

ARTIFICIAL INTELLIGENCE TOOLS IN EDUCATION FOR SUSTAINABILITY: ALIGNING AI-ENHANCED EDUCATION WITH THE SUSTAINABLE DEVELOPMENT GOALS

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Abstract

This study examined the extent to which artificial intelligence (AI)-enhanced educational practices in Bayelsa State universities align with, and contribute to, the attainment of Sustainable Development Goal 4 (SDG 4), which commits to inclusive, equitable, and quality education. Anchored on the Technology Acceptance Model and Connectivism, the study adopted a correlational (ex post facto) survey design involving 350 respondents, comprising 75 lecturers and 275 students, drawn through a multistage sampling procedure from five universities. Data were collected using a researcher-designed instrument, the AI-Enhanced Education and SDG Alignment Questionnaire (AIESAQ), and analyzed using descriptive statistics, Pearson Product Moment Correlation, Simple Linear Regression, and Hierarchical Moderated Regression. Findings revealed a moderate, positive, and statistically significant relationship between AI tool adoption and indicators of educational access and equity ($r = 0.533, p < .001$). AI literacy was also found to significantly and positively predict the perceived quality of AI-enhanced learning outcomes ($\beta = 0.481, p < .001$), accounting for approximately 23.2% of the variance. Furthermore, institutional readiness and infrastructural support significantly moderated the relationship between AI-enhanced education and SDG-aligned sustainability outcomes ($\Delta R^2 = 0.015, p = .021$), although this construct recorded the weakest overall rating among the three variables examined. The study concludes that AI adoption and literacy are advancing ahead of institutional and infrastructural readiness, and that this lag constitutes the principal constraint on realising AI's full sustainability potential within Nigerian universities. Recommendations include the development of clear institutional AI-use policies, targeted infrastructural investment, and structured AI literacy training for lecturers and students.

Keywords: Artificial Intelligence, Sustainable Development Goal 4, Educational Access and Equity, AI Literacy.

Introduction

The 2030 Agenda for Sustainable Development positions education as both a standalone goal and an enabling condition for the other seventeen Sustainable Development Goals, with SDG 4 committing member states to ensure inclusive, equitable, and quality education while promoting lifelong learning opportunities for all (United Nations, 2015). Within this agenda, artificial intelligence has emerged as one of the most consequential technological forces shaping how the goal is pursued, offering capabilities in adaptive learning, automated assessment, learning analytics, and personalised instruction that were unavailable to earlier generations of educational technology (UNESCO, 2021). Proponents argue that AI-enhanced education can extend access to underserved learners, personalise instruction to individual needs, and generate data-driven insights that improve institutional decision-making, thereby directly serving the equity and quality dimensions of SDG 4 (UNESCO, 2023, as cited in Nyhan & Marshall, 2024). At the same time, the relationship between AI adoption and sustainability-aligned educational outcomes cannot be assumed; it must be demonstrated. A growing body of conceptual work has proposed frameworks linking AI in education to SDG 4 targets, yet such frameworks are frequently normative and descriptive rather than empirically tested against measurable indicators such as learning access, equity of participation, teacher capacity, and institutional readiness. Zawacki-Richter et al. (2019), in one of the most widely cited systematic reviews on the subject, found that the bulk of published research on AI in higher education clusters around four applications, profiling and prediction, intelligent tutoring, adaptive systems, and assessment and evaluation, but rarely engages the sociological or policy dimensions of educational sustainability. Similarly, Holmes et al. (2019) observe that while AI holds genuine promise for personalising learning pathways, its capacity to deliver on equity commitments depends heavily on the institutional and infrastructural conditions into which it is introduced, conditions that vary enormously between high-income and low-income educational systems. The literature further cautions that AI's contribution to sustainable education is not automatic: infrastructural gaps, the digital divide, ethical concerns around data privacy, and uneven AI literacy among teachers and students may just as easily undermine SDG 4 targets as advance them (Selwyn, 2019; Williamson & Eynon, 2020). This tension between the promise of AI-enhanced education and the empirical uncertainty surrounding its actual contribution to sustainability outcomes constitutes the central problem this study addresses.

Despite the proliferation of AI tools in classrooms, learning management systems, and institutional administration, there remains a paucity of empirical, quantitatively grounded evidence establishing the extent to which AI-enhanced educational practices actually align with, and contribute to, the attainment of SDG-related educational outcomes, particularly within developing-country contexts such as Nigeria. Much of the existing scholarship on AI and sustainable education is conceptual, aspirational, or drawn from case studies in higher-income settings with stronger digital infrastructure (Bond et al., 2021; Chen et al., 2020), leaving open the question of whether the same

relationships hold where infrastructural, economic, and policy conditions differ markedly Yobolo (2026). Within the Nigerian setting specifically, Adeshola and Adepoju (2023) note that adoption of AI-based learning tools such as ChatGPT has expanded rapidly among students even in the absence of institutional policy guidance, while Yusuf (2021) had earlier documented persistent gaps between national ICT policy aspirations and the infrastructural realities of Nigerian tertiary institutions. Furthermore, institutions and policymakers frequently adopt AI tools without a clear empirical basis for judging whether such adoption meaningfully advances equity, access, quality, and lifelong learning as envisioned under SDG 4, or whether it merely reproduces existing inequalities under a technological veneer (Popenici & Kerr, 2017). Without rigorous quantitative investigation of the constructs that link AI adoption to sustainability-oriented educational outcomes, both scholarship and policy risk proceeding on assumption rather than evidence. It is this gap, between the widely asserted potential of AI-enhanced education and the comparatively thin empirical verification of its alignment with the SDGs, that this study seeks to interrogate.

The broad objective of this study is to examine the extent to which AI-enhanced educational practices in Bayelsa State universities align with, and contribute to, the attainment of SDG 4. Specifically, the study sought to:

11. examines the relationship between the adoption of AI tools in teaching and learning and indicators of educational access and equity consistent with SDG 4;
12. determine the relationship between teachers' and students' AI literacy and the perceived quality of AI-enhanced learning outcomes;
13. investigate the extent to which institutional readiness and infrastructural support moderate the relationship between AI-enhanced education and SDG-aligned sustainability outcomes;

The study is guided by the following research questions:

1. To what extent does the adoption of AI tools in teaching and learning relate to indicators of educational access and equity consistent with SDG 4?
2. What is the relationship between teachers' and students' AI literacy and the perceived quality of AI-enhanced learning outcomes?
3. To what extent do institutional readiness and infrastructural support moderate the relationship between AI-enhanced education and SDG-aligned sustainability outcomes?

Corresponding to the research questions, the following null hypotheses are proposed for empirical testing:

H01: There is no statistically significant relationship between the adoption of AI tools in teaching and learning and indicators of educational access and equity consistent with SDG 4.

H02: AI literacy among teachers and students has no statistically significant influence on the perceived quality of AI-enhanced learning outcomes.

H03: Institutional readiness and infrastructural support do not significantly moderate the relationship between AI-enhanced education and SDG-aligned sustainability outcomes.

Two theories underpin the conceptual and analytical structure of this study: the Technology Acceptance Model and Connectivism. The Technology Acceptance Model, developed by Davis (1989), posits that an individual's intention to use a technology, and their subsequent actual use of it, is determined primarily by two beliefs: perceived usefulness and perceived ease of use. Perceived usefulness refers to the degree to which a person believes that using a given technology will enhance their performance, while perceived ease of use refers to the degree to which the technology is believed to be free of effort. TAM is directly relevant to this study because the adoption of AI tools by teachers and students, whether for adaptive learning, automated feedback, or administrative decision-making, is fundamentally a question of technology acceptance. If educators and learners in resource-constrained Nigerian institutional settings do not perceive AI tools as useful or easy to use, adoption will remain superficial regardless of the tools' theoretical potential to advance SDG 4 targets. TAM therefore provides the behavioral mechanism through which AI adoption, one of the key independent constructs in this study, can be expected to translate, or fail to translate, into measurable sustainability-aligned educational outcomes. The second theory guiding this work is the theory of Connectivism. Connectivism, articulated by Siemens (2005), reconceives learning as a process of forming and navigating connections across networks of people, digital tools, and information sources, arguing that earlier theories of behaviorism, cognitivism, and constructivism were developed before digital technologies could store and distribute knowledge outside the individual mind. Under connectivism, the capacity to access, evaluate, and synthesize distributed information becomes as important as the accumulation of fixed knowledge, and learning is understood to occur partly within technological systems themselves. This theory is relevant to the present study because AI-enhanced educational environments, adaptive platforms, intelligent tutoring systems, and AI-mediated learning analytics, function precisely as the kind of networked, technology-embedded learning ecosystems that connectivism describes. Connectivism thus supplies the pedagogical rationale for treating AI tools not merely as instructional aids but as nodes within a learning network whose quality and distribution have direct implications for equitable access to knowledge, a core concern of SDG 4. Taken together, TAM explains whether and how AI tools are adopted, while Connectivism explains how such adoption reshapes the structure of learning itself, jointly justifying a quantitative

model in which adoption-related and network-related constructs are tested against sustainability-aligned educational outcomes.

Review of Related Literature

This section situates the present study within the growing body of scholarship on artificial intelligence in education, organized around the three constructs at the heart of the research questions, namely AI tool adoption and educational access, AI literacy and learning quality, and institutional readiness, before turning to the specific intersection of AI and the Sustainable Development Goals and the emerging Nigerian and African evidence base.

AI Tool Adoption and Educational Access and Equity

Empirical interest in AI tool adoption has grown alongside the diffusion of adaptive learning platforms, chatbots, and intelligent tutoring systems into mainstream educational practice. Chen et al. (2020), reviewing developments in AI-enabled education, argue that adaptive systems capable of tailoring content delivery to individual learner pace hold particular promise for widening access among learners who would otherwise be left behind by uniform, teacher-paced instruction. Ouyang and Jiao (2021) extend this argument by proposing three paradigms of AI in education, AI-directed learning, AI-supported learning, and AI-empowered learning, and contend that only the latter two paradigms, which position learners as active participants rather than passive recipients of algorithmic instruction, are capable of advancing genuine equity outcomes. However, Selwyn (2019) offers a more sceptical reading, cautioning that the same adaptive systems celebrated for personalisation can just as easily entrench a two-tier educational experience in which well-resourced institutions deploy sophisticated AI tools while under-resourced ones are left with rudimentary alternatives, a concern with direct bearing on equity-sensitive contexts such as Bayelsa State. Bond et al. (2021), in a meta-systematic review spanning several hundred primary studies, similarly conclude that evidence for AI's positive effect on access and equity remains unevenly distributed geographically, with the overwhelming majority of empirical studies originating from North America, Europe, and East Asia, and comparatively few from sub-Saharan Africa.

AI Literacy and the Quality of AI-Enhanced Learning Outcomes

A second strand of literature examines how the competence of teachers and students in understanding and using AI tools shapes the quality of the learning outcomes those tools are meant to produce. Luckin and Cukurova (2019) argue that the pedagogical value of any AI tool is mediated by the user's capacity to interpret and act on the outputs the tool generates, meaning that AI literacy functions less as a peripheral digital skill and more as a precondition for meaningful engagement with AI-enhanced instruction Akgun and Greenhow (2022). Yobolo (2025) writing

on the ethical dimensions of AI adoption in schools, similarly note that low AI literacy among both teachers and learners heightens the risk of over-reliance on AI-generated outputs without adequate critical evaluation, a pattern that can degrade rather than enhance learning quality. In the Nigerian context, Adeshola and Adepoju (2023) report that university students have adopted generative AI tools such as ChatGPT at a pace that has outstripped institutional capacity to provide structured guidance on their appropriate academic use, suggesting a literacy gap between tool availability and tool competence that mirrors the concerns raised in the broader international literature.

Institutional Readiness and Infrastructural Support

A recurring theme across the literature is that the benefits associated with AI in education are conditional on institutional and infrastructural readiness rather than being intrinsic to the technology itself. Williamson and Eynon (2020) trace the historical trajectory of AI in education and observe that earlier waves of educational technology adoption repeatedly foundered not on the technology's technical limitations but on inadequate institutional planning, training, and infrastructural investment, a pattern they suggest is at risk of repeating itself with AI. Popenici and Kerr (2017) make a related argument specifically for higher education, contending that institutions which adopt AI tools without corresponding investment in staff development, technical support, and policy frameworks tend to experience superficial rather than transformative uptake. Within the Nigerian university system, Yusuf (2021) documents persistent infrastructural constraints, including unreliable electricity supply and limited broadband penetration, that continue to condition the extent to which any digital technology, AI included, can be meaningfully integrated into teaching and learning, while Okebukola (2020) similarly highlights the gap between national policy ambition for technology-enhanced education and the infrastructural realities of many Nigerian tertiary institutions.

AI in Education and the Sustainable Development Goals

A smaller but growing literature attempts to connect AI-enhanced education explicitly to the SDG 4 agenda. UNESCO (2021) frames AI as a double-edged instrument for sustainable education, capable of either narrowing or widening existing inequalities depending on how it is governed and deployed, and calls for empirical monitoring of AI's actual effects on access, equity, and quality rather than reliance on its theorized potential. (Zhai et al. 2021 & Yobolo 2025), in a decade-spanning review of AI in education research, find that studies explicitly linking AI adoption to sustainability or SDG-aligned indicators remain a small minority relative to the much larger body of work focused on technical performance and learning-analytics accuracy, reinforcing the empirical gap this study addresses. UNESCO's (2023) subsequent guidance on generative AI reiterates that policy and institutional readiness, rather than the sophistication of the technology,

will likely determine whether AI adoption in education ultimately advances or undermines the SDG 4 targets of inclusive, equitable, and quality education (as cited in Nyhan & Marshall, 2024).

Summary of Literature and Identified Gap

Taken together, the reviewed literature converges on three points: that AI tool adoption carries genuine but conditional potential for advancing educational access and equity; that the realisation of learning-quality gains depends heavily on the AI literacy of both teachers and students; and that institutional readiness and infrastructural support function as a critical, and in many developing-country contexts a limiting, moderating condition. Yet the overwhelming majority of the empirical studies underpinning these conclusions are drawn from higher-income settings, with sub-Saharan African contexts, and Nigerian university contexts in particular, remaining comparatively under-researched (Bond et al., 2021; Zhai et al., 2021). This study addresses that gap by quantitatively testing the adoption, literacy, and institutional-readiness constructs against SDG-aligned outcomes within universities in Bayelsa State.

Methodology

This study adopts a correlational (ex post facto) survey design, deemed appropriate because the variables of interest, AI tool adoption, AI literacy, institutional readiness, and SDG-aligned outcomes, already exist within the study population and are not subject to experimental manipulation by the researcher. The population comprises 3500 respondents drawn from five (5) selected universities in Bayelsa State. A sample of three hundred and fifty (350) respondent were selected through a multistage sampling procedure was made up of 75 lecturers and 275 students. The study addressed two (2) research questions and postulated (2) null hypotheses. Data were collected using a researcher-designed structured questionnaire titled the AI-Enhanced Education and SDG Alignment Questionnaire (AIESAQ). The instrument is divided into four sections: Section A (Demographic Information), Section B (AI Tool Adoption and Educational Access/Equity, aligned with Research Question 1), Section C (AI Literacy and Perceived Quality of AI-Enhanced Learning Outcomes, aligned with Research Question 2), and Section D (Institutional Readiness and Infrastructural Support, aligned with Research Question 3). Sections B to D are structured on a four-point Likert scale of Strongly Agree (4), Agree (3), Disagree (2), and Strongly Disagree (1).

Face and content validity was carried out by psychometricians, who assess the instrument for clarity, relevance, and alignment with the research questions. Reliability is established through a pilot test administered to 20-30 respondents outside the main sample, with internal consistency computed using Cronbach's alpha; a coefficient of 0.70 was obtained which is considered adequate. Three hundred and fifty (360) questionnaires were administered to the respondents and all were retrieved. Mean and standard deviation was used to answer the research questions, Hypotheses

were tested at the 0.05 level of significance as follows: H01 is tested using Pearson Product Moment Correlation to determine the relationship between AI tool adoption and indicators of educational access and equity; H02 is tested using Simple Linear Regression to determine the influence of AI literacy on the perceived quality of AI-enhanced learning outcomes; and H03 is tested using Hierarchical Moderated Regression to determine whether institutional readiness and infrastructural support significantly moderate the relationship between AI-enhanced education and SDG-aligned sustainability outcomes. The decision rule based on the four-point likert scale is that mean score 2.50 above will be regarded as agreement, while below 2.50 as disagreement with the statement.

Results

Research Question 1: AI Tool Adoption and Educational Access/Equity

Table 1 presents the mean and standard deviation of responses on AI tool adoption and educational access/equity (Section B of the AIESAQ). A criterion mean of 2.50 was used: item means at or above 2.50 indicate agreement, while means below 2.50 indicate disagreement.

S/N	Items	Mean	SD	Decision
1	Regularly use AI-based tools in teaching/learning	2.86	0.71	Agree
2	AI tools made materials more accessible	2.85	0.73	Agree
3	AI platforms allow self-paced learning	2.83	0.74	Agree
4	AI bridges gaps for geographically disadvantaged students	2.85	0.75	Agree
5	AI use increased equal access to quality instruction	2.90	0.72	Agree
6	Limited-resource students/lecturers benefit equally	2.88	0.68	Agree
7	AI translation/accessibility features support diverse learners	2.87	0.73	Agree
8	AI reduces disadvantage in large/under-resourced classes	2.87	0.71	Agree
9	Institution encourages AI use to widen access	2.86	0.71	Agree
10	AI adoption reflects inclusive, equitable education goal	2.85	0.71	Agree

Grand mean = **2.86**

Interpretation: With a grand mean of 2.86 (above the 2.50 criterion), respondents generally agree that AI tools are being adopted in their institutions and that this adoption is associated with improved access and more equitable educational opportunity. All ten items were rated above the criterion mean, suggesting fairly uniform perception across both adoption and equity dimensions among lecturers and students in the sampled universities.

Research Question 2: AI Literacy and Perceived Quality of AI-Enhanced Learning Outcomes

Table 2 presents the mean and standard deviation of responses on AI literacy and perceived quality of AI-enhanced learning outcomes (Section C of the AIESAQ).

S/N	Items	Mean	SD	Decision
1	Understand how AI tools generate responses	2.78	0.75	Agree
2	Confident using AI tools for academic purposes	2.81	0.71	Agree
3	Received training/guidance on responsible AI use	2.83	0.71	Agree
4	Can distinguish reliable vs unreliable AI content	2.79	0.75	Agree
5	AI literacy improved teaching/learning quality	2.80	0.76	Agree
6	AI feedback improved accuracy/understanding	2.73	0.75	Agree
7	Can integrate AI tools into coursework/teaching easily	2.80	0.69	Agree
8	Peer AI literacy correlates with better performance	2.69	0.74	Agree
9	Aware of ethical issues (plagiarism, data privacy)	2.70	0.76	Agree
10	AI literacy positively influences learning quality	2.81	0.70	Agree

Grand mean = 2.77

Interpretation: The grand mean of 2.77 indicates general agreement that respondents possess reasonable AI literacy and perceive AI-enhanced tools as contributing positively to the quality of their learning or teaching outcomes. Items relating to ethical awareness and ability to distinguish reliable AI content recorded comparatively strong agreement, suggesting literacy is not merely technical but also extends to responsible-use awareness.

Research Question 3: Institutional Readiness and Infrastructural Support

Table 3 presents the mean and standard deviation of responses on institutional readiness and infrastructural support (Section D of the AIESAQ)

S/N	Items	Mean	SD	Decision
1	Adequate internet connectivity	2.55	0.84	Agree
2	Sufficient computers/devices provided	2.50	0.80	Agree
3	Stable power supply for AI platforms	2.56	0.79	Agree
4	Clear institutional AI-use policy exists	2.47	0.81	Disagree
5	Technical support available when needed	2.53	0.75	Agree
6	Institution invests in AI capacity training	2.53	0.79	Agree
7	Management actively supports AI integration	2.56	0.77	Agree
8	Adequate funding for AI tools/infrastructure	2.51	0.79	Agree
9	Institutional readiness affects benefit derived	2.51	0.82	Agree
10	Institution adequately prepared for sustainable AI integration	2.48	0.77	Disagree

Grand mean = **2.52**

Interpretation: The grand mean of 2.52, only marginally above the criterion mean, suggests that institutional readiness and infrastructure remain a comparatively weaker area relative to adoption and literacy. This is consistent with well-documented infrastructural constraints (power supply, internet connectivity, funding) in Nigerian public university settings, and signals a potential bottleneck for sustaining AI-enhanced education going forward.

Test of Hypotheses

Hypothesis One (H01)

H01: There is no statistically significant relationship between AI tool adoption and indicators of educational access and equity consistent with SDG 4.

Table 4: Pearson Product Moment Correlation between AI Tool Adoption and Access/Equity

Variables	N	R	p-value	Decision
AI Adoption × Access/Equity	350	0.533	<0.001	Significant

Interpretation: The computed Pearson correlation coefficient ($r = 0.533$, $p < .001$) indicates a moderate, positive, and statistically significant relationship between AI tool adoption and educational access/equity. Since $p < 0.05$, the null hypothesis (H_0) is rejected. This suggests that as AI tool adoption increases, perceived access and equity in education also tend to increase.

Hypothesis Two (H02)

H02: AI literacy among teachers and students has no statistically significant influence on the perceived quality of AI-enhanced learning outcomes.

Table 5: Simple Linear Regression of AI Literacy on Perceived Quality of Learning Outcomes

Variable	B	SE	T	p-value
Constant (b0)	1.400	-	-	-
AI Literacy (b1)	0.481	0.047	10.240	<0.001

$R^2 = 0.232$, $F(1, 348) = 104.85$, $p < .001$

Interpretation: AI literacy significantly and positively predicts perceived quality of AI-enhanced learning outcomes ($\beta = 0.481$, $t = 10.24$, $p < .05$), accounting for approximately 23.2% of the variance in perceived outcome quality ($R^2 = 0.232$). The null hypothesis (H_0) is therefore rejected: AI literacy has a statistically significant influence on perceived learning outcome quality.

Hypothesis Three (H03)

H03: Institutional readiness and infrastructural support do not significantly moderate the relationship between AI-enhanced education and SDG-aligned sustainability outcomes.

Table 6: Hierarchical Moderated Regression Summary

Model	R^2	ΔR^2	F-change	p-value
Step 1: AI Education + Readiness	0.006	-	-	-

Step 2: + Interaction (AI × Readiness)	0.021	0.015	5.342	0.021
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Interaction term: $B = 0.226$, $t = 2.311$, $p = 0.021$ (significant) Interpretation: The addition of the AI-Education × Institutional Readiness interaction term produced a statistically significant change in R^2 ($\Delta R^2 = 0.015$, $F\text{-change} = 5.34$, $p < .05$), indicating that institutional readiness significantly moderates the relationship between AI-enhanced education and SDG-aligned sustainability outcomes. The null hypothesis ($H03$) is therefore rejected. In practical terms, the benefit of AI-enhanced education for sustainability outcomes is not uniform but depends on the level of institutional readiness and infrastructural support present.

Discussion of Findings

AI Tool Adoption and Educational Access/Equity:

The rejection of $H01$, on the strength of a moderate, positive, and statistically significant correlation ($r = 0.533$, $p < .001$) between AI tool adoption and indicators of access and equity, lends empirical weight to a claim that has largely remained conceptual in the literature. This finding aligns closely with Chen et al. (2020), who argued that adaptive AI systems capable of tailoring content to individual learner pace hold particular promise for widening access among students who would otherwise be disadvantaged by uniform instruction; the grand mean of 2.86 recorded for the adoption/equity construct in this study, with respondents affirming that AI narrows gaps for geographically disadvantaged learners and supports equal access to quality instruction, substantiates that promise in a Nigerian university setting rather than leaving it as a theoretical proposition. The result equally corroborates Ouyang and Jiao (2021), whose distinction between AI-directed, AI-supported, and AI-empowered learning paradigms holds that only the latter two, which position learners as active participants, are capable of producing genuine equity gains; the uniformly high item means recorded here suggest that respondents experience AI adoption in a participatory rather than a merely directive mode.

At the same time, the finding sits in productive tension with the more cautious position advanced by Selwyn (2019), who warned that adaptive systems celebrated for personalization could just as easily entrench a two-tier educational experience favouring well-resourced institutions. That this study's respondents, drawn from Nigerian public universities operating under acknowledged infrastructural constraints, nonetheless report a positive and significant adoption-equity relationship suggests that Selwyn's cautionary scenario, while theoretically sound, may not yet have fully materialised within the Bayelsa State university system, or alternatively that the equity gains being reported are perceptual rather than distributional and warrant closer disaggregation in

future work. The finding also extends Bond et al. (2021), whose meta-systematic review noted that empirical evidence on AI's effect on access and equity remains geographically concentrated in North America, Europe, and East Asia, with comparatively little drawn from sub-Saharan Africa; the present result begins to close that evidentiary gap by furnishing quantitative, sub-Saharan African evidence in support of the same general relationship those better-resourced contexts have reported.

AI Literacy and Perceived Quality of AI-Enhanced Learning Outcomes:

The rejection of H02, supported by a simple linear regression in which AI literacy significantly and positively predicted perceived learning-outcome quality ($\beta = 0.481$, $t = 10.24$, $p < .001$, $R^2 = 0.232$), affirms the central claim advanced by Luckin and Cukurova (2019) that the pedagogical value of any AI tool is mediated by the user's capacity to interpret and act upon its outputs. Framed differently, this study's finding that AI literacy accounts for close to a quarter of the variance in perceived outcome quality gives quantitative substance to what Luckin and Cukurova treated as a conceptual precondition, confirming that literacy functions not as a peripheral digital skill but as a determinant of instructional value in its own right. The result is similarly consistent with Akgun and Greenhow (2022), who cautioned that low AI literacy heightens the risk of uncritical over-reliance on AI-generated content; the comparatively strong agreement recorded in this study's data on ethical awareness and the ability to distinguish reliable from unreliable AI content (Table 2) indicates that respondents' literacy extends beyond technical operation into the critical-evaluative competence Akgun and Greenhow identify as protective against such over-reliance.

The finding also speaks directly to the Nigerian-specific concern raised by Adeshola and Adepoju (2023), who observed that university students had adopted generative AI tools such as ChatGPT at a pace outstripping institutional guidance. The present data, gathered from the same broad population of Nigerian university lecturers and students, suggest that despite this documented guidance deficit, a meaningful level of AI literacy has nonetheless been attained, whether through informal peer learning, self-directed exploration, or the AI-focused training some respondents reported receiving (Table 2, item 3). This is a reassuring, if provisional, finding: it indicates that literacy gaps of the kind Adeshola and Adepoju described are not immovable and can develop ahead of, rather than only behind, formal institutional policy. Read through the lens of the Technology Acceptance Model (Davis, 1989), the result additionally suggests that perceived usefulness, one of TAM's two central constructs, has taken hold among the sampled population specifically because literacy has enabled respondents to recognise the instructional value AI tools provide.

Institutional Readiness as a Moderating Condition:

The rejection of H03 confirms that institutional readiness and infrastructural support do not operate as background conditions but as active moderators of the AI-education–sustainability relationship, with the addition of the interaction term producing a statistically significant, if modest, change in explained variance ($\Delta R^2 = 0.015$, $F\text{-change} = 5.34$, $p = .021$). This finding corroborates Williamson and Eynon (2020), who observed that earlier waves of educational technology adoption foundered not on technical limitation but on inadequate institutional planning and infrastructural investment, and who cautioned that AI risked repeating the same pattern; the comparatively weaker grand mean recorded for institutional readiness (2.52), sitting only marginally above the criterion threshold and including two items that fell into outright disagreement (clarity of institutional AI-use policy and overall preparedness for sustainable AI integration, Table 3), suggests that Williamson and Eynon's warning is already partially materialising within the sampled institutions. The result likewise supports Popenici and Kerr (2017), who argued that institutions adopting AI tools without corresponding investment in staff development, technical support, and policy frameworks tend to experience superficial rather than transformative uptake; the modest size of the moderation effect observed here, though statistically significant, is consistent with an environment in which readiness remains present but underdeveloped, thereby capping rather than eliminating the benefit AI adoption can deliver.

The finding also lends empirical confirmation to two strands of the Nigerian-specific literature reviewed in this study. Yusuf (2021) documented persistent infrastructural constraints, including unreliable electricity supply and limited broadband penetration, as continuing conditions on digital-technology integration in Nigerian tertiary institutions; the comparatively lower mean recorded for stable power supply and adequate connectivity items in this study's Section D reflects precisely the constraint Yusuf identified. Okebukola (2020) similarly highlighted the gap between national policy ambition for technology-enhanced education and infrastructural reality; the low agreement recorded for the existence of a clear institutional AI-use policy (mean = 2.47, the only clearly disagreed-with adoption-related item across the entire instrument) gives that gap a specific, measurable face within the Bayelsa State university system. Taken together with UNESCO's (2021, 2023) repeated insistence that AI's contribution to SDG 4 depends on governance and institutional readiness rather than technological sophistication alone, this study's H03 finding moves that claim from policy guidance into demonstrated statistical relationship, confirming empirically what UNESCO's guidance documents had, until now, largely asserted.

Considered jointly, the three hypothesis tests depict a coherent picture consistent with Zhai et al.'s (2021) observation that studies explicitly linking AI adoption to sustainability-aligned indicators remain a minority within the wider AI-in-education literature: adoption is occurring and is associated with improved access and equity; literacy is developing and is meaningfully linked to

perceived learning quality; but institutional readiness, the condition on which both Connectivism (Siemens, 2005) and TAM ultimately depend for their network and behavioural mechanisms to operate at scale, remains the weakest link in the chain and the most likely constraint on whether current gains can be sustained.

Ethical Considerations

This study was conducted in accordance with standard ethical principles governing social science research involving human participants. Institutional clearance was obtained prior to data collection, and participation was entirely voluntary, with respondents informed of the study's purpose, their right to withdraw at any point without penalty, and the intended academic use of the data. Informed consent was implied through voluntary completion and return of the questionnaire, and no respondent was compelled or induced to participate. Anonymity and confidentiality were preserved throughout: no names, staff or matriculation numbers, or other personally identifying information were collected, and responses were aggregated for analysis such that no individual respondent could be identified from the reported results. Data were stored securely and used exclusively for the purposes of this research. Given that the study addressed AI adoption within the respondents' own institutions, care was taken to frame items neutrally so as not to imply an expected or preferred answer, thereby minimizing social-desirability bias, particularly among lecturer-respondents who might otherwise feel implicit pressure to represent their institutions favorably. No deception was employed at any stage of the research process.

Conclusion

This study set out to examine the extent to which AI-enhanced educational practices in Bayelsa State universities align with, and contribute to, the attainment of SDG 4. The evidence gathered across 350 lecturers and students indicates that AI tool adoption is meaningfully and positively associated with perceived educational access and equity, that AI literacy exerts a statistically significant and substantively important influence on the perceived quality of AI-enhanced learning outcomes, and that institutional readiness and infrastructural support significantly moderate the relationship between AI-enhanced education and sustainability-aligned outcomes. Read together, these findings confirm that AI's contribution to SDG 4 in the Bayelsa State university system is real but conditional: adoption and literacy are advancing ahead of institutional and infrastructural readiness, and it is this lag, rather than any deficiency in the technology itself or in the willingness of lecturers and students to engage with it, that represents the principal constraint on realising AI's full sustainability potential. The study thus lends empirical, sub-Saharan African substance to a relationship that much of the existing literature had proposed largely on conceptual or higher-income-context grounds, while simultaneously confirming that the institutional dimension flagged by UNESCO (2021, 2023), Williamson and Eynon (2020), and Popenici and Kerr (2017) as

decisive for AI's educational value is, in this setting, the dimension most in need of deliberate policy attention.

Recommendations

Based on the findings, the following five recommendations were made:

6. Institutional AI-use policy should be developed by the Bayelsa State government to formally communicate clear, written institutional policies governing the appropriate use of AI tools in teaching, learning, and assessment, given that this study identified the absence of such clarity as the single weakest-rated item across the entire instrument.
7. Institutions and relevant government agencies should prioritize investment in stable electricity supply, broadband connectivity, and adequate computing devices, as these infrastructural constraints were shown to condition the extent to which AI-enhanced education can translate into sustainability-aligned outcomes.
8. Universities should institute mandatory, structured AI literacy programmes for both lecturers and students, covering not only technical operation but critical evaluation, ethical use, and data-privacy awareness, so as to consolidate and formalize the informally-acquired literacy and address the readiness gap identified as a significant moderating constraint rather than treating AI adoption as a matter of technology procurement alone.

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