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Integrating AI Literacy into Pre-Service Science Teacher Education in Colleges of Education in Plateau State, Nigeria: A Framework for Preparing Educators for AI-Mediated Classrooms

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Abstract

The rapid integration of artificial intelligence (AI) in global education necessitates a purposeful re-orientation of pre-service science teacher preparation. Despite growing policy momentum in Nigeria, Colleges of Education (COEs) in Plateau State remain ill-equipped to embed AI literacy into science teacher education curricula. This study aimed to (i) assess the current level of AI literacy integration in pre-service science teacher education in Plateau State COEs; (ii) identify institutional factors enabling or constraining AI literacy integration; and (iii) develop a contextualised framework for preparing pre-service science teachers for AI-mediated classrooms. Adopting a sequential explanatory mixed-methods design, the study surveyed 112 pre-service science teachers and 15 science education lecturers drawn from two accredited colleges of education in Plateau State using stratified random and purposive sampling. Data were collected through a validated AI Literacy Readiness Questionnaire (ALRQ; Cronbach's $\alpha = .87$) and semi-structured interviews. Quantitative data were analysed using descriptive statistics and independent samples t-tests; qualitative data were analysed thematically. Findings reveal a critically low level of AI literacy readiness ($M = 1.94$, $SD = 0.61$) across all four domains examined. Four qualitative themes characterise institutional barriers: infrastructural inadequacy, lecturer unpreparedness, absence of policy directives, and curriculum rigidity. Prior digital training significantly predicted higher AI literacy among lecturers ($d = 1.39$). The proposed SAIL (Science-AI Literacy Integration) framework offers a structured, theoretically grounded, context-sensitive approach for embedding AI literacy across science education curricula in Nigerian colleges of education.

Keywords: AI literacy, pre-service science teacher education, AI-mediated classrooms, colleges of education

1 Introduction

The emergence of artificial intelligence (AI) as a transformative force in contemporary society has profound implications for education systems worldwide, particularly for the preparation of classroom teachers. In science education, AI tools are increasingly reshaping how concepts are taught, how experiments are simulated, how student performance is assessed, and how scientific inquiry is facilitated (Zawacki-Richter *et al*., 2019; Luckin *et al*., 2016; Hwang *et al*., 2020). From intelligent tutoring systems and adaptive learning platforms to AI-assisted laboratory simulations and generative AI tools such as ChatGPT, the classroom of the twenty-first century is rapidly evolving into an AI-mediated learning environment. This technological shift demands that science teachers not only possess content knowledge and general pedagogical skills, but also develop robust AI literacy defined as the ability to understand, critically evaluate, and effectively deploy AI tools in teaching and learning contexts (Long & Magerko, 2020). In Nigeria, the national aspiration for technological advancement is codified in several policy frameworks, including the National Policy on Education (NPE; Federal Republic of Nigeria, 2013) and the National Digital Economy Policy and Strategy (NDEPS, 2020–2030), which collectively emphasise ICT integration across educational levels. The National Artificial Intelligence Strategy (NAIS, 2024) further signals government commitment to embedding AI across key national sectors, including education. Despite these policy intentions, empirical evidence suggests that teacher education institutions particularly colleges of education charged with producing Nigeria's primary and junior secondary school teachers lag significantly in preparing graduates who can navigate and leverage AI tools in classroom practice (Adekunle & Amosun, 2021; Okonkwo & Awah, 2022; Ayanwale *et al*., 2024). This gap is especially acute in Plateau State, where state-level colleges of education in Gindiri and Pankshin grapple with acute infrastructural deficits, limited bandwidth connectivity, inadequate digital resources, and curricula that have remained largely unchanged since the early 2000s.

While considerable scholarly attention has been devoted to AI integration in higher education settings in developed countries (Hwang *et al*., 2020; Popenici & Kerr, 2017), the literature is remarkably sparse on how developing-country teacher education institutions particularly those in sub-Saharan Africa should approach the challenge of building AI literacy in their pre-service teacher populations. The few African-focused studies available have tended to examine ICT integration broadly, conflating it with AI-specific competencies (Aslan *et al*., 2021). Recent work by Celik (2023) on the Intelligent-TPACK framework and the UNESCO AI Competency Framework for Teachers (2024) have begun to provide more targeted scaffolding, yet their application to Nigerian state COE settings remains unexplored. The present study specifically focuses on College of Education, Gindiri and Federal University of Education, Pankshin two state-level institutions whose resource profiles and institutional contexts differ markedly from federal COEs and whose pre-service teachers have received virtually no scholarly attention in the AI literacy literature.

1.1 Research Objectives

The following objectives guided the study:

1. To assess the current level of AI literacy integration in pre-service science teacher education programmes at College of Education, Gindiri and Federal University of Education, Pankshin.
2. To identify institutional factors that enable or constrain the integration of AI literacy into science teacher education curricula at the two institutions.
3. To develop a contextualised framework for preparing pre-service science teachers for AI-mediated classrooms.

1.2 Research Questions

1. What is the current level of AI literacy integration in pre-service science teacher education programmes at College of Education, Gindiri and Federal University of Education, Pankshin?
2. What institutional factors enable or constrain the integration of AI literacy into science teacher education curricula at the two institutions?
3. How can an AI literacy framework be developed to prepare pre-service science teachers for AI-mediated classrooms?

1.3 Research Hypotheses

The following null hypotheses were formulated for the quantitative inferential analyses:

H01: There is no statistically significant difference in AI literacy readiness scores between male and female pre-service science teachers at College of Education, Gindiri and Federal University of Education, Pankshin.

H02: There is no statistically significant difference in AI literacy readiness scores between science education lecturers who have attended formal digital technology training and those who have not.

The significance of this study lies in its potential to generate contextually specific, evidence-based insights for COEs in Plateau State and, by extension, similar institutions across Nigeria's north-central geopolitical zone.

2 Literature Review

2.1 Conceptualising AI Literacy in Teacher Education

AI literacy has attracted increasing scholarly attention as researchers seek to define the competencies necessary for citizens and professionals to engage meaningfully with AI systems. Long and Magerko (2020) offer one of the most widely cited definitions, describing AI literacy as a set of competencies that enable individuals to critically evaluate AI technologies, communicate and collaborate effectively with AI, and use AI as a tool. In the teacher education context, Ng *et al*. (2021) extended this conception to include pedagogical dimensions the ability not only to understand AI principles but to deploy them purposefully in instructional design, assessment, and student support. Ng *et al*. (2021) organised AI literacy into four domains: Know and Understand AI; Use and Apply AI; Evaluate and Create AI; and AI Ethics. This pedagogical extension is particularly relevant for science teachers, whose discipline is being rapidly reshaped by AI-driven research tools, data analysis systems, and simulation environments. More recently, Celik (2023) proposed the Intelligent-TPACK (I-TPACK) framework, which integrates AI-specific competencies and ethical knowledge into the TPACK structure. The I-TPACK comprises five dimensions: Intelligent Technological Knowledge (AITK), Intelligent Technological Pedagogical Knowledge (AITPK), Intelligent Technological Content Knowledge (AITCK), Intelligent Technological Pedagogical Content Knowledge (AITPACK), and AI Ethics Knowledge. Concurrently, UNESCO released its AI Competency Framework for Teachers (2024) the first global framework of its kind which advocates a human-centred approach integrating AI competencies with principles of human rights, accountability, and agency. In the Nigerian context, Ayanwale *et al*. (2024) examined AI literacy among 529 pre-service teachers and found that conceptual understanding of AI is the strongest predictor of all other AI literacy outcomes, underscoring the foundational importance of the ACU dimension proposed in the present study's SAIL Framework.

The field has witnessed several attempts at competency frameworks. Touretzky *et al.* (2019) proposed the AI K-12 framework, which organises AI literacy around five big ideas: perception, representation and reasoning, learning, natural interaction, and societal impact. While influential, this framework was designed primarily for student learners in the United States and does not account for the pedagogical knowledge teachers must develop to integrate AI meaningfully into science instruction. Mishra, Warr, and Islam (2023) further argued that generative AI fundamentally shifts the TPACK landscape, requiring teachers to develop new capacities for evaluating AI-generated content and designing AI-augmented learning experiences.

2.2 Distinguishing the SAIL Framework from Existing Frameworks

While the frameworks reviewed above make significant contributions, each has limitations that the SAIL Framework is designed to address. Long and Magerko's (2020) framework targets individual citizens broadly and lacks pedagogical specificity for science teacher education. Ng *et al*. (2021) ABCE model was developed primarily in a Hong Kong secondary school context and has not been validated for sub-Saharan African teacher education settings. Celik's (2023) I-TPACK model provides the closest analogue to the SAIL Framework's aspirations but does not offer implementation guidance for resource-constrained, low-connectivity environments such as Gindiri (COE) and Pankshin (FUE). The UNESCO AI Competency Framework (2024), while globally scoped, requires contextualisation for NCCE programmes. The SAIL Framework addresses these gaps by: (i) situating AI literacy development within the specific institutional ecology of state-level Nigerian COEs; (ii) providing curriculum implementation pathways aligned to the NCE Minimum Standards; (iii) incorporating an explicit Contextual Adaptation dimension that accounts for infrastructural constraints endemic to Plateau State institutions; and (iv) grounding professional development in Lave and Wenger's (1991) communities of practice model.

2.3 AI in Science Education: Global and African Perspectives

Globally, AI is transforming science education through adaptive learning systems, AI-assisted laboratory environments, and data-driven personalisation of instruction. Hwang *et al.* (2020) documented how AI-based systems have improved science learning outcomes in K-12 settings by providing immediate, personalised feedback and adaptive problem sets. Zawacki-Richter *et al*. (2019), in their systematic review of AI in higher education, identified four primary application areas relevant to science education: profiling and prediction, intelligent tutoring systems, assessment and evaluation, and adaptive systems. In Africa, the picture is considerably more complex. While a growing number of studies from South Africa, Kenya, and Ghana have examined digital technology integration in teacher education (Aslan *et al*., 2021; Agyei & Voogt, 2011), AI-specific studies remain few. Okonkwo and Awah (2022) documented significant awareness deficits among Nigerian university lecturers regarding AI applications in education, while Adekunle and Amosun (2021) highlighted infrastructure and connectivity barriers as the primary constraints on digital tool adoption in Nigerian secondary schools. These studies collectively suggest that any AI literacy framework designed for Nigerian teacher education must be sensitive to infrastructural realities and the epistemological traditions that shape Nigerian science education.

3 Theoretical Framework

This study is grounded in two complementary theoretical frameworks: the Technological Pedagogical Content Knowledge (TPACK) model (Mishra & Koehler, 2006) and Situated Learning Theory (Lave & Wenger, 1991). Rather than serving as passive background, these frameworks jointly generate the specific dimensions of the SAIL Framework proposed in this study.

3.1 TPACK Extended to AI-TPACK

TPACK provides a robust conceptual lens for understanding how teachers integrate technological knowledge with pedagogical and content knowledge. In the AI literacy context, TPACK is extended to encompass AI-specific technological knowledge (AI-TK), which intersects with science content knowledge (CK) and science pedagogical knowledge (PK) to generate AI-TPACK the knowledge base necessary for effective AI-mediated science teaching (Koehler *et al.,* 2013; Celik, 2023). This extended AI-TPACK conceptualisation directly generates two of the SAIL Framework's dimensions: AI Conceptual Understanding (grounded in AI-TK) and Pedagogical AI Application (grounded in AI-TPACK). The finding by Ayanwale *et al*. (2024) that AI conceptual knowledge is the strongest predictor of all other AI literacy competencies affirms TPACK's primacy as the theoretical scaffold for the SAIL Framework's sequenced dimensions.

3.2 Situated Learning Theory

Situated Learning Theory (Lave & Wenger, 1991) complements AI-TPACK by emphasising that meaningful teacher competency development occurs through authentic, contextualised practice within communities of practice. This theoretical commitment directly generates the SAIL Framework's fourth dimension Contextual Adaptation which insists that AI literacy integration must be rooted in the specific social, institutional, and cultural contexts of Gindiri and Pankshin. Situated Learning Theory further informs the SAIL Framework's professional development model, which prioritises peer learning, collaborative lesson design, and institutionally embedded mentorship over standalone training workshops. Together, AI-TPACK and Situated Learning Theory provide the conceptual scaffolding for the SAIL Framework's four dimensions, their sequencing, and their ecological situatedness.

4 Research Methodology

4.1 Research Design

This study employed a sequential explanatory mixed-methods design (Creswell & Plano Clark, 2018), in which quantitative data were collected and analysed first, followed by qualitative data collection to explain and contextualise the quantitative findings. This design was selected because it allows for a robust assessment of the prevalence and patterns of AI literacy integration (quantitative strand) while simultaneously capturing the nuanced institutional and individual factors that shape those patterns (qualitative strand). The integration of both strands occurs at the interpretation phase, where quantitative findings are explained through qualitative insights. A third methodological strand framework development involved systematic literature synthesis and theoretical mapping, through which the SAIL Framework dimensions were derived from AI-TPACK, Situated Learning Theory, and the empirical findings of the study.

4.2 Participants and Sampling

The study was conducted in two accredited state-level colleges of education in Plateau State: College of Education, Gindiri and Federal University of Education, Pankshin. These institutions were purposively selected as they represent the state-assisted and state-owned COE types producing pre-service science teachers in the Plateau State hinterland. Both institutions serve predominantly rural and semi-urban student populations, share similar resource-constrained operational contexts, and have not previously been the subjects of AI literacy research. The target population comprised all pre-service science teachers in their second and third years of the NCE programme and all science education lecturers across the two institutions. Using stratified random sampling proportional to institutional enrolment figures, 112 pre-service science teachers were selected: Gindiri COE (n = 64) and Pankshin FUE (n = 48). Sample size was determined using Krejcie and Morgan's (1970) formula applied to a target population of approximately 250 eligible students across both institutions. An additional 15 science education lecturers participated in the qualitative strand, selected through purposive sampling to ensure representation across science disciplines (Biology, Chemistry, Physics, Integrated Science) and rank: Gindiri COE (n = 8) and Pankshin FUE (n = 7). Table 2 presents participant demographic characteristics.

Table **2**

Participant Demographic Characteristics

Variable	Category	Pre-Service Teachers (N=112)	Lecturers (N=15)
Gender	Male	61 (54.5%)	9 (60.0%)
	Female	51 (45.5%)	6 (40.0%)
Science Discipline	Biology	32 (28.6%)	5 (33.3%)
	Chemistry	27 (24.1%)	4 (26.7%)
	Physics	27 (24.1%)	3 (20.0%)
	Integrated Science	26 (23.2%)	3 (20.0%)
Institution	Gindiri COE	64 (57.1%)	8 (53.3%)
	Pankshin FUE	48 (42.9%)	7 (46.7%)
Years of Teaching (Lecturers)	< 5 years	—	5 (33.3%)
	5–10 years	—	7 (46.7%)
	> 10 years	—	3 (20.0%)

Note. Usable questionnaires: n = 108 (96.4% response rate).

4.3 Instrumentation

Two primary instruments were used for data collection. The AI Literacy Readiness Questionnaire (ALRQ) was a 42-item instrument structured around four subscales: AI Conceptual Understanding (10 items), Pedagogical AI Application (12 items), Critical AI Evaluation (10 items), and AI Ethics Awareness (10 items). Items were rated on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Content validity was established through expert review by five specialists in science education and educational technology. A pilot test with 25 pre-service teachers from a COE not included in the main study yielded a Cronbach's alpha coefficient of .85, indicating strong reliability (Pallant, 2020). Construct validity was confirmed through exploratory factor analysis supporting a four-factor structure (KMO = .79; Bartlett's test of sphericity: $\chi 2$ (861) = 2,614.7, $p < .001$). The 5-point Likert scale was interpreted using mean range classification adapted from Nworgu (2015): 1.00–1.80 = Very Low; 1.81–2.60 = Low; 2.61–3.40 = Moderate; 3.41–4.20 = High; 4.21–5.00 = Very High. The qualitative strand used a semi-structured interview guide comprising 14 open-ended questions probing lecturers' awareness of AI tools, perceived institutional support for AI integration, curriculum flexibility, and professional development needs. The interview guide was reviewed by two qualitative research specialists and pilot-tested with two lecturers before finalisation.

4.4 Data Collection Procedures

approvals from the respective research ethics committees and institutional management. Questionnaires were administered in paper-and-pencil format during scheduled class sessions to maximise return rates. A total of 108 usable questionnaires were returned from the 112 distributed (96.4% response rate): Gindiri COE (n = 62) and Pankshin FUE (n = 46). Qualitative data were collected in April 2023 through face-to-face, audio-recorded semi-structured interviews conducted at participants' respective institutions in Gindiri and Pankshin. Each interview lasted between 30 and 50 minutes and was transcribed verbatim. Member-checking was conducted with five participants across both sites to verify the accuracy of transcripts.

4.5 Ethical Considerations

Ethical approval was obtained from the Research Ethics Committee of the College of Education, Gindiri (Approval No. COE/G/REC/2023/031) and the Federal University of Education, Pankshin (Approval No. FUE/P/REC/2023/018). Institutional research permissions were obtained from the provost of both institutions. Informed consent was obtained from all participants prior to data collection. Participants were assured of confidentiality and their right to withdraw at any time without penalty. All interview data were anonymised using participant codes (e.g., P1–P15, with institution indicated as G for Gindiri and K for Pankshin). No personal identifiers were included in the data analysis or reporting.

4.6 Data Analysis

Quantitative data were analysed using IBM SPSS Statistics (Version 27). Descriptive statistics (means, standard deviations, frequencies) were computed for all ALRQ subscales, the overall scale, and by institution. An independent samples t-test was used to test H01 (gender comparison) and H02 (digital training comparison). Effect sizes were computed using Cohen's d. An additional independent samples t-test was conducted to examine between-institution differences in AI literacy readiness (Gindiri vs. Pankshin). Qualitative interview data were analysed thematically following Braun and Clarke's (2006) six-phase framework. Themes were developed inductively. A second researcher independently coded a 30% random subsample of transcripts; inter-rater reliability was established at Cohen's $\kappa = .80$. Data saturation was confirmed by the 12th interview, with the three subsequent interviews producing no new codes or themes.

5 Results

5.1 Research Question 1: Current Level of AI Literacy Integration

Table 3 presents descriptive statistics for the four ALRQ subscales and the overall scale score for the combined sample and by institution.

Table **3**

Descriptive Statistics for ALRQ Subscales by Institution (N = 108)

Subscale	Combined M (SD)	Gindiri M (SD)	Pankshin M (SD)	Interpretation
AI Conceptual Understanding	1.81 (0.54)	1.84 (0.56)	1.77 (0.51)	Low
Pedagogical AI Application	1.93 (0.61)	1.97 (0.63)	1.88 (0.58)	Very Low
Critical AI Evaluation	1.96 (0.66)	2.01 (0.68)	1.89 (0.63)	Very Low
AI Ethics Awareness	1.85 (0.52)	1.91 (0.55)	1.77 (0.48)	Very Low
Overall AI Literacy Readiness	**1.89 (0.57)**	**1.93 (0.59)**	**1.84 (0.54)**	**Very Low**

Note. Scale: 1.00–1.80 = Very Low; 1.81–2.60 = Low; 2.61–3.40 = Moderate; 3.41–4.20 = High; 4.21–5.00 = Very High (Nworgu, 2015). Gindiri COE: n = 62; Pankshin FUE: n = 46.

The overall AI literacy readiness score for the combined sample (M = 1.89, SD = 0.57) falls in the 'Very Low' range, indicating critically insufficient readiness for AI-mediated classroom practice across both institutions. Gindiri COE (M = 1.93, SD = 0.59) marginally outperformed Pankshin FUE (M = 1.84, SD = 0.54) on overall readiness, though both scores remain within the Very Low classification. Across subscales, Critical AI Evaluation yielded the highest combined mean (M = 1.96), while AI Conceptual Understanding yielded the lowest (M = 1.81). Notably, AI Conceptual Understanding was the only subscale to score in the 'Low' range (1.81–2.60) for the combined sample, with all remaining subscales falling in the 'Very Low' range. An independent samples t-test comparing overall AI literacy readiness between the two institutions revealed no statistically significant difference, t-(106) = 0.81, p = .420, d = 0.16, indicating that the AI literacy deficit is broadly equivalent across Gindiri and Pankshin despite their different institutional histories and sizes.

5.2 Testing H_{01}: Gender Differences in AI Literacy Readiness

An independent samples t-test revealed no statistically significant difference in overall AI literacy readiness between male (M = 1.91, SD = 0.59) and female (M = 1.86, SD = 0.54) pre-service science teachers across both institutions, t-(106) = 0.46, p = .647, d = 0.09. H01 was therefore retained. The negligible effect size (d = 0.09) confirms that AI literacy deficits are equally distributed across gender groups in both institutions, suggesting that targeted interventions need not be gender-differentiated.

5.3 Testing H_{02}: Effect of Prior Digital Training on Lecturer AI Literacy

Among the 15 science education lecturers, those who had attended at least one formal digital technology training workshop in the preceding three years (n = 6) scored significantly higher on the ALRQ than those who had not (n = 9): M = 2.61 vs. M = 1.72, mean difference = 0.89, 95% CI [0.28, 1.50], t-(13) = 3.14, p = .008, d = 1.28. H02 was therefore rejected. The large effect size (d = 1.28) provides evidence that targeted professional development is associated with meaningfully higher AI literacy readiness among science education faculty, even in constrained institutional settings; however, with a total sample of only 15 lecturers split across two cells (n = 6 and n = 9), this estimate should be interpreted with caution, as it is unstable and vulnerable to outlier influence at this cell size. Given the likely non-normal distribution of scores at this sample size, a non-parametric Mann-Whitney U test would provide a useful robustness check on this finding in future replications. Notably, all six lecturers who had undergone digital training were based at Gindiri COE, which accounts in part for Gindiri marginally higher overall scores.

5.4 Research Question 2: Institutional Enablers and Barriers

Thematic analysis of the 15 lecturer interviews yielded four overarching themes, consistent across both institutions, describing the landscape of AI literacy integration.

Theme 1: Infrastructural Inadequacy

The most pervasive theme across both institutions was the inadequacy of physical and digital infrastructure. Participants at both Gindiri (COE) and Pankshin (FUE) reported unreliable electricity, limited internet connectivity, insufficient computers, and absence of AI-specific tools:

"Our computer laboratory has 18 machines, of which maybe 11 are working at any time. We have over 800 students. You cannot talk about AI in this environment." (P4-G, Chemistry Lecturer, Gindiri COE)

"In Pankshin, we sometimes go two, three days without light. How do I show a student an AI simulation when there is no electricity and no generator fuel?" (P11-K, Physics Lecturer, Pankshin FUE)

Pankshin FUE participants reported more acute infrastructural constraints than Gindiri COE counterparts, with no functioning computer laboratory at the time of data collection and complete reliance on personal mobile devices for any digital content access.

Theme 2: Lecturer Unpreparedness and Low AI Self-Efficacy

Across both institutions, lecturers demonstrated limited familiarity with AI tools and expressed low confidence in AI integration for science teaching:

"I know AI is the future but I cannot teach what I do not understand. I have never received any training on what AI tools are relevant to biology or chemistry teaching." (P2-G, Biology Lecturer, Gindiri COE)

"My students ask me about ChatGPT and I tell them I will find out. I am learning from them, not the other way around. It is embarrassing, honestly." (P13-K, Integrated Science Lecturer, Pankshin FUE)

The data saturation pattern confirmed that conceptual confusion about AI was equally distributed across both institutions, with lecturers at Pankshin FUE expressing slightly lower self-efficacy, reflecting the additional constraint of zero prior digital training exposure in that sample.

Theme 3: Absence of Institutional Policy and Curricular Directives

No participant at either institution could identify an AI-specific institutional policy or curriculum guideline:

"There is no memo, no directive, no meeting that has ever discussed artificial intelligence in this institution since I joined nine years ago." (P7-G, Physics Lecturer, Gindiri COE)

"NCCE sends us documents about curriculum, but AI has never appeared. We implement what NCCE tells us. Nothing more." (P14-K, Biology Lecturer, Pankshin FUE)

Theme 4: Curriculum Rigidity and Examination Pressures

The NCE science curriculum was consistently described as examination-driven and resistant to AI content integration:

"The NCCE examination timetable dictates everything we do. I have 14 weeks to cover a syllabus that takes 20 weeks. There is no space for anything new, including AI." (P5-G, Chemistry Lecturer, Gindiri COE)

"I would be putting my students at risk if I spent time on AI when they need to pass their NCE examinations. That is the honest truth." (P9-K, Chemistry Lecturer, Pankshin FUE)

5.5 Research Question 3: Framework Development

The SAIL Framework was derived through a three-stage development process: (i) systematic review of AI literacy frameworks (Long & Magerko, 2020; Ng *et al*., 2021; Celik, 2023; UNESCO, 2024); (ii) theoretical mapping onto the AI-TPACK and Situated Learning Theory scaffolds; and (iii) calibration of framework dimensions against the empirical findings from both Gindiri COE and Pankshin FUE. The resulting framework is presented in Section 6.

The SAIL Framework: Structure, Dimensions, and Applications

The SAIL (Science-AI Literacy Integration) Framework is a contextually responsive, four-dimensional model for integrating AI literacy into pre-service science teacher education in Nigerian Colleges of Education. It synthesises insights from Long and Magerko (2020), Ng *et al.* (2021), Celik's (2023) Intelligent-TPACK, UNESCO (2024), and the study's empirical findings within the overarching scaffolds of AI-TPACK (Mishra & Koehler, 2006; Koehler et al., 2013) and Situated Learning Theory (Lave & Wenger, 1991). The four dimensions are interdependent and mutually reinforcing, collectively constituting the AI literacy competency that pre-service science teachers require for AI-mediated classrooms.

Dimension 1. AI Conceptual Understanding (ACU)

Grounded in Ng *et al.* (2021) 'Know and Understand AI' domain and the AI-TK component of the I-TPACK model (Celik, 2023), the ACU dimension develops foundational conceptual knowledge of AI among pre-service science teachers. ACU encompasses:

i. Understanding core AI concepts: machine learning, neural networks, natural language processing, generative AI, and how AI systems are trained on data.
ii. Awareness of AI applications in science education: intelligent tutoring systems, adaptive learning platforms, AI-powered virtual laboratories (e.g., PhET), and AI-assisted data analysis tools.
iii. Critical understanding of AI limitations: algorithmic bias, data dependency, hallucination in generative models, and the risks of over-reliance.
iv. Awareness of Nigeria's AI policy landscape: NAIS (2024), NDEPS (2020–2030), and NCCE directives relevant to COE science programmes.

At both Gindiri and Pankshin, ACU is recommended for integration into existing ICT in Education and Science Methods courses at the NCE level, using contextualised examples from the Nigerian secondary school science curriculum and offline-accessible AI learning materials.

Dimension 2. Pedagogical AI Application (PAA)

Grounded in the AITPACK component of Celik's (2023) I-TPACK and Ng *et al*. (2021) 'Use and Apply AI' domain, PAA addresses the practical integration of AI tools with science-specific pedagogical content knowledge. PAA encompasses:

i. Designing AI-augmented science lessons: using AI tools (e.g., ChatGPT for Socratic questioning, PhET simulations, sensor-AI interfaces) to support inquiry-based learning objectives aligned with the NCE science curriculum.
ii. Selecting AI tools matched to specific science content areas: molecular modelling for Chemistry, species identification AI for Biology, motion sensor AI interfaces for Physics.
iii. Facilitating student AI use in ways that promote active inquiry, scientific reasoning, and critical engagement rather than passive content consumption.
iv. Adapting AI-mediated instruction to the large, heterogeneous NCE classrooms and offline/low-bandwidth settings characteristic of Gindiri and Pankshin institutions

Dimension 3 Critical and Ethical AI Reasoning (CEAR)

Grounded in the AI Ethics Knowledge component of the I-TPACK model (Celik, 2023), Ng *et al.* (2021) 'AI Ethics' domain, and UNESCO's (2024) human-centred framework, CEAR develops the critical dispositions and ethical reasoning capacities necessary for responsible AI practice. CEAR encompasses:

i. Evaluating AI-generated scientific content for accuracy, bias, and disciplinary appropriateness given that generative AI models can produce plausible but factually incorrect scientific information.

ii. Recognising and addressing algorithmic bias in AI educational tools, particularly those developed without Nigerian or African educational contexts in view.

iii. Understanding and upholding learner data privacy rights in AI-mediated classroom environments.

iv. Developing and modelling responsible AI use norms for secondary school science students, including academic integrity, critical source evaluation, and equitable AI access.

Dimension 4 Contextual Adaptation (CA)

Grounded in Lave and Wenger's (1991) Situated Learning Theory and the empirical findings from Gindiri and Pankshin particularly Themes 1 and 4 the CA dimension acknowledges that AI literacy integration in these state-level institutions cannot be a transplant of frameworks developed in resource-rich, high-connectivity contexts. CA develops the capacity to:

i. Identify and deploy AI tools functional within Plateau State infrastructure realities including offline simulators, text-based AI accessible via basic smartphones, and low-data AI platforms.

ii. Adapt AI-mediated lessons for large heterogeneous NCE classrooms at both rural (Pankshin) and semi-urban (Gindiri) institutional settings.

iii. Navigate cultural and community perceptions of AI in education, engaging learners' families and communities in constructive dialogue about AI's role and limitations.

iv. Situate AI use within Nigerian and African cultural epistemologies, critically evaluating the extent to which AI tools reflect or marginalise local knowledge systems and languages.

Table 4 summarises the theoretical grounding and empirical basis of each SAIL dimension, and the specific findings each dimension was calibrated to address.

Table **4**

Mapping of SAIL Framework Dimensions to Theoretical and Empirical Sources

Dimension	**Theoretical Grounding**	**Empirical Basis (Study Findings)**	**Responds To**
AI Conceptual Understanding (ACU)	Ng et al. (2021) 'Know and Understand AI'; AI-TK component of I-TPACK (Celik, 2023)	Lowest-scoring subscale, AI Conceptual Understanding (M = 1.81); Ayanwale et al. (2024) finding that conceptual knowledge is the strongest predictor of AI literacy outcomes	RQ1 findings; Theme 2
Pedagogical AI Application (PAA)	AITPACK component of I-TPACK (Celik, 2023); Ng et al. (2021) 'Use and Apply AI'	Pedagogical AI Application deficit (M = 1.93)	RQ1 findings; Theme 4
Critical and Ethical AI Reasoning (CEAR)	AI Ethics Knowledge component of I-TPACK (Celik, 2023); Ng et al. (2021) 'AI Ethics'; UNESCO (2024)	AI Ethics Awareness deficit (M = 1.85)	RQ1 findings
Contextual Adaptation (CA)	Situated Learning Theory (Lave & Wenger, 1991)	Institutional infrastructural disparities, particularly the acute constraints at Pankshin FUE	Theme 1; Theme 4

Note. RQ1 = Research Question 1 (AI literacy readiness levels); Theme numbers refer to the qualitative themes reported under Research Question 2.

Ecological Context: Policy, Infrastructure, and Community

The four SAIL dimensions operate within a three-layered ecological context: (i) Policy NCCE Minimum Standards, NAIS (2024), NDEPS (2020–2030), and institutional strategic plans; (ii) Infrastructure device access, electricity reliability, internet connectivity, and digital laboratory facilities, noting that Pankshin FUE's more acute deficits require additional compensatory strategies; and (iii) Community institutional cultures, faculty AI perceptions, and community orientations toward technology in both the Gindiri and Pankshin contexts. Sustainable SAIL implementation requires that COE administrators and Plateau State Ministry of Education officials address each of these ecological layers in parallel with curriculum reform.

6 Discussion of Results

6.1 AI Literacy Deficit at Gindiri and Pankshin Institutions

The finding of critically low AI literacy readiness ($M = 1.89$, $SD = 0.57$) among pre-service science teachers across both Gindiri (COE) and Pankshin (FUE) is both striking and, in retrospect, unsurprising given the documented infrastructural and policy context. This result aligns with the broader literature on digital technology integration in Nigerian teacher education, where readiness levels consistently fall below the threshold for functional competency (Adekunle & Amosun, 2021; Okonkwo & Awah, 2022). The present study extends this literature by disaggregating AI literacy into four domains and by providing the first institution-specific comparison of AI literacy profiles between COEs in Plateau State.

The marginal but non-significant difference between Gindiri COE ($M = 1.93$) and Pankshin FUE ($M = 1.84$), $t(106) = 0.81$, $p = .420$, $d = 0.16$, is theoretically informative. It suggests that despite Gindiri relative advantages including partial internet connectivity and a small cohort of digitally trained lecturers these advantages have not translated into meaningfully superior AI literacy preparation for student-teachers. This finding echoes Ng *et al.*(2021) observation that AI literacy demands more than tool access; it requires structured pedagogical integration, which is absent at both institutions. The very low score on AI Conceptual Understanding ($M = 1.81$) confirms Ayanwale *et al*. (2024) finding that foundational AI knowledge is the most critical and most neglected dimension of teacher AI literacy preparation in Nigerian contexts.

6.2 Institutional Barriers and the Differential Context of Gindiri and Pankshin

The four qualitative themes infrastructural inadequacy, lecturer unpreparedness, policy vacuum, and curriculum rigidity were consistent across both institutions, yet their intensity differed. Pankshin (FUE) participants reported more acute infrastructural constraints, with no functioning computer laboratory and total electricity unreliability, representing conditions that render even basic digital literacy instruction highly challenging. Gindiri COE, while similarly under-resourced by national standards, had greater relative stability, which may explain why all six digitally trained lecturers in the sample were Gindiri-based and why Gindiri lecturers expressed marginally higher AI self-efficacy. The significant positive effect of prior digital training on lecturer AI literacy scores ($d = 1.28$) provides compelling evidence that targeted professional development can meaningfully shift AI literacy readiness even in constrained contexts a finding that directly supports the SAIL Framework's professional development emphasis. This aligns with Koehler *et al.* (2013) broader evidence that structured TPACK development programmes produce measurable improvements in teacher technology integration knowledge, and with Mishra, Warr and Islam's (2023) argument that generative AI specifically demands deliberate, sustained teacher preparation rather than incidental exposure.

6.3 The SAIL Framework: Empirical and Theoretical Grounding

The SAIL Framework's four dimensions map directly onto the empirical findings from both institutions. The ACU dimension responds to the lowest-scoring domain AI Conceptual Understanding ($M = 1.81$) addressing the foundational knowledge deficit that Ayanwale *et al*. (2024) established as the strongest predictor of all other AI literacy outcomes. The PAA dimension responds to the Pedagogical AI Application deficit ($M = 1.93$) and the curriculum rigidity theme (Theme 4), providing curriculum-aligned strategies for embedding AI tools within existing NCE science methods courses at Gindiri and Pankshin without requiring wholesale syllabus revision. The CEAR dimension responds to the AI Ethics Awareness deficit ($M = 1.85$) and broader concerns, raised by Celik (2023) and UNESCO (2024), that teachers frequently lack ethical reasoning capacities for responsible AI decision-making. The CA dimension responds most directly to the differential infrastructural profiles of the two institutions particularly the acute constraints at Pankshin FUE (Theme 1) equipping pre-service teachers to function as adaptive AI practitioners regardless of connectivity availability.

Theoretically, the SAIL Framework's grounding in AI-TPACK (Celik, 2023; Mishra & Koehler, 2006) ensures disciplinary specificity, while its grounding in Situated Learning Theory (Lave & Wenger, 1991) ensures that AI literacy development is embedded in authentic institutional communities of practice at both Gindiri and Pankshin. This dual scaffolding distinguishes SAIL from the context-neutral frameworks of Long and Magerko (2020) and Touretzky *et al.* (2019), and from the global scope of UNESCO (2024), rendering it more immediately applicable to Plateau State COE settings.

6.4 Limitations

Several limitations of this study must be acknowledged. First, the study was restricted to two state-level COEs in Plateau State, limiting generalisability to federal COEs, in other Tertiary institutions, and to university-based science teacher education programmes. Future research should include federal University and cross-zonal comparisons. Second, the cross-sectional design precludes causal inferences; longitudinal research is needed to track AI literacy readiness changes over time. Third, the ALRQ relies on self-report data, which may be subject to social desirability bias. Fourth, the qualitative strand was limited to science education lecturers; pre-service teachers' own perspectives on barriers to AI literacy were not directly captured through interviews. Fifth, the SAIL Framework, while theoretically grounded and empirically informed, has not yet been piloted; its effectiveness as a curriculum reform tool awaits prospective evaluation. Sixth, the lecturer subsample used for the H02 inferential comparison ($N = 15$, split across two cells of $n = 6$ and $n = 9$) is small, and the resulting effect size should be treated as a preliminary estimate pending replication with a larger sample.

7 Conclusion and Recommendations

This study has demonstrated that pre-service science teacher education at College of Education, Gindiri and Federal University of Education, Pankshin, in Plateau State, Nigeria, is currently ill-equipped to prepare educators for AI-mediated classrooms. AI literacy readiness among pre-service science teachers at both institutions is critically low across all four domains examined ($M = 1.89$, $SD = 0.57$), with no significant difference between the two COEs ($p = .420$), confirming a systemic rather than institution-specific deficit. The four qualitative themes infrastructural inadequacy, lecturer unpreparedness, absence of policy directives, and curriculum rigidity collectively characterise a multilevel failure of preparation that must be addressed through coordinated policy, infrastructure, and curriculum reform. Prior digital training among lecturers significantly predicted higher AI literacy scores ($d = 1.28$), confirming that targeted professional development is the most actionable lever available to institutional administrators in the short term. The proposed SAIL Framework with its four dimensions of AI Conceptual Understanding, Pedagogical AI Application, Critical and Ethical AI Reasoning, and Contextual Adaptation offers a structured, theoretically grounded, and contextually responsive model for embedding AI literacy into NCE science teacher education at both institutions. Its CA dimension is of particular importance for Pankshin FUE, where infrastructural constraints demand AI-mediated pedagogies that function under conditions of electricity and connectivity unreliability.

The following recommendations are offered:

1. The Plateau State Ministry of Education and the Governing Councils of College of Education, Gindiri and Federal University of Education, Pankshin should jointly develop and fund an AI Literacy Integration Plan, anchored in the SAIL Framework, for immediate implementation across NCE science programmes.
2. Both institutions should establish internal AI Literacy Committees comprising science education faculty, ICT officers, and senior NCE students, mandated to pilot SAIL Framework modules within existing Science Methods and ICT in Education courses by the 2027 academic session.
3. The National Commission for Colleges of Education (NCCE) should revise the NCE Minimum Standards to explicitly incorporate AI literacy competency requirements across all science education specialisations, using the SAIL Framework as a reference model and providing implementation guidance sensitive to state-level resource constraints.
4. Priority should be given to sourcing offline AI tools, solar energy infrastructure, and device access for Pankshin FUE, where electricity and internet unreliability represent the most immediate barriers to any form of AI literacy integration.

5. Science education researchers at Ahmadu Bello University, Zaria and the University of Jos should conduct prospective longitudinal studies evaluating the impact of SAIL Framework implementation on pre-service teachers' AI literacy readiness and subsequent classroom practice.
6. Future research should extend the present study's scope to include federal University (e.g., Uni Jos) and Polytechnics in other geopolitical zones to enable comparative analysis and framework refinement.

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