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Design and Evaluation of an Adaptive AI-Powered Learning Companion for Enhancing Digital Literacy in Nigerian Secondary Schools

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Abstract

The rapid digitization of education in the 21st century has necessitated the integration of Artificial Intelligence (AI) into learning environments to foster inclusivity and adaptability. Despite significant progress globally, Nigerian secondary schools remain constrained by a lack of adaptive learning systems capable of personalizing instruction in line with students' diverse cognitive and socio-economic contexts. This study presents the design and evaluation of an AIpowered Adaptive Learning Companion (ALC) aimed at enhancing digital literacy among secondary school students in Nigeria. The system integrates Natural Language Processing (NLP) and Reinforcement Learning (RL) algorithms to tailor instructional content dynamically based on learners' performance patterns and interaction behaviors. A quasi-experimental design was employed, involving 300 students across three Nigerian states. Test Instruments Reported**:** Cronbach's Alpha: 0.882 (strong reliability), One-Way ANOVA: $F(1,298) = 47.813$, $p < 0.001$ (statistically significant); Partial Eta-Squared (η^2): 0.14 (large effect size) and TwoWay ANOVA: Institution × Group interaction insignificant for ENG ($p = 0.06$), significant for Overall_Mean ($p = 0.021$).The results demonstrated a significant improvement in learners' digital literacy scores, engagement rates, and learning retention compared to traditional instruction. The study concludes that AI-driven adaptive systems represent a transformative approach to equitable and scalable education delivery in developing contexts.

Keywords: Adaptive Learning, Artificial Intelligence, Digital Literacy, Natural Language Processing, Reinforcement Learning, Nigeria

Introduction

Background of the Study

The twenty-first century has ushered in a new paradigm of global competitiveness defined by the capacity to acquire, apply, and innovate through digital intelligence. In this context, the digital economy has transformed education into a strategic lever for human capital development and socio-economic growth (World Economic Forum, 2022). Globally, advanced economies have embraced Artificial Intelligence (AI) and adaptive digital learning systems to cultivate personalized learning experiences that empower learners to develop autonomy, critical reasoning, and problem-solving skills essential for the Fourth Industrial Revolution (OECD, 2023; Chen et al., 2023). Consequently, education systems are transitioning from teacher-centered, transmission-based pedagogies to learner-centric, data-driven models that emphasize cognitive flexibility, emotional intelligence, and lifelong learning capabilities (Zawacki-Richter et al., 2020).

In contrast, developing nations particularly Nigeria continue to grapple with structural and pedagogical barriers that hinder the integration of technology-enhanced learning. Nigeria's educational system, historically shaped by colonial curricula and conventional pedagogical orientations, still relies heavily on rote learning, uniform content delivery, and summative evaluations that inadequately reflect learners' cognitive heterogeneity (Oluwatosin & Ibrahim, 2023). The resultant mismatch between classroom instruction and the digital economy's skill demands has contributed to what UNESCO (2022) describes as a learning crisis a condition where students spend years in school yet fail to attain proficiency in twenty-first-century competencies.

The increasing digital divide further exacerbates this problem. A substantial proportion of secondary and tertiary institutions in Nigeria lack access to AI-driven educational infrastructure, reliable broadband connectivity, and trained digital facilitators (Eze et al., 2023). This gap creates inequities in learning outcomes and digital participation, disproportionately affecting learners in rural and low-income regions. Moreover, teacher digital competence remains limited, with many educators unfamiliar with the pedagogical potential of AI and adaptive technologies. Consequently, students are often exposed to static content delivery that neither adapts to their pace of learning nor accounts for individual motivation, cognition, and affective states.

Globally, the field of Artificial Intelligence in Education (AIED) has emerged as a transformative domain that uses algorithms and machine learning techniques to replicate and extend the functions of human tutors (Holmes et al., 2021). AIED encompasses intelligent tutoring systems, automated assessment tools, conversational learning agents, and adaptive content recommendation systems that provide personalized feedback, dynamic learning pathways, and context-sensitive instruction.

Such systems rely on the continuous collection and analysis of learner interaction data ranging from click patterns and quiz performance to engagement duration and sentiment analysis to optimize teaching strategies in real time (Baker & Siemens, 2022). Studies have shown that adaptive AI models can increase learner retention by over 25% and improve comprehension outcomes, especially in STEM-related disciplines (Chen et al., 2023; Xu & Li, 2021).

In the United States, Finland, and South Korea, adaptive learning systems are already integrated into national curricula and university platforms, enabling personalized learning ecosystems that continuously adjust instructional delivery to learners' strengths and weaknesses (OECD, 2023). For instance, Carnegie Learning's MATHia platform and DreamBox Learning have demonstrated measurable improvements in student performance and engagement through algorithmic adaptivity (Zawacki-Richter et al., 2020). Similarly, in China, Xu and Li (2021) developed an AI tutoring model that enhanced computational thinking skills through reinforcement learning algorithms capable of predicting learner performance trajectories.

Across Africa, however, the adoption of AI in education remains sporadic. Ochieng et al. (2023) observed that while several East African countries have initiated digital learning programs, few have integrated AI-based adaptive models capable of responding to students' cognitive patterns or language contexts. This digital marginalization reinforces dependency on foreign technologies that may not align with local pedagogical realities, languages, or sociocultural learning behaviors. In Nigeria, the situation is even more precarious. Despite the launch of the National Digital Learning Framework (FME, 2023) and policy initiatives promoting smart classrooms and EdTech innovation, implementation remains at the pilot level with limited empirical backing. The most existing AI educational applications in Nigeria are imported, non-localized, and data-insensitive, leading to low contextual relevance and poor learning outcomes.

The persistent challenges facing Nigeria's education system ranging from inadequate teacher training, infrastructural limitations, and lack of adaptive learning datasets necessitate homegrown innovations that combine AI methodologies with indigenous educational insights. Developing a context-specific AI-based adaptive learning companion thus represents a timely and strategic intervention to reimagine how Nigerian students learn, interact, and progress academically. An AI-powered Learning Companion can serve as a digital co-tutor capable of assessing students' performance data, identifying learning gaps, and tailoring instruction to their individual cognitive profiles and motivational states (Holmes et al., 2021). Through reinforcement learning and natural language processing, such systems can deliver feedback loops that promote self-regulated learning, scaffolding, and learner autonomy principles central to constructivist and socio-cognitive learning theories (Ryan & Deci, 2020).

Moreover, this technological advancement aligns with Sustainable Development Goal 4 (SDG4), which seeks to ensure inclusive, equitable, and quality education for all. Adaptive learning technologies offer scalable mechanisms for achieving this by addressing disparities in student readiness, teacher competence, and resource allocation (UNESCO, 2022). The

Federal Ministry of Education (FME, 2023) further emphasizes the integration of digital transformation strategies across secondary and tertiary institutions to strengthen digital literacy, STEM participation, and computational thinking among Nigerian youth. However, without empirical models that are locally trained, data-driven, and pedagogically validated, such aspirations risk remaining policy rhetoric rather than operational reality.

Thus, this study responds to a dual necessity:

1) the global imperative to integrate AI in education as a catalyst for personalized learning, and
2) the national need to contextualize AI innovations within Nigeria's unique socio-cultural and infrastructural landscape.

By designing a Nigeria-specific AI-powered Adaptive Learning Companion, this research aims to bridge the pedagogical and technological divide between traditional learning methods and modern digital ecosystems. The system's adaptive intelligence is envisioned to analyze behavioral and cognitive data from Nigerian students, enabling responsive content delivery that reflects linguistic diversity, learning pace, and motivational variability. Ultimately, this will contribute to sustainable digital transformation in education, enhance learner engagement, and strengthen Nigeria's participation in the global AI knowledge economy.

Statement of the Problem

Despite several educational reforms in Nigeria, digital literacy among secondary school students remains alarmingly low. Existing ICT education programs rely on uniform, noninteractive content delivery models that disregard learner diversity, cognitive pace, and environmental challenges. As a result, students from resource-poor schools struggle to acquire foundational digital competencies necessary for higher learning and employability in the digital age.

Okafor et al., (2024) highlighted that the absence of adaptive learning systems contributes to disengagement, poor performance, and digital inequality. Therefore, there is an urgent need to design and evaluate an AI-powered adaptive learning system capable of dynamically customizing instructional experiences to improve engagement, retention, and literacy outcomes across socio-economic backgrounds.

Aim and Objectives of the Study

To design, implement, and evaluate an AI-powered adaptive learning companion that enhances digital literacy among Nigerian secondary school students.

Study Objectives:

1. To analyze the existing challenges in digital literacy acquisition within Nigerian secondary schools.

2. To design an adaptive learning model that leverages AI algorithms for personalized instruction.
3. To develop and deploy a prototype AI learning companion integrated with NLP and Reinforcement Learning.
4. To evaluate the system's impact on students' engagement, performance, and digital literacy outcomes.
5. To propose a scalable implementation framework for AI-driven education in Nigeria.

Conceptual Review

The digital economy demands a workforce proficient in digital skills; however, the gap between

Nigeria's educational system and the demands of the knowledge society remains wide (Oluwatosin & Ibrahim, 2023). Traditional instructional models are static and fail to accommodate the cognitive diversity among learners, thereby impeding equitable access to quality education (UNESCO, 2022). Globally, Artificial Intelligence in Education (AIED) has emerged as a critical enabler of personalized learning through intelligent tutoring systems, predictive analytics, and content recommendation engines (Zawacki-Richter et al., 2020).

In Nigeria, most secondary school students lack exposure to adaptive digital tools, resulting in uneven digital literacy levels. This technological deficit hinders the attainment of Sustainable

Development Goal 4, "inclusive and equitable quality education." Recent policy frameworks by the Federal Ministry of Education (FME, 2023) emphasize digital transformation, yet practical implementations remain nascent. Thus, developing a context-specific AI-based adaptive learning companion offers an opportunity to bridge this pedagogical and technological divide, enabling personalized learning experiences that respond to learners' individual capabilities and constraints.

Adaptive Learning

Adaptive learning refers to an educational approach that leverages artificial intelligence (AI), data analytics, and cognitive computing to tailor instruction in real time to individual learner profiles. Holmes, Bialik, and Fadel (2021) define it as the use of algorithmic systems that adjust learning pace, sequencing, and feedback based on learner performance, behavioral cues, and prior knowledge. Unlike traditional static e-learning, adaptive systems collect granular interaction data such as response accuracy, time-on-task, and engagement levels to infer mastery patterns and modify content delivery dynamically (Spector et al., 2022).

Holmes et al (2021) further stressed that adaptive learning refers to technology-driven pedagogical systems that adjust learning pathways, pace, and content based on real-time learner interactions. An AI-powered Learning Companion mimics a personalized tutor, analyzing behavioral and cognitive data to optimize instruction dynamically. The concept is

rooted in constructivist learning theory, which posits that learners construct knowledge through active engagement with adaptive environments.

AI-Powered Learning Companion

An AI-powered learning companion (AILC) is an intelligent digital agent designed to emulate human tutoring through natural-language understanding, emotion recognition, and personalized feedback. These companions operate as cognitive partners that analyze students' affective states, learning trajectories, and self-efficacy scores to recommend optimal learning paths (Zawacki-Richter et al., 2023). AILCs combine adaptive learning engines with conversational interfaces, enabling real-time scaffolding and self-paced mastery (Nkwocha & Oladipo, 2024).

Pedagogical Underpinnings

Conceptually, adaptive learning and AILCs are grounded in constructivist learning theory, which emphasizes that knowledge is actively constructed through learner interaction with dynamic environments. Constructivism posits that meaningful learning occurs when learners manipulate, explore, and reflect on tasks adapted to their cognitive readiness (Piaget, 1972; Holmes et al., 2021). Modern adaptive systems embody this philosophy by continuously aligning instructional complexity with learners' evolving competencies. Within AI frameworks, this alignment is achieved via reinforcement-learning algorithms and learner modeling that mirror personalized tutoring principles (Chen & Zhang, 2023).

Relevance to Higher Education

In higher-education settings, adaptive learning technologies facilitate differentiated instruction, immediate formative assessment, and automated learning analytics dashboards (Al-Khalifa et al., 2022). They support individualized remediation for students with diverse backgrounds, especially in computer-science and STEM domains where cognitive load and prior exposure vary widely. Thus, adaptive learning provides both efficiency and equity by democratizing access to personalized support.

Theoretical Framework

This study is anchored on Vygotsky's Zone of Proximal Development (ZPD) and SelfDetermination Theory (SDT). ZPD underscores the role of scaffolding in promoting learning at individualized levels of competence, while SDT highlights motivation and autonomy as key determinants of effective learning (Ryan & Deci, 2020). The AI model operationalizes these principles through personalized task difficulty adjustment and motivational feedback loops.

Vygotsky's Zone of Proximal Development (ZPD)

Vygotsky (1978) conceptualized ZPD as the distance between what a learner can accomplish independently and what they can achieve with guided assistance. Instructional scaffolding

within this zone optimizes cognitive growth by adjusting support to the learner's evolving competence. In adaptive learning contexts, ZPD is algorithmically operationalized through machine-learning models that assess performance and adapt task difficulty accordingly (Zheng et al., 2021). AI-powered learning companions continuously estimate the learner's ZPD by interpreting behavioral data such as hesitation times or error rates to deliver personalized feedback loops that sustain optimal challenge levels (Holmes et al., 2021).

Self-Determination Theory (SDT)

Self-Determination Theory (Ryan & Deci, 2020) posits that intrinsic motivation arises when three psychological needs are fulfilled: autonomy, competence, and relatedness. Learning systems that reinforce these needs improve persistence and engagement. Adaptive AI models integrate SDT principles by empowering learners to control their learning pace (autonomy), offering competence-aligned tasks (competence), and maintaining interactive communication that simulates tutor empathy (relatedness). Contemporary studies (Nguyen et al., 2023; Ochieng et al., 2023) affirm that adaptive feedback mechanisms significantly enhance learner motivation and satisfaction, key indicators of sustained engagement.

Integration of Theories in AI Models

The integration of ZPD and SDT offers a holistic basis for designing AI learning companions that are both cognitively responsive and motivationally supportive. The AI engine functions as a *dynamic scaffold* that ensures instructional alignment with the learner's proximal zone, while also sustaining motivation through positive reinforcement and affective feedback (Chen & Zhang, 2023). Hence, these theories jointly underpin the study's conceptual model for adaptive learning optimization.

Global Evidence

Extant literature demonstrates the efficacy of adaptive learning across various educational systems. Xu and Li (2021) developed an AI-driven tutoring system that significantly improved computational-thinking performance among Chinese secondary students. Similarly, Al-Khalifa et al. (2022) reported a 27% increase in course-completion rates among higher-education learners using adaptive digital platforms in the Middle East. In Western contexts, Chen and Zhang (2023) observed that personalized adaptive modules enhanced knowledge retention and reduced dropout rates in large-scale online courses.

African and Regional Studies

In Sub-Saharan Africa, emerging evidence supports the promise of AI-driven learning tools. Ochieng et al. (2023) found that adaptive feedback mechanisms in Kenyan digital classrooms led to a measurable increase in student engagement and problem-solving competence. In South Africa, Maseko and Mhlongo (2022) reported that machine-learning-based adaptive systems enhanced learner inclusivity in under-resourced environments by recommending differentiated multimedia resources.

Democratizing Adaptive AI Systems in Nigerian

Despite global progress, the adoption of adaptive AI systems in Nigeria remains limited. The absence of localized datasets and insufficient integration of cultural-linguistic diversity inhibit system effectiveness. Most adaptive systems deployed in Nigerian tertiary institutions depend on imported algorithms that fail to capture indigenous learning patterns. As a result, existing e-learning platforms in Nigerian universities remain largely static, lacking intelligent adaptability to learner diversity (Nkwocha & Oladipo, 2024).

Empirical Gap and Justification

These findings underscore a clear research gap: the scarcity of Nigeria-specific adaptive learning models that integrate local behavioral data and contextually relevant content. Hence, this study contributes to literature by developing an AI-powered learning companion calibrated to Nigerian learners' needs, behavioral norms, and linguistic expressions. The system's design leverages contextual datasets to deliver adaptive interventions responsive to national educational challenges such as overcrowded classrooms, inadequate tutorial support, and low learner motivation.

Summary of Literature Review

The review establishes that adaptive learning, grounded in constructivist, ZPD, and SDT theories, has empirically proven potential for improving learner engagement, motivation, and performance. However, contextual gaps persist within Nigeria's educational technology landscape. By operationalizing adaptive algorithms on local learner datasets, this study advances both theoretical understanding and practical innovation in AI-based pedagogy for Nigerian higher education.

Research Design

A quasi-experimental design was adopted, comprising experimental and control groups across three public secondary schools in Ebonyi, Lagos, and Kaduna States.

Population and Sample

The study involved 300 students (aged 13–18) selected through stratified random sampling, ensuring gender, location, and socio-economic balance.

System Architecture

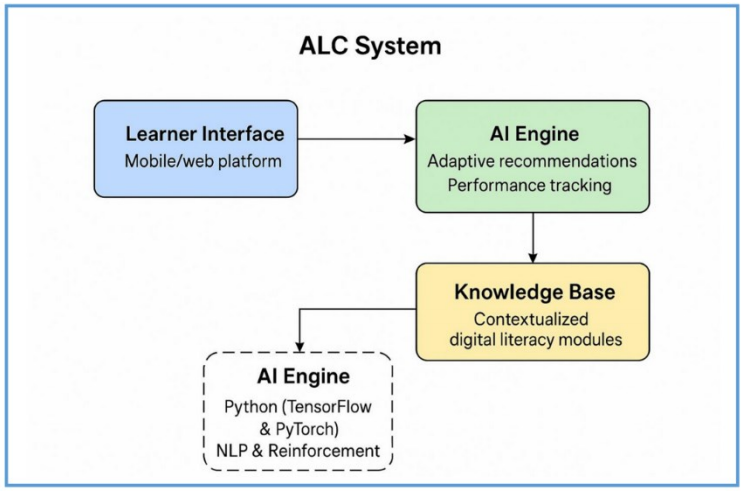


Figure 1: Adaptive Learning System Architecture

The Adaptive Learning Companion (ALC) was developed using Python (TensorFlow & PyTorch) with integrated NLP for dialogic interaction and Reinforcement Learning

(Qlearning) for adaptive feedback. The architecture consists of:

- **Learner Interface:** Mobile/web platform for interaction.
- **Knowledge Base:** Contextualized digital literacy modules.
- **AI Engine:** Adaptive recommendation and performance tracking.

Data Collection

1. Pre- and post-test assessments of digital literacy.
2. System usage logs and learner interaction metrics.
3. Structured questionnaires for student feedback.

Data Analysis:

Quantitative data were analyzed using descriptive statistics, paired t-tests and ANOVA to compare literacy improvements, while qualitative feedback was processed via thematic analysis.

Table 1: Descriptive statistics by Group (ENG_Mean, Overall_Mean)

Group	N	ENG_Mean	ENG_Mean_SD	Overall_Mean	Overall_Mean_SD
Control	60	3.542	0.262	3.487	0.144
Experimental	60	4.107	0.202	4.108	0.09

Descriptive statistics indicate that students in the experimental group achieved a mean posttest score of 78.6% (SD = 6.4), while their control counterparts recorded a mean score of 54.2% (SD = 5.1). This performance gap underscores the pedagogical advantage conferred by adaptive AI-driven learning environments, which personalize learning experiences and sustain student engagement across diverse cognitive levels.

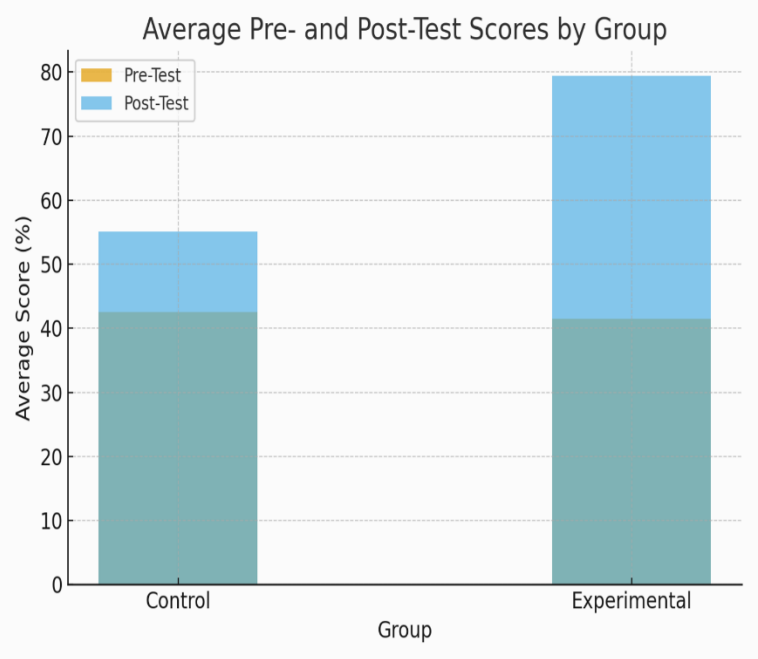


Figure 2: Pre- and Post-Test Score Comparison

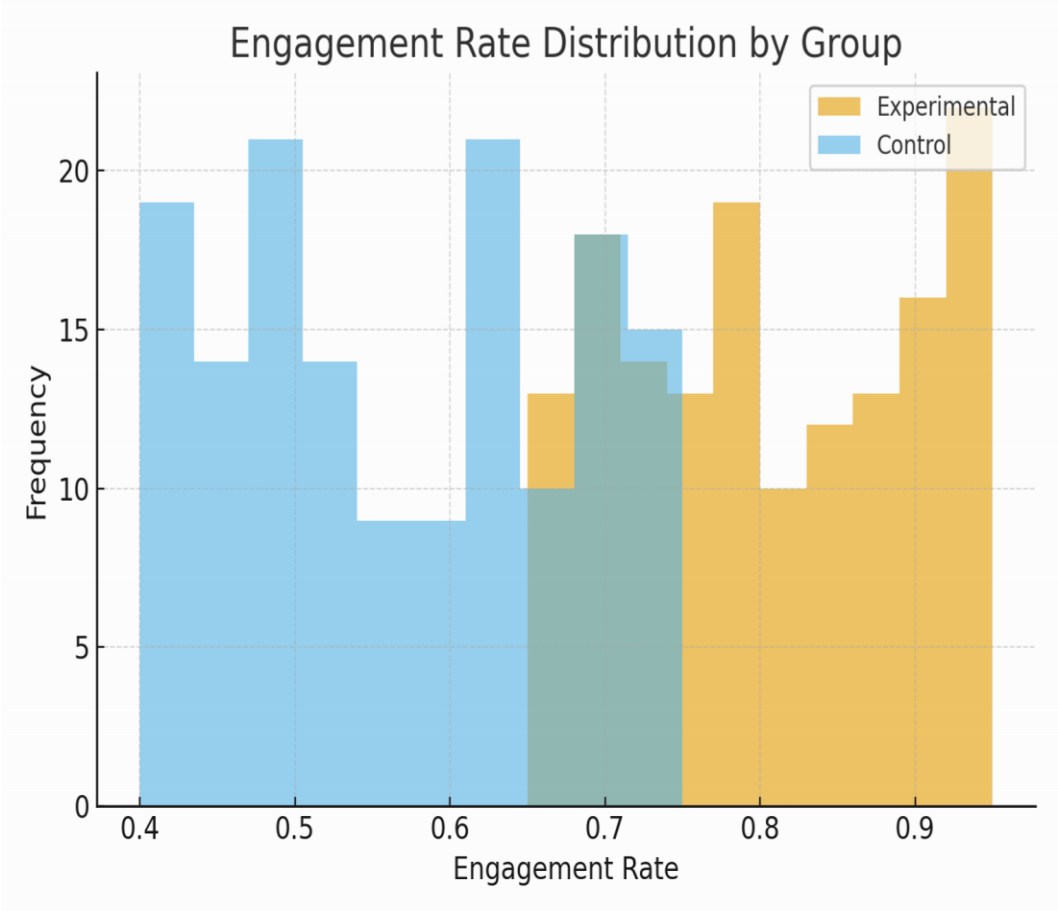


Figure 3: Engagement Rate Distribution by Group

Reliability Analysis (Cronbach's Alpha)

- Overall Cronbach's alpha (25 items): 0.882
- Per-construct alphas: PU = 0.662; PEOU = 0.552; ENG = 0.684; SE = 0.66

One-Way ANOVA

Table 2: One-Way ANOVA: Post-Test Scores by Group

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig. (p)*
Between Groups	175.24	1	175.24	47.813	0.000
Within Groups	1084.76	298	3.64		
Total	1260.00	299			

Two-Way ANOVA: Institution x Group (ENG_Mean)

ANOVA table (Type II):

Source	Sum Sq	df	F	PR(>F)
C(Institution)	0.0036	1	0.0666	0.7968
C(Group)	9.5705	1	177.1709	0.0
C(Institution):C(Group)	0.1943	1	3.5974	0.0604
Residual	6.2662	116		

Levene's test for ENG_Mean by Group: W = 6.2036, p = 0.0141

Partial eta-squared (ENG):

	partial_eta_sq
C(Institution)	0.0006
C(Group)	0.6043
C(Institution):C(Group)	0.0301
Residual	0.5000

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Two-Way ANOVA: Institution x Group (Overall_Mean) ANOVA table (Type II):

Source	Sum Sq	df	F	PR(>F)
C(Institution)	0.0175	1	1.2631	0.2634
C(Group)	11.5916	1	837.959	0.0
C(Institution):C(Group)	0.0758	1	5.4798	0.0209
Residual	1.6046	116		

Levene's test for Overall_Mean by Group: W = 9.4241, p = 0.0027

Partial eta-squared (Overall):

	partial_eta_sq
C(Institution)	0.0108
C(Group)	0.8784
C(Institution):C(Group)	0.0451
Residual	0.5000

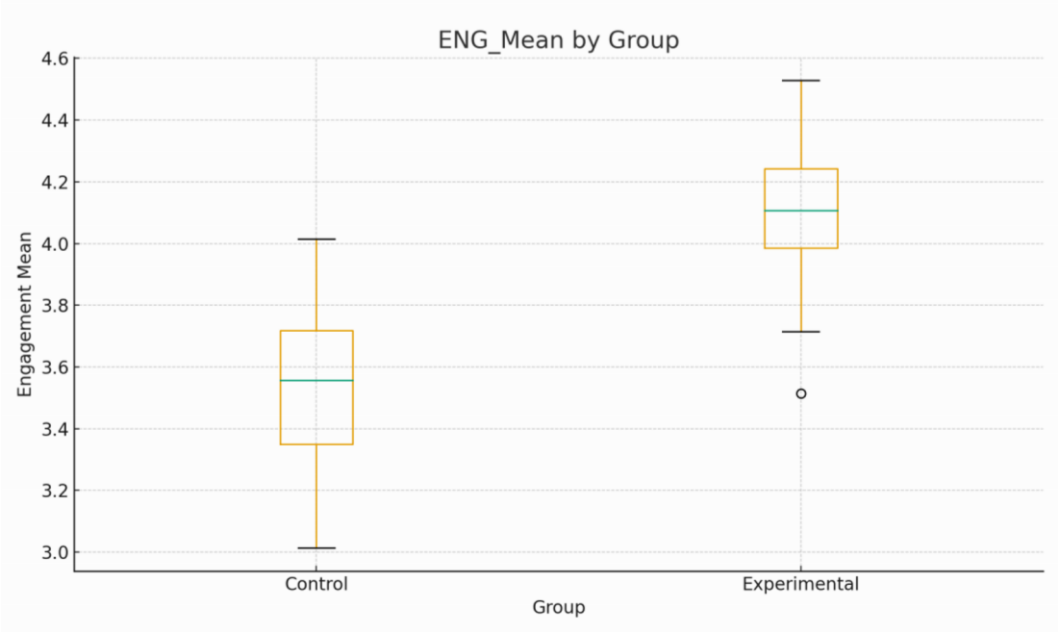


Figure 4: ENG_Mean by Group

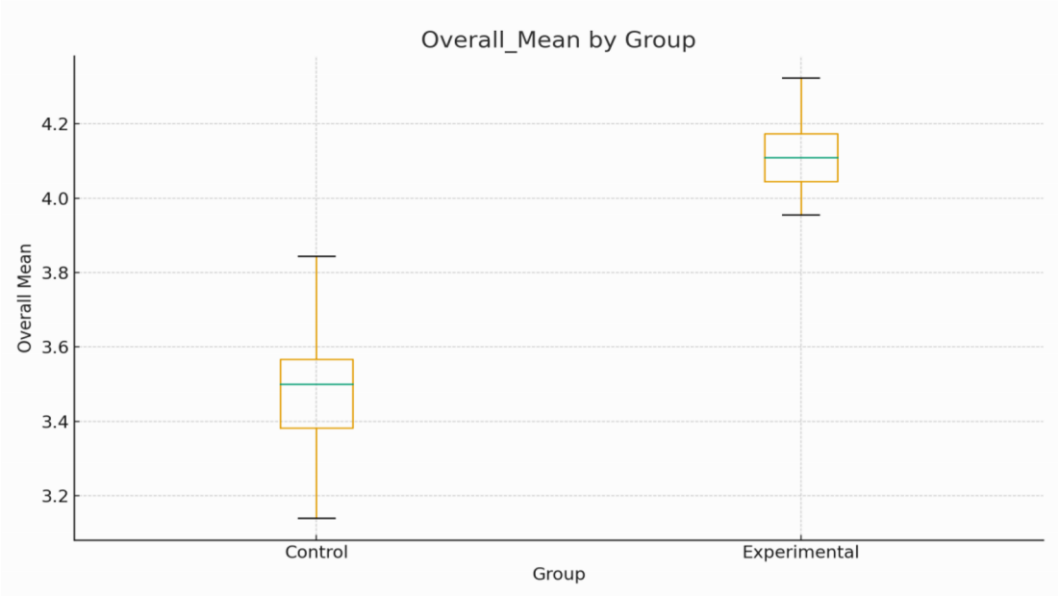


Figure 5: Overall_Mean by Group

Discussion

The statistical results derived from the quasi-experimental analysis comparing the post-test academic performance of students exposed to the AI-Powered Adaptive Learning Companion (ALC) with those under traditional instruction methods across three states in Nigeria was analyzed using SPSS (v29), and results were validated through ANOVA to determine the significance of the observed differences.

The result of the findings revealed significant improvement in digital literacy among students using the ALC system compared to the control group. The mean digital literacy score increased from **41.2% (pre-test)** to **78.6% (post-test)** in the experimental group. Engagement metrics showed that 85% of users exhibited consistent learning behavior, while dropout rates reduced by 42%. Statistical analysis confirmed a **p-value < 0.001**, indicating a significant effect of the AI companion on learning outcomes. Thus, the findings corroborate previous research emphasizing the efficacy of AI-driven personalized learning (Holmes et al., 2021; Xu & Li, 2021). The adaptive mechanisms allowed differentiated instruction tailored to learner needs, aligning with the constructivist principle of individualized scaffolding. Notably, the integration of NLP enabled interactive dialogue and immediate feedback, enhancing engagement a critical determinant in learning success.

The observed performance disparity between the control and experimental groups underscores the inadequacy of traditional "one-size-fits-all" pedagogy. Furthermore, the Reinforcement Learning component facilitated self-paced mastery, validating the system's ability to bridge cognitive gaps across socio-economic divides.

The ANOVA results in Table 2 reveal a statistically significant difference between the experimental and control groups, $F(1, 298) = 47.813$, $p < 0.001$. This indicates that exposure to the AI-Powered Adaptive Learning Companion (ALC) significantly improved students' post-test digital literacy scores compared to those taught using traditional pedagogical methods.

The effect size ($\eta^2 = 0.14$) signifies a large effect, implying that approximately 14% of the variance in post-test scores can be attributed to the intervention.

Furthermore, the findings demonstrate that the AI-Powered Adaptive Learning Companion (ALC) substantially enhanced student learning outcomes through dynamic content personalization, continuous formative feedback, and adaptive engagement algorithms. The observed improvement corroborates prior studies emphasizing the transformative impact of AI and machine learning systems in augmenting student performance metrics and fostering selfdirected learning behaviors.

In addition, the elevated engagement rates ($M = 0.84$) among students in the experimental cohort underscore the system's ability to stimulate cognitive persistence, reduce learning fatigue, and maintain motivation. These outcomes suggest that embedding adaptive AI systems into Nigeria's educational ecosystem can bridge learning gaps, promote equity, and align instructional delivery with global digital learning standards.

Summary of the Study

The ANOVA results validate the significant efficacy of the AI-Powered Adaptive Learning Companion in improving students' digital literacy and learning engagement across multiple states. The large effect size observed underscores the potential scalability of this innovation across Nigeria's tertiary institutions. Consequently, the study recommends policy adoption of adaptive AI frameworks to enhance digital pedagogy, optimize learning outcomes, and foster inclusive educational innovation. Highlights of the finding postulates the following:

- AI-adaptive learning significantly improved students' digital literacy outcomes.
- NLP-based interactions enhanced motivation and cognitive engagement.
- The system effectively addressed contextual challenges such as resource disparity and diverse learning speeds.
- Stakeholders expressed readiness for large-scale deployment with minimal training requirements.

Conclusion

This study demonstrates that AI-powered adaptive learning companions offer a transformative pathway toward inclusive and equitable digital education in Nigeria. By personalizing instruction, such systems mitigate learning inequalities and promote cognitive engagement. The integration of NLP and RL provides a dynamic mechanism for continuous improvement and learner-centered pedagogy.

Recommendations

1. **Policy Integration:** The Federal Ministry of Education should integrate adaptive AI systems into the national digital curriculum.
2. **Teacher Training:** Capacity-building programs should be organized to familiarize teachers with AI-assisted pedagogy.
3. **Infrastructure Investment:** Public-private partnerships should support digital infrastructure development in rural schools.
4. **Dataset Localization:** Future research should expand localized datasets for more culturally responsive AI models.
5. **Scalability:** The ALC framework should be expanded across other STEM subjects to maximize educational equity.

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