i2.2424

Ayandibu, E. O. (2024). Artificial intelligence and ethical implications in South African higher education: A policy framework perspective. *International Journal of Innovative Technologies in Economy, (3)*, Article 47.

Ayanwale, M. A., & Molefi, R. R. (2024). Exploring intention of undergraduate students to embrace chatbots: from the vantage point of Lesotho. *International Journal of Educational Technology in Higher Education, 21*(1), 20. https://doi.org/10.1186/s41239-024-00451-8

Ayanwale, M. A., & Ndlovu, M. (2024). Investigating factors of students' behavioral intentions to adopt chatbot technologies in higher education: Perspective from expanded diffusion theory of innovation. *Computers in Human Behavior Reports, 14*, 100396. https://doi.org/10.1016/j.chbr.2024.100396

Baba, K., Faddouli, E., & Cheimanoff, N. (2024). Mobile-optimized AI-driven personalized learning: A case study at Mohammed VI Polytechnic University. *International Journal of Interactive Mobile Technologies, 18*(4). https://doi.org/10.3991/ijim.v18i04.46547

Babington-Ashaye, A., de Moerloose, P., Diop, S., & Geissbuhler, A. (2023). Design, development and usability of an educational AI chatbot for People with Haemophilia in Senegal. *Haemophilia, 29*(4), 1063–1073. https://doi.org/10.1111/hae.14815

Basitere, M., & Ivala, E. (2017). Evaluation of an adaptive learning technology in a first-year extended curriculum programme physics course. *South African Computer Journal, 29*(3), 1–15. https://doi.org/10.18489/sacj.v29i3.476

Becker, G. S. (1964). *Human capital*. National Bureau of Economic Research.

Begamudra Rangavittal, P. (2024). Transforming higher education with artificial intelligence-benefits, challenges, and future directions. *International Journal of Science and Research (IJSR)*. https://doi.org/10.21275/SR24525214415

Bekdemir, Y. (2024). The urgency of AI integration in teacher training: Shaping the future of education. *Journal of Research in Didactical Sciences, 3*(1), 37–41. https://doi.org/10.51853/jorids/15485

Boateng, G. (2024). Leveraging AI to advance science and computing education across Africa: Challenges, progress and opportunities. In *Artificial Intelligence in Education: The Intersection of Technology and Pedagogy* (pp. 205–222). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-71232-6_10

Bosch, T., Jordaan, M., Mwaura, J., Nkoala, S., Schoon, A., Smit, A., & Mare, A. (2023). *South African university students' use of AI-powered tools for engaged learning*. Available at SSRN 4595655. https://doi.org/10.2139/ssrn.4595655

Boubker, O. (2024). From chatting to self-educating: Can AI tools boost student learning outcomes? *Expert Systems with Applications, 238*, 121820. https://doi.org/10.1016/j.eswa.2023.121820

Budu, K. W. A., Yinping, M., & Mireku, K. K. (2018). Investigating the effect of behavioral intention on e-learning systems usage: Empirical study on tertiary education institutions in Ghana. *Mediterranean Journal of Social Sciences, 9*(3), Article 123. https://doi.org/10.2478/mjss-2018-0062

Censrehurd, Z. Y. T., & Nyugha, P. G. (n.d.). The importance of artificial intelligence to Africa's development process: Prospects and challenges on tertiary education institutions in Ghana. *Mediterranean Journal of Social Sciences, 9*(3).

Chaaban, Y., Sellami, A., & Michaleczek, I. (Eds.). (2024). *Understanding wellbeing in higher education of the Global South: Contextually sensitive and culturally responsive perspectives*. Taylor & Francis. https://doi.org/10.4324/9781003491613

Chan, C. K. Y. (2023). A comprehensive AI policy education framework for university teaching and learning. *International Journal of Educational Technology in Higher Education, 20*(1), 38. https://doi.org/10.1186/s41239-023-00408-3

Chasokela, D. (2025). Integrating artificial intelligence in STEM education: Enhancing 21st century skills in Zimbabwean universities. *Journal of Research in Environmental and Science Education, 2*(2), 68–80. https://doi.org/10.70232/jrese.v2i2.16

Chen, S., Cheng, H., & Huang, Y. (2024). Emotion recognition in self-regulated learning: Advancing metacognition through AI-assisted reflections. In Y. Chaaban, A. Sellami, & I. Michaleczek (Eds.), *Trust and inclusion in AI-mediated education: Where human learning meets learning machines* (pp. 185–212). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-64487-0_9

Chisom, O. N., Unachukwu, C. C., & Osawaru, B. (2023). Review of AI in education: transforming learning environments in Africa. *International Journal of Applied Research in Social Sciences, 5*(10), 637–654. https://doi.org/10.51594/ijarss.v5i10.725

Chisom, O. N., Unachukwu, C. C., & Osawaru, B. (2024). STEM education advancements in African contexts: A comprehensive review. *World Journal of Advanced Research and Reviews, 21*(1), 145–160. https://doi.org/10.30574/wjarr.2024.21.1.2719

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

da Silva, A. F. A. (2024). *Critical thinking and artificial intelligence in education* [Master's thesis, Universidade NOVA de Lisboa].

Dada, S., Flores, C., Bastable, K., Tönsing, K., Samuels, A., Mukhopadhyay, S., & Moore, R. (2024). Use of an intelligent tutoring system for a curriculum on augmentative and alternative communication: Feasibility for implementation. *International Journal of Language & Communication Disorders, 59*(6), 2279–2293. https://doi.org/10.1111/1460-6984.13084

Davis, F. D. (1989). Technology acceptance model: TAM. *Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption, 205*(219), 5.

Deci, E. L., & Ryan, R. M. (2012). Self-determination theory. In P. A. M. Van Lange, A. W. Kruglanski, & E. T. Higgins (Eds.), *Handbook of theories of social psychology* (Vol. 1, pp. 416–436). Sage. https://doi.org/10.4135/9781446249215.n21

DeVries, R. (2000). Vygotsky, Piaget, and education: A reciprocal assimilation of theories and educational practices. *New Ideas in Psychology, 18*(2-3), 187–213. https://doi.org/10.1016/S0732-118X(00)00008-8

El Hammoumi, S., Zerhane, R., & Idrissi, R. J. (2022). The impact of using interactive animation in biology education at Moroccan Universities and students' attitudes towards animation and ICT in general. *Social Sciences & Humanities Open, 6*(1), 100293. https://doi.org/10.1016/j.ssaho.2022.100293

Elkhateeb, M., Shehab, A., & El-Bakry, H. (2019). Mobile learning system for Egyptian higher education using agile-based approach. *Education Research International, 2019*(1), 7531980. https://doi.org/10.1155/2019/7531980

Essel, H. B., Vlachopoulos, D., Tachie-Menson, A., Johnson, E. E., & Baah, P. K. (2022). The impact of a virtual teaching assistant (chatbot) on students' learning in Ghanaian higher education. *International Journal of Educational Technology in Higher Education, 19*(1), 57. https://doi.org/10.1186/s41239-022-00362-6

Essien, A., Bukoye, O. T., O'Dea, X., & Kremantzis, M. (2024). The influence of AI text generators on critical thinking skills in UK business schools. *Studies in Higher Education*, 1–18. https://doi.org/10.1080/03075079.2024.2316881

Farooqi, M. T. K., Amanat, I., & Awan, S. M. (2024). Ethical considerations and challenges in the integration of artificial intelligence in education: A systematic review. *Journal of Excellence in Management Sciences, 3*(4), 35–50. https://doi.org/10.69565/jems.v3i4.314

Fomunyam, K. G. (2021). Agenda 2063: Science, Technology, Engineering, and Mathematics (STEM) education to the rescue. *International Journal of Engineering Research and Technology, 13*(7), 1603–1609.

Funda, V., & Mbangeleli, N. B. A. (2024). Artificial Intelligence (AI) as a tool to address academic challenges in South African higher education. *International Journal of Learning, Teaching and Educational Research, 23*, 520–537. https://doi.org/10.26803/ijlter.23.11.27

Garud, R., Gehman, J., & Giuliani, A. P. (2016). Technological exaptation: A narrative approach. *Industrial and Corporate Change, 25*(1), 149–166. https://doi.org/10.1093/icc/dtv050

Gikunda, K. (2023). *Empowering Africa: An in-depth exploration of the adoption of artificial intelligence across the continent*. arXiv preprint arXiv:2401.09457.

Guerra-López, I., & El Dallal, S. (2021). A content analysis of change management strategies used in technological transitions in higher education institutions from the lens of a strategic alignment framework. *Online Learning, 25*(3), 191–207. https://doi.org/10.24059/olj.v25i3.2395

Guettala, M., Bourekkache, S., Kazar, O., & Harous, S. (2024). Generative artificial intelligence in education: Advancing adaptive and personalized learning. *Acta Informatica Pragensia, 13*(3), 460–489. https://doi.org/10.18267/j.aip.235

Hamiza, O., Sambo, M., & Tsuma, C. (2014). Students' adoption of E-learning platforms: a comparative study in Uganda and Nigeria. *International Journal of Educational Research and Development, 2*, 5–13.

Hashiyana, V., & Kamati, W. (2025). An artificial intelligence-powered chatbot-integrated web-based application: A case study of the University of Namibia. In *Cutting-Edge Technologies for Business Sectors* (pp. 205–244). IGI Global. https://doi.org/10.4018/979-8-3693-9586-8.ch008

Hlatshwayo, M. N. (2023). Academic development in the period of disruption: A decolonial insight. In *Academic staff development: Disruptions, complexities, and change* (p. 91).

Hlatshwayo, M. N., Khumalo, S. D., & Nzimande, N. (2021). The pandemic is our portal: Re-imagining teaching and learning in the time of Covid-19. *African Perspectives of Research in Teaching and Learning, 5*, 59–77.

Hlongwane, J., Shava, G. N., Mangena, A., & Muzari, T. (2024). Towards the integration of artificial intelligence in higher education, challenges and opportunities: The African context, a case of Zimbabwe. *International Journal of Research and Innovation in Social Science, 8*(3S), 417–435. https://doi.org/10.47772/IJRISS.2024.803028S

Jantjies, M., Moodley, T., & Maart, R. (2018, December). Experiential learning through virtual and augmented reality in higher education. In *Proceedings of the 2018 international conference on education technology management* (pp. 42–45). https://doi.org/10.1145/3300942.3300956

Joseph, O. B., & Uzondu, N. C. (2024). Integrating AI and machine learning in STEM education: Challenges and opportunities. *Computer Science & IT Research Journal, 5*(8), 1732–1750. https://doi.org/10.51594/csitrj.v5i8.1379

Juma, L., Chavula, P., Kayusi, F., Omwenga, M. K., Mishra, R., & Mwewa, T. (2025). AI in dissertation examination: Opportunities for undergraduates and postgraduates in Zambia, Rwanda, and Kenya. *LatIA, (3)*, 329. https://doi.org/10.62486/latia2025329

Kacha, K. T., Charles, T., Alemnge Fedelis, L., & Célestin, N. (2024). Learning management systems and self-directed learning in higher education institutions in Cameroon. *Learning, 8*(4).

Kanyemba, K., Phiri, F., Munsanje, V. M., & Mwaanga, O. (2023). Exploring the use of artificial intelligence in higher learning institutions: a case of David Livingstone College of education. *MULUNGUSHI UNIVERSITY MULTIDISCIPLINARY JOURNAL, 4*(2), 59–72.

Kazimova, D., Tazhigulova, G., Shraimanova, G., Zatyneyko, A., & Sharzadin, A. (2025). Transforming university education with AI: A systematic review of technologies, applications, and implications. *International Journal of Engineering Pedagogy, 15*(1). https://doi.org/10.3991/ijep.v15i1.50773

Kim, N. J., & Kim, M. K. (2022, March). Teacher's perceptions of using an artificial intelligence-based educational tool for scientific writing. In *Frontiers in Education* (Vol. 7, p. 755914). Frontiers Media SA. https://doi.org/10.3389/feduc.2022.755914

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.
Kondo, T. S., & Diwani, S. A. (2023). Artificial intelligence in Africa: a bibliometric analysis from 2013 to 2022. *Discover Artificial Intelligence, 3*(1), 34. https://doi.org/10.1007/s44163-023-00084-2
Kundu, A., & Bej, T. (2025). *Psychological impacts of AI use on school students: A systematic scoping review of the empirical literature*. SSRN. https://doi.org/10.2139/ssrn.5239192
Lampou, R. (2023). The integration of artificial intelligence in education: Opportunities and challenges. *Review of Artificial Intelligence in Education, 4*, e15. https://doi.org/10.37497/rev.artif.intell.educ.v4i00.15
Laseinde, O. T., Adejuyigbe, S. B., Mpofu, K., & Campbell, H. M. (2015, December). Educating tomorrows engineers: Reinforcing engineering concepts through Virtual Reality (VR) teaching aid. In *2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 1485–1489). IEEE. https://doi.org/10.1109/IEEM.2015.7385894
Madahana, M., Khoza-Shangase, K., Moroe, N., Mayombo, D., Nyandoro, O., & Ekoru, J. (2022). A proposed artificial intelligence-based real-time speech-to-text to sign language translator for South African official languages for the COVID-19 era and beyond: In pursuit of solutions for the hearing impaired. *South African Journal of Communication Disorders, 69*(2), 915. https://doi.org/10.4102/sajcd.v69i2.915
Mahendra, S. B., Saputra, A., & Nugroho, W. R. (2022). ICT and artificial intelligence integration in classroom practice: A case study in STEM instruction. *Indonesian Journal of Informatics Education, 8*(2), 130–138.
Maina, A. M., & Kuria, J. (2024, May). Building an AI future: research and policy directions for Africa's higher education. In *2024 IST-Africa Conference (IST-Africa)* (pp. 1–9). IEEE. https://doi.org/10.23919/IST-Africa63983.2024.10569692
Maluleke, A. F. (2024). Enhancing learning analytics through learning management systems engagement in African higher education. *Journal of Education, Learning and Technology, 5*, 130–149. https://doi.org/10.38159/jelt.2024565
Mariyono, D., & Alif Hidayatullah, A. N. (2025). Navigating the moral maze: Ethical challenges and opportunities of generative chatbots in global higher education. *Applied Computational Intelligence and Soft Computing, 2025*(1), 8584141. https://doi.org/10.1155/acis/8584141
Mashilo, M., & Shekgola, M. (2024). Utilising artificial intelligence chatbots for student support at comprehensive open distance e-learning higher learning institutions in the fifth industrial revolution. *Journal of Education, Society & Multiculturalism, 5*(1), 26–48. https://doi.org/10.2478/jesm-2024-0003
Massaty, M. H., Fahrurozi, S. K., & Budiyanto, C. W. (2024). The role of AI in fostering computational thinking and self-efficacy in educational settings: A systematic review. *Indonesian Journal of Informatics Education, 8*(1). https://doi.org/10.20961/ijie.v8i1.89596
Mathebula, S., Ramaila, S., & Mavuru, L. (2024). Utilizing robotics to foster twenty-first century skills and competencies in grade 5 natural sciences classrooms. *International Journal of Technology, Knowledge and Society, 20*(2), 85. https://doi.org/10.18848/1832-3669/CGP/v20i02/85-107
Matome, T. J., & Jantjies, M. (2021). Student perceptions of virtual reality in higher education. *Balancing the tension between digital technologies and learning sciences*, 167–181. https://doi.org/10.1007/978-3-030-65657-7_10
Mhlanga, D. (2025). *Enhancing and sustaining digital transformation in education post-COVID-19: Strategies for success in the fourth industrial revolution*. SSRN. https://doi.org/10.2139/ssrn.5222640
Mhlanga, D., & Moloi, T. (2020). COVID-19 and the digital transformation of education: What are we learning on 4IR in South Africa? *Education Sciences, 10*(7), 180. https://doi.org/10.3390/educsci10070180
Mishara, P. (2024). The ethical implications of AI in education: privacy, bias, and accountability. *Journal of Information and Education Research, 4*, 3550. https://doi.org/10.52783/jier.v4i2.1827
Mission, R., Fio, R. J., & Mission, A. R. (2024). AI-powered pedagogy: Integrating artificial intelligence in information technology education for future workforce readiness. *Journal of Innovative Technology Convergence, 6*(4). https://doi.org/10.69478/JITC2024v6n4a06
Mtebe, J., & Raisamo, R. (2014). Investigating students' behavioural intention to adopt and use mobile learning in higher education in East Africa. *International Journal of Education and Development using ICT, 10*(3).
Mubangizi, J. C. (2024). Artificial intelligence, human rights and sustainable development: An African perspective. *Perspectives of Law and Public Administration, 13*(3), 374–389. https://doi.org/10.62768/PLPA/2024/13/3/04
Muchabaiwa, W., & Gondo, R. (2022). COVID-19 and the virtual classroom conundrum in Zimbabwean universities. *Journal of Education (University of KwaZulu-Natal), (86)*, 107–125. https://doi.org/10.17159/2520-9868/i86a06
Mumbi, M., & Nyirenda, M. (2024). Towards automated assessment of learning management systems in higher education institutions in Zambia. *Open Journal of Applied Sciences, 14*(5), 1279–1294. https://doi.org/10.4236/ojapps.2024.145083
Muthmainnah, M., Seraj, I., & Oteir, I. (2022). Playing with AI to investigate human-computer interaction technology and improving critical thinking skills to pursue 21st century age. *Education Research International, 2022*(1), 6468995. https://doi.org/10.1155/2022/6468995

Mutsvangwa, A., & Zezekwa, N. (2021). STEM education: A ray of hope for African countries. *Unnes Science Education Journal, 10*(2), 79–89. https://doi.org/10.15294/usej.v10i2.45746

Mwalumbwe, I., & Mtebe, J. S. (2017). Using learning analytics to predict students' performance in Moodle learning management system: A case of Mbeya University of Science and Technology. *The Electronic Journal of Information Systems in Developing Countries, 79*(1), 1–13. https://doi.org/10.1002/j.1681-4835.2017.tb00577.x

Ndlovu, B., Ndlovu, S., Dube, S., & Maguraushe, K. (2025). Artificial intelligence chatbots in education: Academics' beliefs, concerns, and pathways for integration. *Indonesian Journal of Information Systems, 7*(2), 109–122. https://doi.org/10.24002/ijis.v7i2.10805

Nsabimana, A., Nganga, M., & Niyizamwiyitira, C. (2024). *Smart classrooms and education outcomes*.

Numviyumukiza, E., Niyonsenga, J., Niyibizi, J. B., et al. (2024). *Are low and middle-income country universities "AI resilient": Exploring the use of ChatGPT among medicine and health sciences students in Rwanda* [Preprint]. Research Square. https://doi.org/10.21203/rs.3.rs-5150455/v1

Nurmuhammedovna, F. N. (2025). Integration of artificial intelligence in the higher education institutions. *Current Research Journal of Pedagogics, 6*(1), 50–52. https://doi.org/10.37547/pedagogics-crjp-06-01-12

Nyathi, V. S., & Sisimayi, T. P. (2024). Adaptive learning technologies for higher education: Exploring the use of interactive online learning platforms for higher education. In *Adaptive Learning Technologies for Higher Education* (pp. 91–124). IGI Global. https://doi.org/10.4018/979-8-3693-3641-0.ch005

Nyeko, J. S., & Ogenmungu, C. (2017). Determinants of electronic learning adoption in higher institutions of learning in Uganda: A learners' perspective. *Global Journal of Computer Science and Technology, 17*(1), 1–15.

Oladele, J. I., Ndlovu, M., & Ayanwale, M. A. (2022). Computer adaptive-based learning and assessment for enhancing STEM education in Africa: a fourth industrial revolution possibility. In *Mathematics Education in Africa: The Fourth Industrial Revolution* (pp. 131–144). Springer International Publishing. https://doi.org/10.1007/978-3-031-13927-7_8

Onyesolu, M. O., Oladipo, O. F., & Ezeani, I. M. (2012). Simulating desktop virtual reality for higher education. *International Journal of Ubiquitous Sciences, 1*(1), 1–6.

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

Owusu-Fordjour, C., Koomson, C. K., & Hanson, D. (2020). The impact of COVID-19 on learning: The perspective of the Ghanaian student. *European Journal of Education Studies, 7*(3), 43–56.

Patel, S., & Ragolane, M. (2024). The implementation of artificial intelligence in South African higher education institutions: Opportunities and challenges. *Technium Education and Humanities, 9*, 51–65. https://doi.org/10.47577/teh.v9i.11452

Rangavittal, P. B. (2024). Transforming higher education with artificial intelligence: Benefits, challenges, and future directions. *International Journal of Science and Research (IJSR), 13*(5). https://doi.org/10.21275/SR24525214415

Ray, R. K., Singh, N. K., Gupta, S., Singh, A., & Dash, D. P. (2025). Beyond technology: A multi-theoretical examination of immersive technology adoption in Indian healthcare. *Communications of the Association for Information Systems, 57*(1), 12.

Reeves, H., Grandjean Lapierre, S., Razafindrina, K., Andriamiadanarivo, A., Rakotosamimanana, N., Razafindranaivo, T., & Fair, E. (2020). Evaluating the use of educational videos to support the tuberculosis care cascade in remote Madagascar. *The International Journal of Tuberculosis and Lung Disease, 24*(1), 28–35. https://doi.org/10.5588/ijtld.19.0161

Reina-Parrado, M., Román-Graván, P., & Hervás-Gómez, C. (2025). Integration of artificial intelligence and machine learning in education: A systematic review. *International Journal of Educational Methodology, 11*(2), 203–216. https://doi.org/10.12973/ijem.11.2.203

Revesai, Z., Mutanga, B., Chisosa, T., & Meki, V. (2024). Digital empowerment in social work: Leveraging AI to enhance educational access in developing nations. *Indonesian Journal of Informatics Education*. https://doi.org/10.20961/ijie.v8i2.92951

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In *An integrated approach to communication theory and research* (pp. 432–448). Routledge.

Rop, F. K. (2017). *Application of plagiarism detection software to enhance research: A case of University of Nairobi post graduate students and lecturers* [Doctoral dissertation].

Roshan, M., Olivares, H., & Lopez, R. R. (2023). Harnessing AI to foster equity in education: Opportunities, challenges, and emerging strategies. *Journal of Intelligent Learning Systems and Applications, 15*(4), 123–143. https://doi.org/10.4236/jilsa.2023.154009

Roshan, S., Iqbal, S. Z., & Qing, Z. (2024). Teacher training and professional development for implementing AI-based educational tools. *Journal of Asian Development Studies, 13*(2), 1972–1987. https://doi.org/10.62345/jads.2024.13.2.154

Saifullah, S., Yawan, H., Syafitri, N., & Nurhaliza, S. (2024). Integrating AI chatbot into learning management system: Enhancing student engagement and learning outcomes. *Dharmas Education Journal (DE_Journal), 5*(2), 1346–1359. https://doi.org/10.56667/dejournal.v5i2.1605

Santos, S. M. A. V., da Silva, C. G., de Carvalho, I. E., de Castilho, L. P., das Neves Meroto, M. B., Tavares, P. R., & Moniz, S. S. D. O. R. (2024). The art of personalization of education: Artificial intelligence on the stages of special education. *Contribuciones a las Ciencias Sociales, 17*(2), e4971. https://doi.org/10.55905/revconv.17n.2-008

Saputro, T. M. E., & Fitriawan, M. (2023). The role of artificial intelligence in Indonesian science education: Teacher readiness and ethical considerations. *Indonesian Journal of Informatics Education, 9*(1), 1–10.

Sardi, J., Candra, O., Yuliana, D. F., Yanto, D. T. P., & Eliza, F. (2025). How generative AI influences students' self-regulated learning and critical thinking skills? A systematic review. *International Journal of Engineering Pedagogy, 15*(1). https://doi.org/10.3991/ijep.v15i1.53379

Selwyn, N., Henderson, M., & Chao, S. H. (2017). The possibilities and limitations of applying 'open data' principles in schools. *Cambridge Journal of Education, 47*(2), 167–187. https://doi.org/10.1080/0305764X.2016.1143449

Shonhe, L., Jain, P., & Akakandelwa, A. (2023). *Students' experiences with the utilisation of the 4IR technologies in online learning: a case study of institutions of higher learning in Botswana and Zambia*. https://doi.org/10.70759/a4zmzy13

Shumiye, Y. D. (2024). Artificial intelligence program implementation in STEM education: Cases of Ethiopia STEM Center. *European Journal of Health and Biology Education, 11*(1), 7–12. https://doi.org/10.29333/ejhbe/14344

Sidorkin, A. M. (2025). AI integration blueprint: Transforming higher education for the age of intelligence. *AI-EDU Arxiv*. https://doi.org/10.36851/ai-edu.vi.5126

Singh, A. S., Doifode, A., Pillai, D., & Bhosale, T. (2024, August). Role of artificial intelligence in promoting sustainable development goals with a focus on inclusive education. In *2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC)* (pp. 1475–1479). IEEE. https://doi.org/10.1109/ICESC60852.2024.10690140

Skhephe, M. (2022). The virtual classroom: Challenges of COVID-19 pandemic in accounting subject classrooms in the eastern cape province, South Africa. *African Perspectives of Research in Teaching and Learning, 6*(2), 112–124.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Altering element interactivity and intrinsic cognitive load. In *Cognitive load theory* (pp. 203–218). Springer. https://doi.org/10.1007/978-1-4419-8126-4_5

Thembane, N. (2023, February). Perceptions of medical laboratory science students on the implementation of information and communications technology in medical education. In *The Focus Conference (TFC 2022)* (pp. 196–213). Atlantis Press. https://doi.org/10.2991/978-2-38476-006-0_17

Thembane, N. (2024). Understanding student perspectives on e-assessments in a South African university of technology. *African Perspectives of Research in Teaching and Learning, 8*(1), 106–119.

Trist, E., Pasmore, W. A., & Sherwood, J. J. (1960). *Socio-technical systems*. Tavistock.

Umezuruike, C., & Ngugi, H. N. (2020). Imminent challenges of adoption of big data in educational systems in sub-saharan Africa nations. *International Journal of Recent Technology and Engineering, 8*(5), 4544–4550. https://doi.org/10.35940/ijrte.E6885.018520

Victor, A. (2025). Artificial intelligence in global health: An unfair future for health in Sub-Saharan Africa? *Health Affairs Scholar, 3*(2), qxaf023. https://doi.org/10.1093/haschl/qxaf023

Waghid, Z. (2023). Teacher educators' pedagogical practices in global citizenship education using the soft vs critical GCE framework. *Cogent Education, 10*(2), 2251757. https://doi.org/10.1080/2331186X.2023.2251757

Walter, Y. (2024). Embracing the future of artificial intelligence in the classroom: the relevance of AI literacy, prompt engineering, and critical thinking in modern education. *International Journal of Educational Technology in Higher Education, 21*(1), 15. https://doi.org/10.1186/s41239-024-00448-3

Xu, Q., Liu, Y., & Li, X. (2025). Unlocking student potential: How AI-driven personalized feedback shapes goal achievement, self-efficacy, and learning engagement through a self-determination lens. *Learning and Motivation, 91*, 102138. https://doi.org/10.1016/j.lmot.2025.102138

Yakubu, M. A., Sain, Z. H., Lawal, U. S., & Hakim, M. A. R. (2025). Student perceptions of artificial intelligence as a virtual tutor and its relation to self-efficacy in learning. *Indonesian Journal of Progressive Pedagogy, 1*(1).

Yang, C., Suleman, H., & Chavula, J. (2016, May). A topology visualisation tool for National Research and Education Networks in Africa. In *2016 IST-Africa Week Conference* (pp. 1–11). IEEE. https://doi.org/10.1109/ISTAFRICA.2016.7530605

Yousif, J. H. (2025). Artificial intelligence revolution for enhancing modern education using zone of proximal development approach. *Applied Computing Journal*, 386–398. https://doi.org/10.52098/acj.20255239

Zembylas, M. (2023). A decolonial approach to AI in higher education teaching and learning: Strategies for undoing the ethics of digital neocolonialism. *Learning, Media and Technology, 48*(1), 25–37. https://doi.org/10.1080/17439884.2021.2010094

Zouhaier, S. (2023). The impact of artificial intelligence on higher education: An empirical study. *European Journal of Educational Sciences, 10*(1), 17–33. https://doi.org/10.19044/ejes.v10no1a17