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Research Article

Transforming STEM Education in African Universities Through Artificial Intelligence: Status, Barriers, and a Strategic Pathway for Sustainable Adoption

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Abstract

Artificial Intelligence (AI) has specifically started to revolutionize the way educators and students view learning on global pedagogical paradigms, opening up transformative pathways for personalized instruction and data-driven management. Nonetheless, its uptake in African Higher Education Institutions (HEIs), especially across STEM disciplines, is strongly asymmetric as a result of systemic divides. This work is a Systematic Literature Review (SLR) that explores: technological trends, educational advantages, and structural barriers to the prevalence of AI in STEM education within Africa. Following PRISMA 2020 guidelines, 140 peer-reviewed studies from articles published between the years of 2015 and 2025 were synthesized through a thematic analysis and PESTEL analysis. The results show a dramatic increase in research interest since 2020, primarily originating from areas able to support better access and use of digital infrastructure, particularly in Nigeria and South Africa. The most popular technologies included Generative AI, Intelligent Tutoring Systems, and Learning Analytics. Pedagogically, these tools promote student engagement, provide customized and adaptive learning trails for learners, and automate assessment processes. In contrast, macro-environmental profiling exposes systemic bottlenecks: chronic deficits in digital infrastructure (intermittent electricity and erratic broadband), acute funding constraints, a pervasive AI talent gap among educators, as well as an absence of regulatory frameworks for data protection and responsible governance. In bridging these gaps, this paper proposes an integrated and tiered Africa-centric framework that combines infrastructure, literacy education, curriculum alignment with available job opportunities, and the need for moral governance to create effective global learning solutions while enhancing workforce readiness across the African continent. The framework offers a strategic guide to policymakers and

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university leaders striving towards an inclusive, sustainable, and responsible digitalization that aligns with the African Union Agenda 2063 and the United Nations Sustainable Development Goals.

Keywords: Artificial Intelligence; STEM Education; Higher Education; Africa; PESTEL Analysis; Systematic Literature Review; Digital Transformation; Sustainable Development

Introduction

Artificial Intelligence (AI) has emerged as one of the most transformative technologies of the twenty-first century, reshaping numerous sectors, including healthcare, finance, transportation, agriculture, governance, and education. In higher education, AI technologies are increasingly being integrated into teaching, learning, assessment, research, and administrative processes, thereby redefining traditional educational practices and institutional operations (Luckin et al., 2016; Holmes et al., 2022). Advances in machine learning, deep learning, natural language processing, learning analytics, and generative AI have enabled universities to develop innovative approaches to personalized learning, adaptive instruction, automated assessment, intelligent tutoring, and data-driven decision-making (Zawacki-Richter et al., 2019; Chan, 2023).

Artificial Intelligence refers to computational systems capable of performing tasks that typically require human intelligence, including learning, reasoning, problem-solving, decision-making, and language understanding (Russell & Norvig, 2021). In educational contexts, AI encompasses intelligent technologies that support teaching, learning, assessment, and educational management through adaptive and data-driven approaches (UNESCO, 2021; Zawacki-Richter et al., 2019). Modern AI systems can analyze large volumes of educational data, identify learning patterns, provide personalized recommendations, and support institutional decision-making, making them increasingly valuable tools for enhancing educational quality and effectiveness.

The rapid emergence of generative AI systems and Large Language Models (LLMs), including ChatGPT, Gemini, Claude, and Copilot, has further accelerated the adoption of AI in higher education. These technologies support academic writing, content generation, coding assistance, language translation, research synthesis, and personalized feedback, thereby creating new opportunities for improving teaching effectiveness and student learning outcomes (Kasneci et al., 2023). Recent advances in Natural Language Processing (NLP) and transformer-based architectures have enabled the development of powerful Large Language Models capable of generating human-like text, supporting multilingual communication, and facilitating personalized educational interactions (Brown et al., 2020; Jurafsky & Martin, 2023). These capabilities have significantly expanded the potential of AI-assisted teaching and learning in higher education. However, their growing use has also raised concerns regarding academic integrity, ethical governance, transparency, bias, and the evolving role of educators in AI-mediated learning environments (Tlili et al., 2023). Consequently, AI is increasingly viewed not merely as an educational technology but as a transformative force capable of reshaping knowledge creation, dissemination, and utilization within contemporary higher education systems.

The growing influence of AI is closely linked to the broader context of the Fourth Industrial Revolution (4IR), characterized by the convergence of artificial intelligence, robotics, big data analytics,

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cloud computing, the Internet of Things (IoT), and advanced digital technologies (Schwab, 2017). As economies become increasingly knowledge-driven and technology-intensive, higher education institutions face mounting pressure to equip graduates with the competencies required for rapidly evolving labour markets. These competencies include computational thinking, digital literacy, data analytics, creativity, problem-solving, collaboration, and AI literacy (UNESCO, 2021; OECD, 2023). Consequently, universities worldwide are redesigning curricula and pedagogical approaches to align educational outcomes with the demands of the digital economy.

As AI becomes increasingly embedded in education and society, AI literacy has emerged as a critical twenty-first-century competency. AI literacy encompasses the knowledge, skills, attitudes, and ethical awareness required to understand, evaluate, and responsibly interact with AI systems (Long & Magerko, 2020). Developing AI literacy among both educators and students is increasingly recognized as essential for maximizing the benefits of AI while mitigating associated risks. Beyond technical proficiency, AI literacy enables learners to critically assess AI-generated outputs, understand algorithmic limitations, recognize ethical concerns, and apply AI tools responsibly within academic and professional contexts.

The significance of AI is particularly evident in Science, Technology, Engineering, and Mathematics (STEM) education. STEM disciplines play a critical role in scientific advancement, technological innovation, and economic development, making them central to national competitiveness in the digital age. AI-powered technologies such as intelligent tutoring systems, adaptive learning platforms, virtual laboratories, predictive analytics, simulation environments, and automated feedback systems enhance learner engagement, facilitate personalized learning, and improve conceptual understanding of complex scientific concepts (Crompton & Burke, 2023). Furthermore, AI-supported learning environments promote the development of twenty-first-century competencies, including innovation, computational thinking, critical reasoning, and interdisciplinary problem-solving skills. These capabilities are increasingly essential for preparing graduates to participate effectively in AI-driven economies and technologically advanced societies.

Across Africa, interest in AI integration within higher education has increased substantially over the past decade. Countries such as Nigeria, South Africa, Kenya, Ghana, Rwanda, Morocco, and Egypt have initiated efforts to incorporate AI technologies into teaching, learning, research, and institutional management. Universities are increasingly adopting Learning Management Systems (LMS), Intelligent Tutoring Systems (ITS), learning analytics, machine learning applications, and generative AI tools to enhance educational delivery and student engagement (Chisom et al., 2024; Maina & Kuria, 2024). The COVID-19 pandemic further accelerated digital transformation across the continent, compelling institutions to adopt online learning platforms and AI-supported technologies to ensure continuity of education (Fordjour et al., 2020). As a result, AI-related research, policy discussions, and implementation initiatives have expanded significantly since 2020.

The integration of AI into African higher education presents significant opportunities for educational transformation and socio-economic development. AI technologies can enhance access to quality education, support personalized learning, improve instructional efficiency, and facilitate evidence-based decision-making. Furthermore, AI adoption aligns with the aspirations of the African Union Agenda 2063 and the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 9 (Industry, Innovation and Infrastructure). By strengthening digital literacy, innovation capacity, and

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workforce readiness, AI has the potential to contribute to sustainable economic growth and social development across the continent.

Despite these opportunities, AI integration within African higher education remains uneven and faces numerous challenges. Many institutions continue to struggle with inadequate digital infrastructure, unreliable electricity supply, limited internet connectivity, insufficient funding, shortages of skilled personnel, and weak technological ecosystems (Boateng, 2024; UNESCO, 2024). In addition, disparities between urban and rural institutions contribute to unequal access to AI-enhanced educational opportunities. Challenges related to data privacy, algorithmic bias, ethical governance, academic integrity, and digital inequality further complicate the responsible deployment of AI technologies in educational settings (Williamson & Eynon, 2020; Kasneci et al., 2023).

Although existing studies have examined AI adoption, digital transformation, and educational technology integration in African universities, much of the literature focuses on specific technologies, isolated case studies, or individual institutional experiences. Limited attention has been given to the development of comprehensive, Africa-centered frameworks that integrate pedagogical effectiveness, AI literacy, ethical governance, sustainability, and workforce development considerations. Furthermore, there remains a need for systematic synthesis of evidence regarding the opportunities, challenges, and strategic pathways for AI-driven curriculum transformation in African STEM education.

To address this gap, this study systematically reviews the current state of AI integration in STEM programs across African higher education institutions. The study examines emerging trends, educational benefits, implementation challenges, ethical considerations, and sustainability issues associated with AI adoption. Drawing on evidence from the literature, the study proposes an Africa-centered framework for AI-driven STEM education transformation that promotes pedagogical integrity, AI literacy, ethical governance, innovation, and sustainable development. By doing so, the study contributes to ongoing discussions on how African universities can leverage AI responsibly and effectively to enhance educational quality, strengthen workforce readiness, and support the achievement of the Sustainable Development Goals (SDGs).

2. Theoretical Framework

The integration of Artificial Intelligence (AI) into African higher education STEM programs is a multidimensional phenomenon that encompasses technological innovation, pedagogical transformation, institutional change, workforce development, and ethical governance. To provide a comprehensive understanding of these complexities, this study is anchored on five complementary theoretical perspectives: Diffusion of Innovations Theory, Technology Acceptance Model, Constructivist Learning Theory, Human Capital Theory, and Socio-Technical Systems Theory.

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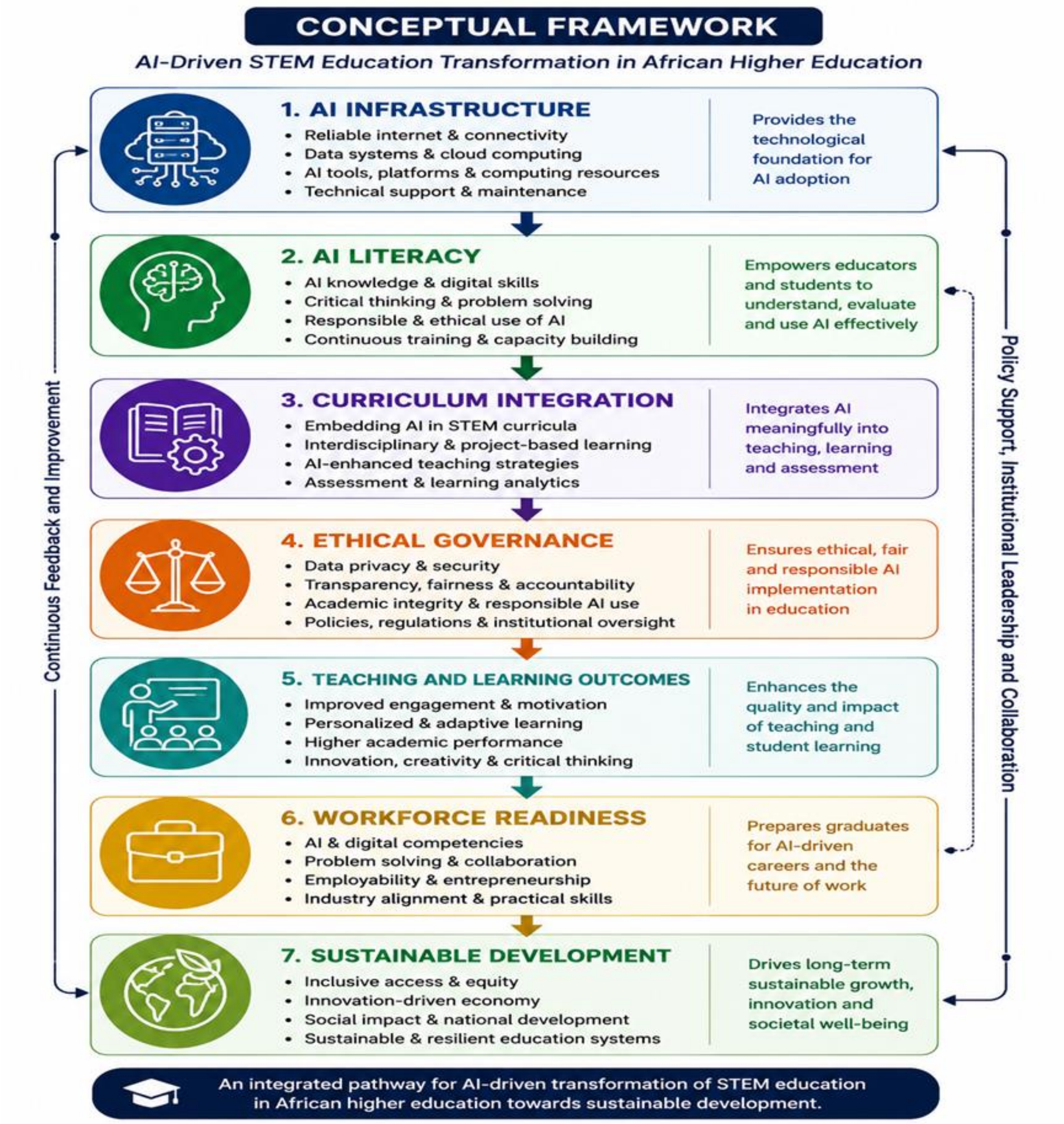

Figure 1. An integrated pathway for AI transformation of STEM education in African higher education towards sustainable development**.**

2.1 Diffusion of Innovations Theory

The Diffusion of Innovations (DOI) Theory, developed by Rogers (2003), explains how innovations are communicated and adopted over time within social systems. According to the theory, adoption depends on factors such as relative advantage, compatibility, complexity, trialability, and observability. In higher education, AI technologies are considered innovations whose successful adoption depends on institutional readiness, perceived usefulness, organizational culture, and stakeholder acceptance.

Within African universities, the diffusion of AI technologies varies considerably due to disparities in infrastructure, funding, digital literacy, and policy support. DOI therefore, provides a useful lens for understanding differences in AI adoption across institutions and regions. The theory also highlights the importance of change agents, leadership support, and knowledge dissemination in promoting sustainable AI integration.

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2.2 Technology Acceptance Model

The Technology Acceptance Model (TAM), proposed by Davis (1989), is one of the most widely used frameworks for understanding user acceptance of technology. TAM posits that two primary factors influence technology adoption: perceived usefulness and perceived ease of use.

In the context of AI-driven STEM education, lecturers and students are more likely to adopt AI technologies when they perceive them as enhancing teaching effectiveness, learning outcomes, research productivity, and administrative efficiency. Conversely, concerns regarding complexity, reliability, ethics, and academic integrity may reduce acceptance. TAM therefore provides valuable insights into the behavioral and attitudinal factors influencing AI adoption within African higher education institutions.

2.3 Constructivist Learning Theory

Constructivist Learning Theory argues that learners actively construct knowledge through interaction, collaboration, reflection, and experiential learning (Piaget, 1972; Vygotsky, 1978). Learning is viewed as an active process rather than a passive reception of information.

AI-powered educational technologies align closely with constructivist principles by enabling personalized learning, adaptive instruction, intelligent tutoring, virtual simulations, and collaborative problem-solving environments. Through AI-supported learning systems, students can engage with content at their own pace, receive individualized feedback, and participate in authentic learning experiences that enhance conceptual understanding and critical thinking skills. This theoretical perspective helps explain the pedagogical value of AI integration in STEM education.

2.4 Human Capital Theory

Human Capital Theory emphasizes the role of education and skill development in enhancing productivity, innovation, and economic growth (Becker, 1993). The theory suggests that investments in education generate long-term economic and social returns by improving workforce competencies and knowledge capacity.

The integration of AI into STEM education contributes directly to human capital development by equipping students with digital literacy, computational thinking, data analytics, problem-solving, and AI literacy skills required in contemporary labor markets. Given Africa’s aspirations for digital transformation and industrial development, Human Capital Theory provides a strong justification for integrating AI into higher education curricula.

2.5 Socio-Technical Systems Theory

Socio-Technical Systems Theory argues that organizational outcomes are shaped by interactions between technological systems and social structures (Trist & Bamforth, 1951). Successful implementation of technology therefore requires alignment between technical infrastructure, institutional policies, organizational culture, and human capabilities.

This perspective is particularly relevant to AI adoption in African higher education, where technological challenges often intersect with governance, ethics, funding, institutional readiness, and workforce capacity issues. The theory emphasizes that sustainable AI integration requires holistic consideration of both technological and social dimensions of educational transformation.

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2.6 Conceptual Integration of the Theories

Collectively, these theories provide a comprehensive framework for understanding AI-driven curriculum transformation in African higher education. Diffusion of Innovations Theory explains institutional adoption processes; Technology Acceptance Model addresses user acceptance; Constructivist Learning Theory highlights pedagogical implications; Human Capital Theory emphasizes workforce development; and Socio-Technical Systems Theory captures the interaction between technology and institutional environments. Together, these frameworks guide the analysis of AI integration, benefits, challenges, ethical considerations, and sustainability strategies within African STEM education.

3. Research Methodology

3.1 Research Design

This study adopted a Systematic Literature Review (SLR) design to examine the integration of Artificial Intelligence into STEM programs within African higher education institutions. A systematic review was selected because it provides a rigorous, transparent, and replicable approach for identifying, evaluating, and synthesizing existing scholarly evidence on a research topic (Kitchenham & Charters, 2007; Snyder, 2019).

The review focused on literature published between 2015 and 2025, reflecting the period characterized by rapid growth in machine learning, deep learning, learning analytics, and generative AI technologies. The study synthesized evidence from peer-reviewed journal articles, conference proceedings, book chapters, policy reports, and institutional publications to examine current adoption trends, benefits, challenges, ethical concerns, governance issues, and sustainability strategies associated with AI integration in African STEM education. The systematic review was guided by the PRISMA 2020 framework to ensure methodological rigor, transparency, and reproducibility (Page et al., 2021).

3.2 PRISMA Framework

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines, which are internationally recognized standards for conducting and reporting systematic reviews (Page et al., 2021).

The review process consisted of four stages:

Identification

Relevant studies were identified through comprehensive searches of Scopus, Web of Science, Google Scholar, ERIC, and IEEE Xplore. Additional records were obtained from institutional reports, policy documents, and reference list searches.

Screening

Duplicate records were removed using reference management software. Titles and abstracts were screened to determine relevance to the study objectives.

Eligibility

Full-text articles were assessed using predefined inclusion and exclusion criteria to determine their suitability for the review.

Inclusion

Studies meeting all eligibility requirements were retained for final synthesis and analysis.

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The PRISMA framework enhanced the transparency, reliability, and reproducibility of the review process.

3.3 Search Strategy

A comprehensive search strategy was developed to identify relevant literature on AI integration in African higher education. Searches were conducted using combinations of keywords, synonyms, and Boolean operators.

The primary databases included Scopus, Web of Science, Google Scholar, ERIC, and IEEE Xplore because of their extensive coverage of educational technology, artificial intelligence, computer science, and higher education research.

Examples of search strings included:

i. “Artificial Intelligence” AND “Higher Education” AND Africa
ii. “AI in STEM Education”
iii. “Machine Learning” AND Universities
iv. “Generative AI” AND Education
v. “ChatGPT” AND Higher Education
vi. “AI Adoption” AND African Universities
vii. (“Artificial Intelligence” OR AI OR “Machine Learning”)
viii. (“Higher Education” OR University OR Tertiary Education)
ix. (“STEM Education” OR Science OR Engineering OR Technology)
x. (Africa OR “African Universities”)

Search terms were refined iteratively to maximize retrieval of relevant studies while minimizing irrelevant records.

Table 1. Literature Search Results

Concept	Keywords	Database	Retrieved	Duplicates Removed	Screened	Eligible	Included
Artificial Intelligence	"Artificial Intelligence", AI, "Machine Learning", "Generative AI", ChatGPT	Scopus	325	58	267	85	42
Higher Education	"Higher Education", University, "Tertiary Education"	Web of Science	210	36	174	61	28

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STEM Education	"STEM Education", Science, Technology, Engineering, Mathematics	ERIC	145	22	123	44	19
Region	Africa, "African Universities"	IEEE Xplore	178	31	147	39	17
STEM Education	Higher Education", University, "Tertiary Education"	Google Scholar	620	142	478	88	34
		Total	**1,478**	**289**	**1,189**	**317**	

3.4 Inclusion and Exclusion Criteria

To ensure consistency and relevance, explicit inclusion and exclusion criteria were established before data collection.

Inclusion Criteria

Studies were included if they:

1. Examined AI applications in higher education.
2. Focused on African educational contexts.
3. Addressed STEM education or related disciplines.
4. Were published between 2015 and 2025.
5. Were peer-reviewed journal articles, conference proceedings, book chapters, or reputable policy reports.
6. Were available in English.
7. Provided empirical, conceptual, or policy-related evidence relevant to AI integration.

Exclusion Criteria

Studies were excluded if they:

1. Focused exclusively on primary or secondary education.
2. Examined AI applications outside educational contexts.
3. Opinion pieces were lacking scholarly evidence.
4. Were duplicate publications.
5. Lacked methodological transparency.
6. Were unavailable in full-text format.

3.5 Data Extraction Procedures

A standardized data extraction protocol was developed to facilitate systematic collection and organization of information from selected studies. Data extraction was guided by recommendations for evidence synthesis and systematic reviews (Kitchenham & Charters, 2007).

The following information was extracted:

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i. Author(s) and publication year
ii. Country or region
iii. Research objectives
iv. Study design and methodology
v. Sample characteristics
vi. AI technologies examined
vii. Educational context
viii. Major findings
ix. Reported benefits
x. Implementation challenges
xi. Ethical considerations
xii. Policy recommendations

The extracted information was organized into thematic matrices to facilitate comparison and synthesis across studies.

3.6 Quality Assessment

To ensure the reliability and credibility of findings, all included studies underwent quality assessment based on methodological rigour, relevance, validity, reliability, and publication quality (Petticrew & Roberts, 2006).

Assessment criteria included:

Methodological Rigor

i. Clearly defined objectives
ii. Appropriate research design
iii. Transparent data collection methods
iv. Adequate analytical procedures

Relevance

i. Alignment with AI integration in higher education
ii. Relevance to African educational contexts
iii. Contribution to STEM education research

Validity and Reliability

i. Credibility of findings
ii. Evidence-based conclusions
iii. Consistency between objectives, methods, and results

Publication Quality

i. Peer-review status
ii. Academic impact
iii. Citation record where available

Studies were classified as high, moderate, or low quality. Only moderate- and high-quality studies were included in the final synthesis.

3.7 Data Analysis

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The study employed a combination of thematic analysis and PESTEL analysis to provide both educational and contextual insights into AI integration across African higher education institutions.

3.7.1 Thematic Analysis

Thematic analysis followed the six-step framework proposed by Braun and Clarke (2006):

1. Familiarization with the data.
2. Generation of initial codes.
3. Searching for themes.
4. Reviewing themes.
5. Defining and naming themes.
6. Producing analytical narratives.

This process enabled identification of recurring themes related to AI adoption patterns, educational benefits, implementation challenges, ethical concerns, governance issues, sustainability strategies, and policy implications.

3.7.2 PESTEL Analysis

To complement thematic analysis, a PESTEL framework was employed to examine macro-level factors influencing AI adoption (Yüksel, 2012).

The analysis considered:

Political Factors: National AI policies, government strategies, and educational reforms.

Economic Factors: Funding availability, infrastructure investment, and workforce development priorities.

Social Factors: Digital literacy, stakeholder readiness, equity, inclusion, and societal attitudes toward AI.

Technological Factors: Internet connectivity, computing infrastructure, AI tools, innovation ecosystems, and digital transformation capacity.

Environmental Factors: Sustainability implications of AI deployment, energy consumption, and environmentally responsible digital transformation.

Legal Factors: Data protection regulations, intellectual property rights, AI governance frameworks, privacy requirements, and ethical compliance standards.

The integration of thematic and PESTEL analyses provided both micro-level educational insights and macro-level contextual understanding of AI implementation across African higher education institutions. This combined analytical approach strengthened the comprehensiveness of the review and informed the development of evidence-based recommendations for sustainable AI-driven curriculum integration.

4. Results

4.1 Geographic Distribution and Characteristics of Included Studies

Table 4 presents the geographical distribution of the 140 studies included in the systematic review. The findings indicate that research on AI integration in STEM education within African higher education is unevenly distributed across the continent.

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Table 2. Geographic Distribution of Included Studies (N = 140)

Country/Region	Frequency (n)	Percentage (%)
Nigeria	45	32.1
South Africa	28	20.0
Kenya	18	12.9
Ghana	14	10.0
Rwanda	10	7.1
Egypt	9	6.4
Other African Countries	16	11.5
Total	**140**	**100.0**

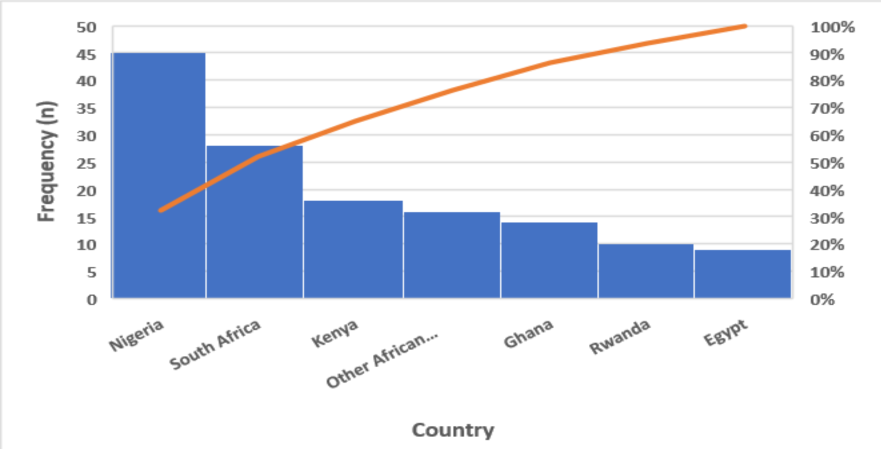

Figure 2. Geographic distribution of studies on AI-driven STEM education in African higher education institutions (2015–2025).

Results Narrative

The analysis revealed considerable variation in the geographical distribution of AI-related STEM education research across African higher education institutions. Nigeria accounted for the largest proportion of studies (n = 45, 32.1%), followed by South Africa (n = 28, 20.0%). Together, these two countries contributed more than half (52.1%) of all studies included in the review.

Kenya (12.9%) and Ghana (10.0%) also demonstrated notable levels of scholarly activity in AI-driven STEM education, while Rwanda (7.1%) and Egypt (6.4%) contributed smaller but increasingly significant proportions. The remaining 11.5% of studies originated from other African countries, reflecting emerging but less established research activity in AI-enhanced higher education across the continent.

Overall, the findings suggest that AI research within African higher education remains concentrated in a limited number of countries, particularly those with relatively stronger digital infrastructure, higher research capacity, and more developed innovation ecosystems.

4.2 Publication Trend of AI Research in African Higher Education (2015–2025)

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Table 5 and Figure 3 present the annual distribution of studies included in this systematic review. The publication trend provides insight into the evolution of scholarly interest in Artificial Intelligence (AI) integration within STEM education across African higher education institutions over the period 2015–2025.

Year	**Number of Studies**
2015	2
2016	3
2017	4
2018	6
2019	8
2020	14
2021	19
2022	24
2023	28
2024	21
2025	11
Total	**140**

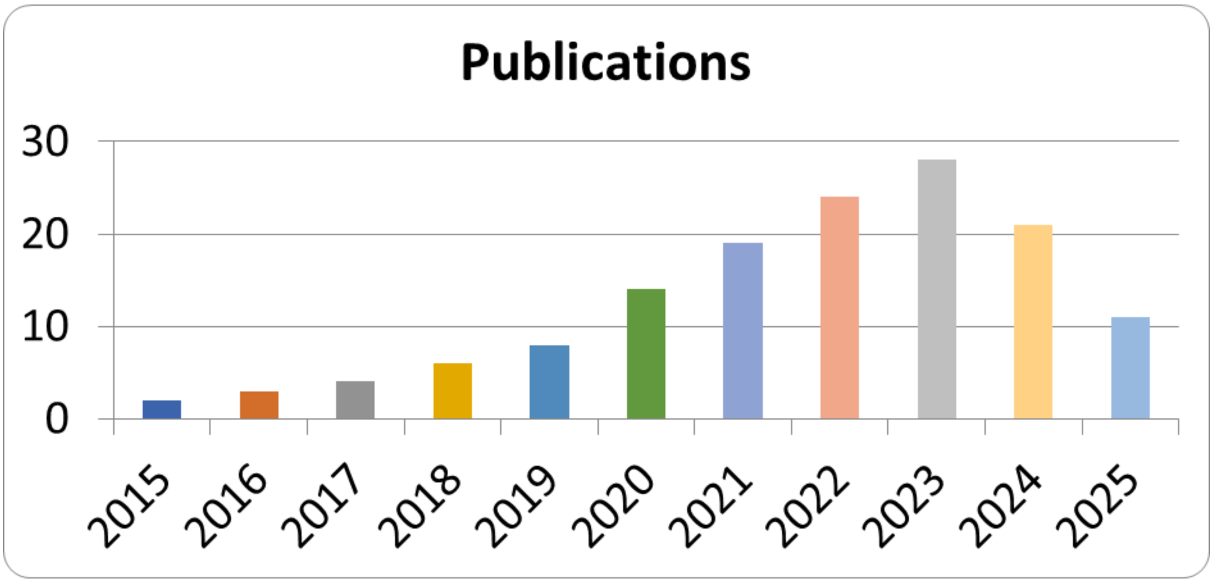

Figure 3. Annual publication trend of studies on AI integration in STEM education across African higher education institutions between 2015 and 2025.

Results

The annual distribution of publications demonstrates a consistent increase in scholarly interest in AI integration within African higher education over the review period. Between 2015 and 2019, publication output remained relatively low, increasing gradually from two studies in 2015 to eight studies in 2019. This period may be considered the formative stage of AI-related educational research on the continent.

A substantial increase in publication activity was observed from 2020 onward. The number of studies nearly doubled from eight in 2019 to fourteen in 2020 and continued to rise steadily, reaching nineteen

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studies in 2021 and twenty-four studies in 2022. Publication output peaked in 2023 with twenty-eight studies, representing the highest annual contribution during the review period.

Although a decline was observed in 2024 (n = 21) and 2025 (n = 11), the overall research output remained considerably higher than that recorded during the pre-2020 period. Collectively, the findings indicate sustained growth in AI-focused educational research across African higher education institutions, particularly during the years following the COVID-19 pandemic.

4.3 AI Technologies Reported in African Higher Education STEM Programs

To understand the technological landscape of AI integration in African higher education, the included studies were analyzed according to the primary AI technologies reported. The findings are presented in Table 6 and Figure 4.

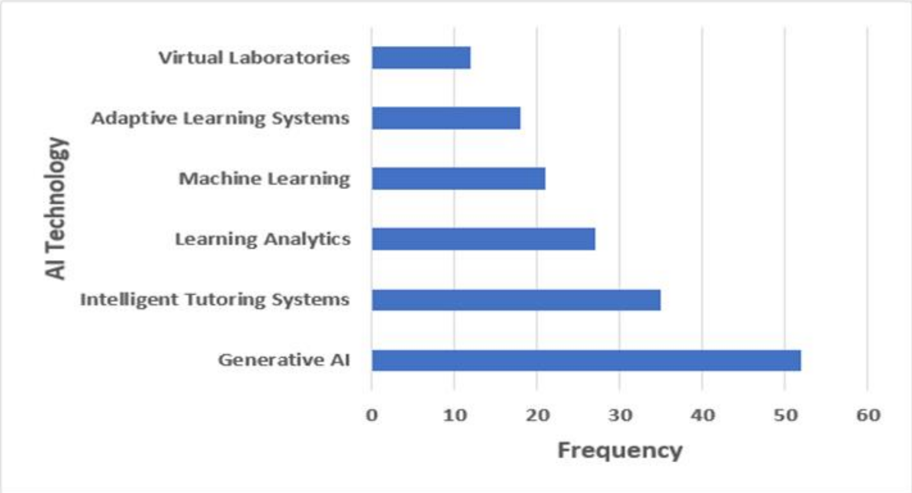

Figure 4: Bar chart representing AI Technology against Frequency (n)

4.3 AI Technologies Reported in African Higher Education STEM Programs

To understand the technological landscape of AI integration in African higher education, the included studies were analyzed according to the primary AI technologies reported. The findings are presented in Table 6 and Figure 4.

AI Technology	Studies Reporting Technology (n)	Percentage of Studies (%)
Generative AI	52	37.1
Intelligent Tutoring Systems	35	25.0
Learning Analytics	27	19.3
Machine Learning Applications	21	15.0
Adaptive Learning Systems	18	12.9
Virtual Laboratories	12	8.6

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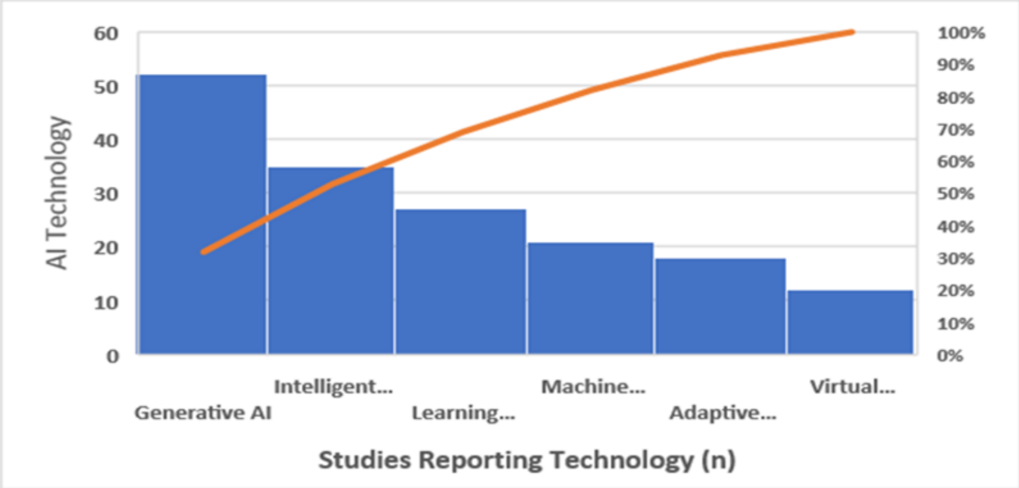

Figure 5. Histogram representing Frequency distribution of AI technologies reported in studies on AI integration within African higher education STEM programs.

Results Narrative

The analysis revealed substantial variation in the types of AI technologies adopted and investigated across African higher education institutions. Generative AI emerged as the most frequently reported technology, appearing in 52 studies. This category included Large Language Models (LLMs) and generative AI platforms such as ChatGPT, Gemini, Claude, and Copilot, which have increasingly been used to support teaching, learning, academic writing, research assistance, and curriculum development.

Intelligent Tutoring Systems (ITS) constituted the second most frequently reported technology, appearing in 35 studies. These systems were primarily employed to provide personalized learning support, adaptive feedback, and automated instructional assistance. Learning Analytics was identified in 27 studies and was commonly utilized for monitoring student performance, predicting learning outcomes, and informing data-driven educational decision-making.

Machine Learning applications were reported in 21 studies, particularly within STEM disciplines involving predictive modelling, data analysis, and problem-solving activities. Adaptive Learning Systems appeared in 18 studies and were used to customize instructional content according to learner needs and progress. Virtual Laboratories were the least frequently reported technology, appearing in 12 studies, although they demonstrated growing importance for supporting practical STEM instruction in resource-constrained educational environments.

Overall, the findings suggest that African higher education institutions are increasingly adopting AI technologies that support personalization, automation, and data-driven learning processes, with a particularly strong emphasis on generative AI applications.

4.4 Educational Benefits of Artificial Intelligence in African Higher Education

Thematic analysis of the included studies identified six major educational benefits associated with the integration of Artificial Intelligence (AI) in STEM education across African higher education institutions. The frequency with which each benefit was reported is presented in Table 7 and Figure 5.

Table 7. Educational Benefits of Artificial Intelligence in African Higher Education

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Thematic analysis of the included studies identified six major educational benefits associated with the integration of Artificial Intelligence (AI) in STEM education across African higher education institutions. The frequency with which each benefit was reported is presented in Table 7 and Figure 5. Percentages are based on the total number of studies included in the review (N = 140). Individual studies frequently reported multiple educational benefits; therefore, percentages do not sum to 100%.

Educational Benefit	**Studies Reporting Benefit (n)**	**Percentage of Studies (%)**
Personalized Learning	85	60.7
Student Engagement	72	51.4
Improved Learning Outcomes	68	48.6
Assessment Automation	51	36.4
Research Support	47	33.6

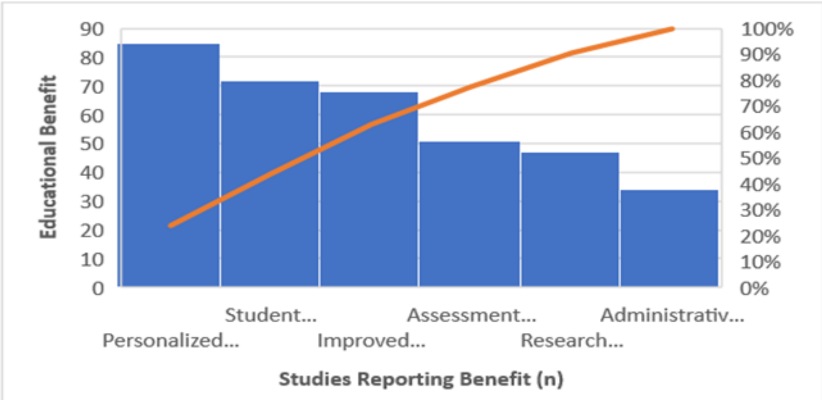

Figure: Histogram representing Education benefit, Studies Report Benefit (n) and the Percentage (%) studied

Results Narrative

The findings indicate that personalised learning was the most frequently reported educational benefit, appearing in 85 studies (60.7%). AI-powered systems were widely used to tailor instructional content, learning pathways, and feedback mechanisms according to individual learner needs and performance levels. This suggests a growing emphasis on learner-centred educational approaches across African higher education institutions.

Student engagement emerged as the second most frequently reported benefit, appearing in 72 studies (51.4%). Several studies highlighted the ability of AI-enabled platforms to promote interactive learning experiences, increase participation, and enhance student motivation through adaptive content delivery and intelligent feedback mechanisms.

Improved learning outcomes were reported in 68 studies (48.6%), indicating that AI technologies contribute to enhanced academic performance, knowledge retention, and conceptual understanding within

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STEM disciplines. Assessment automation was identified in 51 studies (36.4%), reflecting the increasing use of AI for grading, formative assessment, and feedback generation.

Research support functions, including literature discovery, data analysis, academic writing assistance, and knowledge synthesis, were reported in 47 studies (33.6%). Administrative efficiency was the least frequently reported benefit, appearing in 34 studies (24.3%), although several studies emphasized the role of AI in streamlining institutional processes, resource allocation, and student management systems.

Overall, the results suggest that AI integration in African higher education is primarily driven by pedagogical objectives aimed at improving teaching effectiveness, learner engagement, and educational outcomes.

4.5 Challenges to AI Integration in African Higher Education

Despite the growing adoption of Artificial Intelligence (AI) technologies across African higher education institutions, the reviewed studies identified several significant barriers that continue to impede effective implementation. The major challenges reported in the literature are presented in Table 8 and Figure 6.

Challenge	**Studies Reporting Challenge (n)**	**Percentage of Studies (%)**
Poor Infrastructure	92	65.7
Limited Funding	81	57.9
Internet Connectivity Constraints	76	54.3
AI Skills Gap	73	52.1
Ethical Concerns	58	41.4
Data Privacy Issues	42	30.0

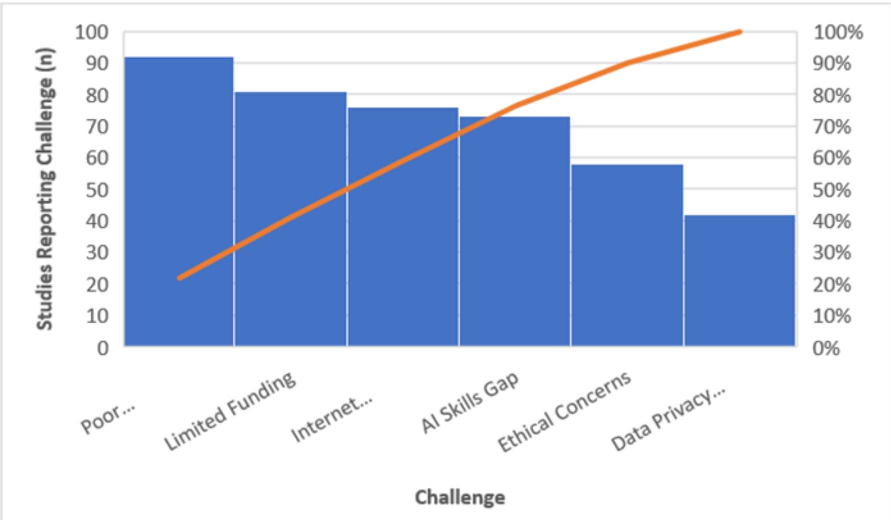

Figure: Histogram representing Studies Reporting Challenge (n), Challenge and the Percentage (%) studied

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Results Narrative

The findings reveal that infrastructural limitations remain the most significant challenge to AI adoption in African higher education institutions. Poor infrastructure was reported in 92 studies (65.7%), making it the most frequently cited barrier. These infrastructural constraints include inadequate computing facilities, unreliable electricity supply, insufficient digital learning platforms, and limited access to advanced technological resources required for AI deployment.

Limited funding emerged as the second most frequently reported challenge, appearing in 81 studies (57.9%). Many institutions face difficulties securing financial resources for AI-related infrastructure, software acquisition, staff training, maintenance, and research activities. Internet connectivity constraints were reported in 76 studies (54.3%), highlighting the continued impact of inadequate broadband access and unstable network services on digital learning environments.

The AI skills gap was identified in 73 studies (52.1%), indicating widespread shortages of qualified personnel capable of developing, implementing, and managing AI technologies within higher education settings. Ethical concerns, including algorithmic bias, transparency, accountability, and responsible AI use, were reported in 58 studies (41.4%). Data privacy issues appeared in 42 studies (30.0%), reflecting growing concerns regarding student data protection, cybersecurity, and regulatory compliance.

Overall, the results suggest that AI integration in African higher education is constrained by a combination of technological, economic, human-capacity, and governance-related factors that require coordinated institutional and policy responses.

4.6 PESTEL Analysis of Factors Influencing AI Integration in African Higher Education

To complement the thematic analysis, a PESTEL framework was employed to identify the macro-environmental factors influencing the adoption and sustainability of Artificial Intelligence (AI) within African higher education institutions. The analysis revealed significant political, economic, social, technological, environmental, and legal factors that collectively shape AI implementation across the continent.

PESTEL Dimension	Key Findings	Implications for AI Integration
Political	Weak AI policies and fragmented implementation strategies	Slower institutional adoption and limited strategic direction
Economic	Funding constraints and limited investment in digital infrastructure	Reduced capacity for AI deployment and sustainability
Social	Low AI literacy, digital skills gaps, and stakeholder resistance	Slower acceptance and effective utilization of AI technologies
Technological	Inadequate infrastructure, unreliable electricity,	Restricted implementation of advanced AI applications

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	and poor internet connectivity	
Environmental	Energy consumption concerns and sustainability challenges associated with digital technologies	Increased operational costs and sustainability considerations
Legal	Emerging data protection regulations and evolving AI governance frameworks	Need for stronger regulatory compliance and ethical safeguards

Results Narrative

The PESTEL analysis revealed that AI adoption in African higher education is influenced by multiple interconnected environmental factors. Politically, many countries continue to operate without comprehensive national AI strategies or coordinated policy frameworks for higher education, resulting in fragmented implementation efforts and inconsistent institutional priorities.

Economic challenges emerged primarily in the form of funding constraints and limited investments in digital infrastructure. Numerous studies reported insufficient financial resources for acquiring AI technologies, upgrading institutional infrastructure, and supporting staff development initiatives.

From a social perspective, low levels of AI literacy among educators, students, and administrators were identified as major barriers to effective adoption. Concerns regarding technological readiness, resistance to change, and limited awareness of AI capabilities were also frequently reported.

Technological factors constituted some of the most significant obstacles to implementation. Inadequate internet connectivity, unreliable electricity supply, insufficient computing resources, and limited access to advanced digital infrastructure continue to hinder large-scale AI deployment across many institutions.

Environmental considerations focused primarily on the sustainability implications of expanding digital infrastructure. Several studies highlighted concerns regarding energy consumption, carbon footprints associated with data-intensive technologies, and the long-term sustainability of AI-enabled educational ecosystems.

Finally, legal factors reflected the evolving nature of AI governance across Africa. While data protection regulations and digital governance initiatives are increasingly emerging, many countries still lack comprehensive regulatory frameworks specifically addressing AI ethics, accountability, transparency, and educational data governance.

Discussion

5.1 Geographic Concentration of AI Research in African Higher Education

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Figure 2 illustrates the distribution of studies included in the review according to country of origin. Nigeria contributed the largest share of publications (n = 45), followed by South Africa (n = 28), while Egypt recorded the lowest contribution among the major countries represented (n = 9).

The analysis revealed considerable variation in the geographical distribution of AI-related STEM education research across African higher education institutions. Nigeria accounted for the largest proportion of studies (n = 45, 32.1%), followed by South Africa (n = 28, 20.0%). Together, these two countries contributed more than half (52.1%) of all studies included in the review.

Kenya (12.9%) and Ghana (10.0%) also demonstrated notable levels of scholarly activity in AI-driven STEM education, while Rwanda (7.1%) and Egypt (6.4%) contributed smaller but increasingly significant proportions. The remaining 11.5% of studies originated from other African countries, reflecting emerging but less established research activity in AI-enhanced higher education across the continent.

Overall, the findings suggest that AI research within African higher education remains concentrated in a limited number of countries, particularly those with relatively stronger digital infrastructure, higher research capacity, and more developed innovation ecosystems.

As shown in Figure 2, research output on AI-driven STEM education is heavily concentrated in Nigeria and South Africa, which together contributed more than half of the studies included in the review. This pattern highlights significant disparities in research productivity and AI adoption across African higher education systems.

The findings demonstrate a clear concentration of AI-related STEM education research in Nigeria and South Africa, which together accounted for more than half of all studies reviewed. This pattern reflects broader disparities in research productivity, digital infrastructure, funding availability, and institutional capacity across African higher education systems.

Nigeria's leading position may be attributed to its large higher education sector, growing technology ecosystem, increasing investment in digital transformation initiatives, and expanding interest in artificial intelligence applications within education. Similarly, South Africa's strong representation reflects its comparatively advanced research infrastructure, established innovation systems, and substantial investments in higher education research and development.

The relatively high contributions from Kenya, Ghana, and Rwanda further suggest the emergence of regional innovation hubs where governments and universities have increasingly prioritized digital transformation and AI capacity development. Recent national strategies promoting digital skills, technology entrepreneurship, and educational innovation may have contributed to the growing body of AI-related research originating from these countries.

Conversely, the lower representation of many African countries highlights persistent structural challenges that continue to hinder AI adoption and research development. These challenges include inadequate digital infrastructure, limited funding opportunities, shortages of AI specialists, unreliable electricity supply, and weak institutional support mechanisms. The uneven distribution of research activity, therefore, reflects broader digital divides that characterise higher education systems across the continent.

From the perspective of Diffusion of Innovations Theory, the observed concentration of studies suggests that AI adoption is progressing more rapidly among institutions operating within favourable innovation environments. Countries with stronger technological ecosystems and policy support appear to

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function as early adopters, while institutions in less developed contexts remain in earlier stages of the adoption process. Similarly, Socio-Technical Systems Theory emphasizes that successful AI integration depends not only on technological availability but also on the alignment of governance structures, institutional readiness, human capacity, and supportive policy frameworks.

These findings underscore the need for continental strategies that promote equitable access to AI infrastructure, strengthen research collaborations, and support capacity-building initiatives across underrepresented regions. Expanding AI research and implementation beyond a small group of leading countries will be essential for achieving inclusive and sustainable STEM education transformation throughout Africa.

5.2 Evolution of AI Research in African Higher Education

The publication trend observed in this review reveals a significant expansion of scholarly interest in AI-driven STEM education across African higher education institutions during the last decade. While publication activity remained relatively modest between 2015 and 2019, a pronounced increase occurred after 2020, culminating in a peak of twenty-eight studies in 2023.

This trend corresponds closely with the digital transformation initiatives that emerged during and after the COVID-19 pandemic. The widespread disruption of conventional face-to-face teaching compelled universities across Africa to rapidly adopt online learning platforms, digital instructional technologies, learning management systems, and AI-supported educational tools. Consequently, both researchers and policymakers increasingly explored the potential of AI technologies to enhance educational continuity, personalized learning, assessment automation, and student engagement.

The observed increase also reflects growing institutional recognition of AI as a strategic component of Fourth Industrial Revolution (4IR) preparedness. Universities are increasingly integrating AI-related competencies into STEM curricula to equip graduates with skills required for emerging digital economies. The expansion of AI literacy initiatives, machine learning applications, intelligent tutoring systems, learning analytics, and generative AI technologies has further stimulated research activity within the sector.

From the perspective of Diffusion of Innovations Theory, the post-2020 surge in publications suggests that AI technologies have progressed beyond the early awareness stage and are increasingly entering broader institutional adoption phases within African higher education systems. Similarly, Human Capital Theory provides an explanation for the growing emphasis on AI research, as universities seek to develop workforce competencies that align with evolving labour market demands and digital transformation agendas.

The slight decline observed in 2024 and 2025 should be interpreted cautiously, as publication databases often experience indexing delays and incomplete coverage of recently published studies. Consequently, the lower figures for these years may not necessarily indicate a reduction in research activity but rather reflect the timing of data collection and publication indexing processes.

Overall, the publication trend demonstrates that AI has transitioned from an emerging research topic to a mainstream area of inquiry within African higher education. The sustained growth in publication output highlights increasing recognition of AI's potential to transform teaching, learning, research, and workforce development, thereby contributing to broader educational modernization and sustainable development objectives across the continent.

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5.3 Emerging AI Technologies and Their Role in STEM Education Transformation

The findings indicate that Generative AI has become the dominant technological focus within AI-related STEM education research in African higher education. The prominence of generative AI technologies reflects the rapid global expansion of Large Language Models (LLMs) and conversational AI systems following the public release of tools such as ChatGPT and similar platforms. These technologies have significantly altered educational practices by providing real-time academic support, content generation, language assistance, coding support, and personalized learning opportunities.

The substantial representation of Intelligent Tutoring Systems further demonstrates the growing interest in learner-cantered educational technologies. Consistent with Constructivist Learning Theory, intelligent tutoring platforms facilitate active learning by providing individualized feedback, adaptive guidance, and opportunities for self-paced knowledge construction. These capabilities are particularly valuable in African higher education contexts where large class sizes and limited instructional resources may constrain personalized teaching.

The increasing adoption of Learning Analytics highlights the growing importance of evidence-based educational decision-making. Universities are increasingly leveraging educational data to identify learning patterns, monitor student engagement, predict academic performance, and implement targeted interventions. Such developments align with global trends toward data-informed teaching and institutional management.

The relatively lower frequency of Virtual Laboratories and Adaptive Learning Systems may reflect infrastructural and financial limitations that continue to affect many African universities. These technologies often require substantial investments in computing resources, internet connectivity, software infrastructure, and technical expertise. Their lower representation therefore reinforces concerns regarding unequal technological capacity across institutions and regions.

From the perspective of the Technology Acceptance Model (TAM), the widespread adoption of Generative AI may be explained by its high perceived usefulness and ease of use. Unlike more complex educational technologies that require specialized implementation and maintenance, generative AI tools can often be accessed through user-friendly interfaces with minimal technical expertise. This accessibility has accelerated adoption among both educators and students.

Similarly, Diffusion of Innovations Theory suggests that generative AI technologies possess characteristics that facilitate rapid diffusion, including observable benefits, compatibility with existing educational practices, and relatively low barriers to experimentation. Consequently, these technologies have spread more rapidly than infrastructure-intensive solutions such as virtual laboratories and advanced adaptive learning environments.

Overall, the findings demonstrate that AI integration within African higher education is increasingly shifting from traditional automation tools toward intelligent, interactive, and personalized learning technologies. This transition has important implications for curriculum reform, educator training, ethical governance, and workforce preparation in the era of the Fourth Industrial Revolution.

5.4 Educational Value of AI for STEM Teaching and Learning

The findings demonstrate that the most significant contribution of AI to African higher education lies in its capacity to facilitate personalized learning. More than sixty percent of the reviewed studies reported AI-supported personalization as a key educational benefit, highlighting the growing shift from traditional teacher-centered approaches toward adaptive and learner-centered pedagogies. AI technologies enable the

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customization of instructional content, learning pace, and assessment strategies based on individual learner profiles, thereby addressing the diverse educational needs characteristic of many African higher education institutions.

The prominence of student engagement and improved learning outcomes further underscores the transformative potential of AI within STEM education. AI-powered learning environments provide interactive experiences that encourage active participation, continuous feedback, and collaborative problem-solving. These capabilities are particularly relevant within STEM disciplines, where conceptual complexity and practical application often require sustained learner interaction and individualized support.

From the perspective of Constructivist Learning Theory, the findings suggest that AI technologies serve as cognitive and instructional scaffolds that support knowledge construction through active engagement and personalized learning experiences. Intelligent tutoring systems, adaptive learning platforms, and generative AI tools enable learners to interact dynamically with educational content, thereby facilitating deeper understanding and self-directed learning.

The increasing use of AI for assessment automation also reflects broader trends toward data-driven educational practices. Automated assessment systems can reduce instructor workload, provide immediate feedback, and enhance the consistency of evaluation processes. Such capabilities are particularly valuable in African universities that frequently contend with large student populations and limited academic staffing.

The emergence of AI as a research-support tool represents another important development. Generative AI technologies and machine learning applications are increasingly being used to support literature reviews, academic writing, data analysis, coding, and research design. These functions have the potential to improve research productivity and strengthen institutional knowledge-generation capacity.

Nevertheless, the relatively lower frequency of administrative efficiency benefits suggests that AI adoption in African higher education remains predominantly focused on teaching and learning rather than comprehensive institutional transformation. This finding may indicate that many institutions are still in the early stages of AI maturity, where pedagogical applications are prioritized before broader organizational integration.

Overall, the results demonstrate that AI is increasingly positioned as a strategic enabler of educational quality, learner engagement, and academic performance in African higher education. These benefits align closely with Sustainable Development Goal 4 (Quality Education) and support broader efforts to enhance the quality, accessibility, and relevance of STEM education across the continent.

5.5 Barriers to Sustainable AI Adoption in African Higher Education

The findings demonstrate that infrastructural deficiencies and financial constraints constitute the most significant obstacles to AI integration within African higher education institutions. The prominence of these barriers reflects broader structural inequalities that continue to characterize the digital transformation landscape across many African countries.

The high frequency of infrastructure-related challenges suggests that many universities lack the foundational technological resources necessary to support advanced AI applications. Reliable electricity supply, high-performance computing facilities, broadband connectivity, cloud-based services, and digital learning ecosystems remain unevenly distributed across the continent. As a result, institutions often struggle to move beyond pilot projects toward large-scale AI implementation.

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Funding limitations further exacerbate these challenges. Effective AI adoption requires substantial investment in hardware, software, data infrastructure, faculty development, cybersecurity systems, and institutional support mechanisms. In many African higher education systems, competing budgetary priorities and limited research funding restrict the ability of institutions to sustain long-term AI initiatives.

The widespread reporting of AI skills shortages highlights an equally important human-capacity challenge. Successful AI integration depends not only on technological infrastructure but also on the availability of educators, researchers, administrators, and technical personnel with appropriate digital competencies. The findings therefore reinforce the importance of continuous professional development, AI literacy programs, curriculum reform, and workforce capacity-building initiatives.

From the perspective of the Technology Acceptance Model (TAM), inadequate infrastructure and limited digital skills may reduce both perceived usefulness and perceived ease of use, thereby slowing AI adoption among educators and students. Similarly, Diffusion of Innovations Theory suggests that institutions lacking adequate technological and organizational support are less likely to progress beyond the early stages of innovation adoption.

The findings also reveal increasing concern regarding ethical governance and data privacy. As AI systems become more integrated into teaching, learning, and institutional decision-making processes, issues such as algorithmic bias, transparency, accountability, surveillance, and data ownership become increasingly significant. These concerns underscore the need for robust governance frameworks capable of ensuring responsible and ethical AI deployment within educational environments.

Socio-Technical Systems Theory provides a useful lens for interpreting these findings. The theory emphasizes that successful technology implementation depends on the alignment of technical infrastructure, institutional structures, human capabilities, governance mechanisms, and organizational culture. The persistence of multiple interconnected barriers identified in this review suggests that AI integration should be approached as a systemic transformation process rather than a purely technological intervention.

Overall, the findings indicate that while African higher education institutions increasingly recognize the transformative potential of AI, substantial investments in infrastructure, funding, capacity development, ethical governance, and digital policy frameworks are required to achieve sustainable and equitable AI adoption across the continent.

5.6 PESTEL Perspectives on Sustainable AI Adoption in African Higher Education

The PESTEL analysis demonstrates that AI adoption within African higher education institutions is influenced by a complex interaction of political, economic, social, technological, environmental, and legal factors. These findings reinforce the argument that successful AI integration requires a holistic ecosystem approach rather than isolated technological interventions.

The political dimension highlights the importance of national policy frameworks in shaping institutional AI adoption. The absence of comprehensive AI strategies in many African countries may contribute to fragmented implementation efforts and uncertainty regarding long-term institutional planning. Countries with clearly articulated digital transformation agendas appear more likely to create enabling environments for educational AI innovation.

Economic factors emerged as one of the most influential determinants of AI adoption. Funding constraints directly affect infrastructure development, technology acquisition, faculty training, and research

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capacity. Consequently, economic limitations continue to widen disparities between institutions with adequate resources and those operating in resource-constrained environments.

The social dimension underscores the central role of human capacity in AI implementation. Low AI literacy levels and digital skills gaps suggest that technological investments alone are insufficient to achieve meaningful educational transformation. Capacity-building initiatives, faculty development programs, and AI-focused curriculum reforms are therefore essential components of sustainable implementation strategies.

Technological challenges remain the most immediate barrier to AI deployment. Persistent deficiencies in internet connectivity, electricity supply, cloud infrastructure, and computing capacity limit institutional readiness and reduce opportunities for innovation. These findings are consistent with broader evidence regarding digital inequality across African higher education systems.

Environmental concerns introduce an emerging dimension to AI adoption that has received relatively limited attention in the educational literature. As institutions increasingly adopt data-intensive AI technologies, considerations relating to energy efficiency, environmental sustainability, and responsible digital transformation become increasingly important for long-term planning.

The legal dimension reflects the growing importance of governance and regulatory oversight in AI-enabled educational environments. The expansion of generative AI, learning analytics, and automated decision-making systems raises important questions regarding privacy, data ownership, accountability, intellectual property, and algorithmic fairness. Strengthening AI governance frameworks will therefore be essential for promoting trust and ensuring ethical deployment.

From the perspective of Socio-Technical Systems Theory, these findings demonstrate that AI adoption cannot be understood solely as a technological process. Rather, successful implementation depends on the alignment of technological resources, institutional structures, policy environments, human capabilities, financial investments, and governance mechanisms. This interconnectedness explains why many institutions continue to encounter implementation challenges despite increasing awareness of AI's educational potential.

Overall, the PESTEL analysis underscores the necessity for comprehensive policy interventions that simultaneously address infrastructure development, funding mechanisms, capacity building, ethical governance, and sustainability considerations. Such coordinated efforts will be critical for achieving equitable and sustainable AI-driven transformation of STEM education across African higher education institutions.

5.7 Pedagogical Transformation through AI-Supported STEM Education

Artificial Intelligence is increasingly transforming pedagogical practices within African higher education institutions by facilitating learner-centered and adaptive instructional approaches. The findings revealed that personalized learning (60.7%), student engagement (51.4%), and improved learning outcomes (48.6%) were among the most frequently reported educational benefits of AI integration. These findings suggest a gradual shift from traditional teacher-centered pedagogies toward more interactive and individualized learning environments.

From the perspective of Constructivist Learning Theory, learning occurs when students actively construct knowledge through exploration, interaction, reflection, and problem-solving (Piaget, 1972; Vygotsky, 1978). AI-powered technologies support these processes by enabling adaptive and personalized

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learning experiences. Intelligent Tutoring Systems provide individualized guidance, immediate feedback, and customized learning pathways that accommodate diverse learner needs and abilities. Such systems enhance conceptual understanding and allow students to learn at their own pace.

Similarly, adaptive learning platforms analyze student performance data and dynamically adjust instructional content to optimize learning outcomes. These technologies promote self-directed learning and increase learner autonomy, which are key principles of constructivist pedagogy. Virtual laboratories further extend learning opportunities by providing simulated environments where students can conduct experiments, explore scientific concepts, and develop practical skills regardless of physical resource constraints.

The findings therefore demonstrate that AI technologies function not merely as instructional tools but as pedagogical enablers that facilitate active learning, collaboration, critical thinking, and problem-solving within STEM disciplines. Consequently, AI integration has the potential to improve educational quality while supporting more inclusive and flexible learning environments across African universities.

5.8 Workforce Readiness and Human Capital Development

The findings indicate that AI adoption contributes significantly to workforce development by enhancing digital competencies, computational thinking skills, and technological literacy among students. The increasing integration of Generative AI, Machine Learning applications, Learning Analytics, and Intelligent Tutoring Systems reflects growing recognition of the need to prepare graduates for emerging labor market demands associated with the Fourth Industrial Revolution.

Human Capital Theory provides a useful framework for interpreting these findings. According to Becker (1993), investments in education and skills development enhance productivity, innovation capacity, and economic growth. AI integration within STEM education strengthens human capital by equipping students with competencies required in technology-driven economies, including AI literacy, data analysis, digital problem-solving, and innovation skills.

Furthermore, AI-supported learning environments expose students to technologies increasingly utilized within industry, thereby improving employability and workforce readiness. Graduates who possess AI-related competencies are likely to be better positioned for employment in sectors such as information technology, engineering, healthcare, finance, manufacturing, and research.

The findings also suggest that AI literacy should be considered a foundational twenty-first-century competency. Beyond technical proficiency, AI literacy enables graduates to critically evaluate AI-generated outputs, understand ethical implications, and utilize AI responsibly within professional contexts. Consequently, AI integration in STEM education contributes not only to educational improvement but also to broader economic transformation and sustainable development objectives across Africa.

5.9 Sustainability and Socio-Technical Readiness for AI Integration

The findings demonstrate that sustainable AI adoption depends on the interaction of technological, organizational, policy, and human factors. The prominence of infrastructure deficits, funding constraints, AI skills shortages, and governance concerns suggests that successful AI implementation requires more than technological investment alone.

Socio-Technical Systems Theory provides an appropriate lens for understanding these complexities. The theory argues that organizational outcomes emerge from interactions between technological systems and social structures (Trist & Bamforth, 1951). In the context of African higher education, AI integration

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requires alignment among infrastructure, institutional leadership, policy frameworks, governance mechanisms, and human capacity.

The PESTEL analysis further reinforces this perspective. Technological challenges such as inadequate internet connectivity and unreliable electricity supply continue to restrict implementation. Politically, weak national AI policies limit institutional strategic planning. Economically, insufficient funding constrains infrastructure development and staff training. Socially, low AI literacy slows adoption and utilization. Legally, evolving data protection regulations highlight the need for stronger governance frameworks. Environmentally, concerns regarding energy consumption and sustainability emphasize the importance of responsible digital transformation.

These findings suggest that universities should adopt a holistic approach to AI integration by simultaneously addressing infrastructure development, capacity building, ethical governance, policy support, and sustainability considerations. Such an ecosystem-based approach is essential for achieving equitable and long-term AI-driven educational transformation across African higher education institutions.

5.10 Proposed Framework for Sustainable AI-Driven STEM Education Transformation

Based on the findings of the systematic review and PESTEL analysis, this study proposes an Africa-cantered framework for sustainable AI integration in STEM education. The framework comprises seven interconnected components: AI Infrastructure, AI Literacy, Curriculum Integration, Ethical Governance, Teaching and Learning Outcomes, Workforce Readiness, and Sustainable Development.

The framework recognizes AI infrastructure as the foundational requirement for successful implementation. Adequate digital infrastructure, internet connectivity, computing resources, and reliable power supply create the conditions necessary for AI adoption. Building upon this foundation, AI literacy enables educators and students to develop the knowledge and competencies required for effective and responsible AI utilization.

Curriculum integration ensures that AI technologies and competencies are embedded within STEM programs. Ethical governance provides safeguards relating to privacy, transparency, accountability, fairness, and academic integrity. Together, these components support improved teaching and learning outcomes, including personalized learning, enhanced engagement, assessment automation, and improved academic performance.

Improved educational outcomes subsequently contribute to workforce readiness through the development of digital skills, innovation capacity, computational thinking, and AI competencies. Ultimately, workforce readiness supports broader sustainable development goals by strengthening human capital, enhancing economic competitiveness, promoting innovation, and contributing to social development across Africa.

The framework therefore offers a strategic roadmap for policymakers, institutional leaders, and educators seeking to achieve responsible, inclusive, and sustainable AI transformation within African higher education systems.

6. Implications for Policy and Practice

The findings of this study have significant implications for policymakers, higher education administrators, curriculum developers, educators, and other stakeholders involved in the digital transformation of higher education across Africa.

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6.1 Policy Implications

The findings demonstrate the need for comprehensive national and institutional AI policies to guide the responsible integration of Artificial Intelligence within higher education. Many African countries continue to lack coordinated AI strategies, resulting in fragmented implementation and inconsistent institutional practices. Governments should therefore develop clear policy frameworks that support AI adoption, establish ethical guidelines, strengthen data governance mechanisms, and promote equitable access to digital technologies.

Furthermore, public investment in digital infrastructure should be prioritized to address persistent challenges relating to internet connectivity, electricity supply, cloud computing resources, and technological capacity. Strengthening regional and continental collaborations through initiatives such as the African Union Agenda 2063 can facilitate knowledge sharing, resource mobilization, and capacity-building efforts that accelerate AI readiness across higher education institutions.

6.2 Institutional Implications

Higher education institutions should adopt strategic approaches to AI integration that align technological innovation with pedagogical objectives, workforce development goals, and ethical governance requirements. Institutional leaders should invest in modern digital infrastructure, establish AI innovation centers, and create supportive environments for experimentation and educational innovation.

Universities should also develop institutional AI governance frameworks addressing issues such as academic integrity, algorithmic transparency, accountability, data privacy, intellectual property rights, and responsible AI use. Such measures are necessary to ensure trust, legitimacy, and sustainability in AI-enabled educational environments.

6.3 Curriculum and Pedagogical Implications

The findings highlight the importance of embedding AI literacy and digital competencies within STEM curricula. Curriculum reforms should move beyond teaching students how to use AI tools and instead emphasize critical understanding of AI concepts, ethical implications, data literacy, computational thinking, and problem-solving skills.

Educators should leverage AI-powered technologies such as intelligent tutoring systems, adaptive learning platforms, learning analytics, and virtual laboratories to support personalized and student-centered learning. Professional development programs should be expanded to equip lecturers with the pedagogical and technical competencies required to integrate AI effectively into teaching and assessment practices.

6.4 Workforce and Economic Implications

AI-driven STEM education has important implications for workforce development and economic competitiveness. The integration of AI into higher education can contribute to the development of highly skilled graduates capable of participating effectively in digital economies and Fourth Industrial Revolution (4IR) industries.

Policymakers and universities should therefore strengthen partnerships with industry, technology companies, and research institutions to ensure that educational programs remain aligned with emerging labor market demands. Such collaborations can support internship opportunities, innovation ecosystems, entrepreneurship development, and knowledge transfer initiatives that enhance graduate employability and innovation capacity.

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6.5 Sustainability Implications

Sustainable AI adoption requires consideration of environmental, social, and governance dimensions. Institutions should adopt energy-efficient digital infrastructure, promote responsible data management practices, and incorporate sustainability principles into AI implementation strategies. Achieving sustainable AI-driven transformation will require balanced investments in technology, human capacity, governance, and environmental stewardship.

Overall, the study underscores the necessity of adopting a holistic ecosystem approach that integrates infrastructure development, AI literacy, curriculum transformation, ethical governance, workforce readiness, and sustainability considerations to achieve meaningful and equitable educational transformation across African higher education institutions.

7. Conclusion

Artificial Intelligence is increasingly reshaping higher education globally and presents significant opportunities for transforming STEM education across African universities. This study systematically reviewed the literature on AI integration in African higher education between 2015 and 2025 to examine adoption trends, educational benefits, implementation challenges, and sustainability considerations associated with AI-driven educational transformation.

The findings reveal growing scholarly and institutional interest in AI integration, particularly following the COVID-19 pandemic and the rapid emergence of Generative AI technologies. AI applications such as Generative AI, Intelligent Tutoring Systems, Learning Analytics, Machine Learning, Adaptive Learning Systems, and Virtual Laboratories are increasingly being utilized to enhance personalized learning, student engagement, assessment processes, research support, and educational outcomes.

Despite these opportunities, significant barriers continue to impede widespread and sustainable adoption. Infrastructure deficits, funding limitations, internet connectivity challenges, AI skills shortages, ethical concerns, and data privacy issues remain substantial obstacles across many African higher education institutions. The PESTEL analysis further demonstrates that political, economic, social, technological, environmental, and legal factors collectively influence AI implementation and sustainability.

Drawing upon the findings and the theoretical foundations of Diffusion of Innovations Theory, Technology Acceptance Model, Constructivist Learning Theory, Human Capital Theory, and Socio-Technical Systems Theory, the study proposes an Africa-centered framework for sustainable AI-driven STEM education transformation. The framework emphasizes the interconnected roles of AI infrastructure, AI literacy, curriculum integration, ethical governance, teaching and learning outcomes, workforce readiness, and sustainable development.

The study concludes that successful AI integration within African higher education requires more than technological adoption. It necessitates coordinated investments in infrastructure, capacity development, governance frameworks, curriculum innovation, and policy support. By addressing these interconnected dimensions, African universities can leverage AI responsibly and effectively to enhance educational quality, strengthen workforce competitiveness, foster innovation, and contribute to the achievement of the Sustainable Development Goals (SDGs).

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Future research should focus on empirical validation of the proposed framework, comparative cross-country analyses of AI implementation, and longitudinal studies examining the long-term educational, economic, and societal impacts of AI-driven transformation in African higher education.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships, which may be considered potential competing interests.

Author Contributions

Agaku Raymond Msughter: Conceptualization, methodology, literature search, data collection, data analysis, framework development, visualization, writing—original draft preparation, and manuscript revision.

Stephen Terzungwe Tyowua: Supervision, methodology validation, theoretical framework development, critical review and editing of the manuscript, and intellectual content enhancement.

Mbapinen Phoebe Adikpo-Andza: Literature review, data interpretation, manuscript editing, quality assurance, and review of the final manuscript.

Ode Samuel Omenka: Manuscript editing, quality assurance, and review of the final manuscript.

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