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Assessing Artificial Intelligence Literacy Among Pre-Service Science Teachers: Challenges and Strategies for Improvement

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Abstract. The increasing use of artificial intelligence (AI) despite its challenges across different disciplines, including education, has called for the development of AI literacy (AIL) among pre-service teachers (PSTs). Efforts have focused on its ethical considerations, awareness, and student accessibility. Yet, limited research in Africa has explored the AIL levels of university students, who are critical consumers of AI technology. This study examined the AIL of pre-service science teachers (PSSTs), the challenges encountered, and strategies to improve their AIL. The study employed a sequential explanatory mixed-methods approach, with a survey followed by semi-structured interviews. A questionnaire was administered to 180 PSSTs in Anambra State, Nigeria, who were sampled using a simple random technique. Five PSSTs with moderate levels of AIL participated in semi-structured interviews for the qualitative phase of the study. The study was anchored on Vygotsky's socio-cultural theory. Data were analysed using bar charts, means, and percentages, and thematically. The findings reveal a limited AIL level among PSSTs. The challenges faced by the PSSTs in developing AIL include limited support from the institution, poor understanding of AI concepts, limited access to AI-driven tools, unstable power supply to power AI-driven tools, and insufficient AI-related coursework. In addition, strategies identified for improving PSSTs' AIL are the provision of mentorship, workshops, the integration of AI tools such as ChatGPT with face-to-face learning, integrating AI into existing courses, and developing new courses. The study underlines the need for teacher educators, policymakers, and curriculum developers in Africa to integrate AI into the PSST curriculum.

Keywords: artificial intelligence; artificial intelligence literacy; pre-service science teachers; challenges; strategies for improvement; Nigeria

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1. Introduction

In the 21st century, artificial intelligence (AI) is one of the most transformative technologies that is redefining human interaction, learning, and knowledge acquisition. According to Ahmad et al. (2021), AI describes systems capable of mental functions such as learning and logical reasoning. These functions entail several tasks, including problem-solving, speech recognition, plan drafting, and image formation. The AI systems are made to function with different degrees of independence. Thus, AI is a computer system that possesses human traits such as self-correction, adaptation, and the ability to process complex data and tasks. Research from South Africa has shown that integrating AI literacy (AIL) into higher education can enhance learning results, encourage diversity in the classroom, and strengthen collaborations (Funda & Piderit, 2024; Opesemowo & Adekomaya, 2024).

AI literacy is the capacity to appropriately identify, use, and evaluate AI-related technologies and systems under moral principles (Xiao et al., 2024). Instead of requiring understanding of the underlying theory, it emphasises competence and acceptable application. Together with other educational programs, Selwyn (2022) opined that AIL can change the future of AI while promoting human values. Nahar et al. (2025) conceptualised AIL into four frameworks, namely preparation, which involves building basic knowledge of AI ideas or concepts; understanding, which focuses on how AI systems work; application, which emphasises putting AI tools into real settings; and responsible use, which involves the ethical use of AI, as well as its societal effects.

When students develop AIL, they understand the function of AI in science, education, and society to become future innovators. Still, research indicates that computer science is the primary discipline in which AIL is taught (Kandlhofer et al., 2016; Wong et al., 2020). The requirement of *AIL for everyone*, especially in developing countries such as Nigeria, may be partially realised if this trend continues. Therefore, the necessity of fostering AIL in all classrooms and disciplines, including science education and not just computer science, has been emphasised by Southworth et al. (2023).

Science education students are future scientists and educators with the potential to shape how science is taught in schools. As such, the significance of AIL cannot be overemphasised, as its demand is increasing in education, healthcare, industry, agriculture, as well as transportation sectors. According to Chiu et al. (2023), science teachers are pivotal in improving students' critical thinking and scientific reasoning and creating inquiry-driven classrooms, aligning with AI competencies. The ability of science teachers to understand, appraise, and use AI can go a long way towards enhancing experimentation, inquiry-based learning, engagement, and scientific communication.

Moreover, science education is positioned for the effective integration of AI-driven tools, making science teachers significant agents that bridge AIL and STEM education (Almasri, 2024). AI literacy promotes science teaching by enhancing positive attitudes towards science-based problem learning (Su, 2022), promoting

self-learning (Al Darayseh, 2023), enhancing scientific reasoning and interdisciplinary learning (Park et al., 2023), and reducing teaching workload through practical automated assessment, personalised feedback, and timely instructional delivery (Almasri, 2024). AI literacy, according to Topal et al. (2021), can also help improve science teaching by facilitating learning and improving student performance. For Kim and Kim (2022), STEM students' scientific writing improves when teachers are literate in using AI. Therefore, with an in-depth understanding of AI, science teachers can solve problems effectively, improve teaching strategies, and enhance student learning outcomes.

However, this is hindered by some challenges, as current science education programmes in many Nigerian universities place limited emphasis on emerging technology such as AI. For Kamalov et al. (2023), university-level AI implementation has been constrained by multiple concerns, including a shortage of AI-driven tools, curriculum gaps, and poor AI knowledge. This disparity between the global advancements in AI and outdated curriculum content creates a gap in students' readiness for an AI-driven future that requires AIL (Almasri, 2024). The integration of AI into education worldwide is increasingly recognised as vital for adapting to the rapidly changing digital environment, especially for Nigerian pre-service teachers (PSTs). This is because improving AIL can enhance digital transformation in education for personalised learning experiences, adaptive learning platforms, augmented instruction, and AI-driven technologies.

Despite the potential of AIL, there is a dearth of empirical studies on the AIL level of pre-service science teachers (PSSTs). Previous studies have only concentrated on indicating a range of awareness and proficiency across Africa and Nigeria in particular. For instance, Ibrahim (2024) evaluated lecturers' knowledge and perceptions of AI, Egara and Mosimege (2024) and Holmes et al. (2022) explored the incorporation of AI into teaching strategies, while Pedro et al. (2019) were concerned with AI ethics.

Moreover, existing studies have been conducted predominantly outside the African context, where universities are under-resourced. In China, Kong et al. (2021) investigated university students' literacy levels in AI and found a high AIL level across students of diverse backgrounds. In addition, Lérias et al. (2024) conducted research with higher education students in Portugal and found a high level of AIL among the students. Ndung'u and Signe (2020) revealed that teachers in South Africa are not AI-literate, influencing their effective utilisation of AI.

Additionally, Mansoor et al. (2024) provided a detailed insight into AIL, using a transnational survey of 1800 university students. The study was conducted across four countries, namely Malaysia, Saudi Arabia, Egypt, and India. The results showed a high AIL level among Malaysian university students, which was significant compared to other countries in the study. It was also revealed that although Egypt, Saudi Arabia, and India showed moderate AIL, a considerable disparity was established between Egypt and the other two countries, with Egypt being the lowest. Although the Masakhane Decolonize Science Project, according to Ravindran (2023), is proffering strategies towards ensuring improved AIL

among Africans by developing AI models that can translate African languages using training datasets, more strategies still need to be devised towards improving students' AI literacy to be at par with their counterparts in China and Europe.

Furthermore, in contrast to the contributions of global research on AIL for future educators, there are limited empirical studies on AIL among PSSTs in higher education institutions. In Nigeria, beyond just the students and their schools, the entire educational system and the African continent can be affected by students' level of AIL. Teachers who are not AI-literate may struggle to integrate AI tools, missing out on opportunities for improved learning outcomes, personalised education, global collaboration, and decision-making.

With significant implications for the future of education, addressing PSSTs' deficiencies in AIL necessitates a thorough analysis of AIL. Cleopas (2023) asserted that efforts should be made to address the barriers to AIL among educators and nurture innovations towards AI integration within the higher education landscape. As such, this study is also significant as it addresses the problem connected with AI integration in higher education. This is ensured by examining PSSTs' perceptions of their challenges and potential strategies to improve their AIL using a mixed-method design. By providing insights into the current situation and suggesting methods to raise PSTs' level of AIL, this study sought to advance PSSTs' understanding of AIL in developing nations.

The following research question guided the study:
1. What is the level of AI literacy of pre-service science teachers?
2. What are the challenges encountered by pre-service science teachers in developing their AI literacy?
3. What are the strategies identified by pre-service science teachers for improving their AI literacy?

2. Literature Review

2.1 Conceptualizing AI Literacy in Education

The use of AI in teaching and learning, as well as students' evaluation, has led to its increased application in education. The development of AIL in the educational sector was influenced by the ideas of an early researcher, Seymour Papert (1980), who emphasised that interaction with an intelligent system may foster machine literacy. Burgsteiner et al. (2016) defined AIL as including understanding AI concepts and their applications, while Long and Magerko (2020) broadened the definition by asserting that literacy in AI is the collection of abilities that enhance AI evaluation, collaboration, communication, and the use of AI in homes, workplaces, and online platforms. AI literacy, according to Zhao et al. (2022), includes knowledge, skills, attitudes, as well as reliable information needed to understand AI.

Studies have conceptualised AIL into various dimensions. For instance, Long and Magerko (2020) identified five themes of AIL, namely: "What is AI?" "What can AI do?" "How does AI work?" "How should AI be used?" and "How do people perceive AI?" Their framework emphasises individual proficiency to assess,

communicate, collaborate, and utilise AI. For Ng et al. (2021), AIL can be divided into four concepts: knowing and understanding AI, using and applying AI, evaluating and creating AI, and AI ethics. According to Zhang et al. (2023), in addition to helping students get ready for the workforce, AIL fosters innovation and creativity by allowing humans and machines to work together (Benjamin, 2019). Moreover, it promotes AI thinking (Yim, 2023), guarantees moral comprehension of AI data (Mertala et al., 2022; Xia et al., 2023), and combats misinformation (Ali et al., 2021).

Despite these advantages, contradictions exist regarding the most effective way to define and apply AIL across contexts. For example, Long and Magerko (2020) highlighted perception and understanding of AI concepts, while Ng et al. (2021) stressed the importance of application and ethics. This suggests a need for an integrated framework that harmonises different dimensions of AIL. Thus, the significance of AIL encompasses its ability to advance knowledge of AI–human interaction (Rosling & Littlemore, 2011), explain various AI concepts, and apply AI to address societal and educational issues.

2.2 AI Literacy in African and Global Contexts

According to Gillani et al. (2023), teachers must be AI-literate to improve their use of emerging technologies effectively. They explained that AI has the potential to enhance human educational opportunities. However, research on AIL in Africa and Nigeria in particular remains scarce. For example, Dai et al. (2024) investigated the degree of AIL among Chinese university students and found a high AIL level among the students.

Chenqi et al. (2023) explored Chinese students AIL level, using a mixed-methods sequential explanatory design. The study involved 152 PSTs in the quantitative phase and 16 in the qualitative (interview) phase. They revealed that although a modest level of literacy was established, PSTs showed limited knowledge, ethics, and awareness. Asghar et al. (2025) used 427 participants to investigate the link between dimensions of AIL among university students in Ghana and Nigeria.

A quantitative cross-sectional survey design was used for the investigation. They discovered that affective elements have a favourable impact on cognitive outcomes when mediated by ethical understanding and behavioural involvement, and that this effect is independent of national differences. The study recognised that AIL is still in the early stages of development in West African contexts. Arkorful et al. (2025) provide deeper insight into the AIL level among basic teachers in Ghana using a cross-sectional survey and 319 basic schoolteachers. The study highlights a moderate level of AIL among the teachers and a policy gap in the country's educational system.

Meanwhile, Nsoh et al. (2023) and Thomas and Gambari (2022) highlighted encouraging attempts to use local solutions to incorporate AI into universities in underdeveloped nations and the urgent need to develop AIL among higher education students. These studies reveal the AIL levels of students across different regions, with limited studies done in Africa, often due to poor infrastructure and

curricular limitations. This underscores the need to determine students' current level of AIL before implementing AI-focused interventions.

2.3 Integrating AI Literacy into Educational Curricula

There is an increasing effort to implement AI at all educational levels. AI literacy is considered an extension of digital literacy; however, it is crucial to note that AI is different from digital technologies because of its adaptive and independent nature (Ng et al., 2022). For this reason, teaching AIL includes explanations of crucial topics, including data biases, surveillance, AI ethics, AI knowledge, and the possible effects on employment and sustainable development.

A study by Vazhayil et al. (2019) using multiple cohorts of teachers in India emphasised the significance of incorporating AI principles into teacher education programmes. Although the study showed that teachers were interested in using game-based learning and peer teaching to introduce AI, it also highlighted issues such as infrastructure, pedagogy, material delivery, and cultural influences. This emphasised the necessity of curriculum changes that integrate AI ideas and offer adequate support for PSTs. According to Holmes (2022), academic AIL may involve knowing how private EdTech corporations gather and use data or the pedagogical underpinnings on which AI-based technologies function and provide instruction, as well as knowing how to act and educate appropriately.

In consideration of the difficulties in creating an AI literacy course and using a qualitative research approach, Chigwada (2024) proposed a framework that integrates needs assessments, curriculum design, instruction strategies, assessment methods, and evaluation. Also, collaboration between faculty, departments, and librarians in higher institutions was suggested to ensure an effective AIL programme in South Africa. The six key concepts of the AIL intelligence curriculum, according to Yim (2023), are perception, representation and reasoning, learning, natural interaction, societal/ethical/environmental implications, and AI thinking, all of which facilitate critical data analysis and conceptual innovation.

3. Theoretical Framework

This study is anchored on Vygotsky's (1978) socio-cultural theory. Vygotsky's (1978) socio-cultural theory postulates that learning is a social procedure in which knowledge is acquired by interaction with peers and cultural tools. This social connection aids in the learner's autonomous growth and knowledge absorption. Pivotal to this theory and very crucial for the growth of AIL among PSTs are the zone of proximal development (ZPD), scaffolding, cultural instruments, and mediating learning. In the ZPD, a student requires assistance from others until they can function on their own.

In the context of AI, the ZPD may represent the difference between students' comprehension of AI principles using ChapGPT, DeepSeek, Meta, and other AI resources and their ability to properly integrate them into the learning objectives. In scaffolding, students work together in the classroom and laboratory to complete tasks and improve their comprehension using AI tools. Vygotsky (1978) also emphasised cultural instruments, such as language, symbols, and modern

technology, which align with AI as a mediating tool to enhance comprehension. For PSTs, being AI-literate goes beyond merely utilising AI tools. It encompasses their ability to mediate knowledge, understand AI ethics, and strengthen or question established norms through strategies such as mentoring and collaboration. By identifying PSSTs' AIL levels, teacher educators can provide effective scaffolds that support PSTs in developing independent strategies to enhance a deeper understanding of scientific concepts.

4. Methodology

4.1 Research Design

The study adopted an explanatory sequential mixed-methods design. This design provides an understanding of a research problem by systematically collecting, analysing, and integrating quantitative and qualitative data (Creswell & Creswell, 2018). The approach uses two phases in collecting data. The first involves collecting quantitative data, and the second involves collecting qualitative data, which helps provide validity to the quantitative results. This design was deemed appropriate in this study, as it offered a comprehensive review of the research problem using the survey approach and semi-structured interviews.

4.2 Participants

The study involved a population of 1,201 PSSTs from Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. The 180 participants used in this study were selected through a simple random sampling technique from five areas of specialisation: biology, chemistry, physics, mathematics, and integrated science.

This represents 15% of the population, which is more than the 10% recommended by Creswell and Creswell (2018) for maximising statistical reliability and generalisability for survey research. After the quantitative phase, five PSSTs were purposefully chosen from each area of specialisation to participate in interviews. Likewise, participants with moderate AIL scores were selected in accordance with the recommendations of Palinkas et al. (2015) regarding the use of purposive sampling in mixed-methods research. This ensured a balance of viewpoints and a greater understanding of the challenges and strategies for improving PSSTs' AIL.

4.3 Instrumentation

The survey instrument for the quantitative analysis is titled Pre-Service Science Teachers' AI Literacy, Challenges and Strategies Questionnaire (PSSTAILCSQ). The questionnaire is divided into two sections. The respondents' personal information, including gender and area of specialisation, is addressed in the first section. The second section has three clusters (A, B, and C). While Cluster A includes items on AIL levels, Clusters B and C include items on challenges and strategies.

Using a modified 4-point Likert scale with responses of *strongly agree* (4), *agree* (3), *disagree* (2), and *strongly disagree* (1), the survey was made using a Google form and distributed to the PSSTs via email and WhatsApp. The instrument was adapted from Ayanwale et al. (2024) for its thoroughness in capturing the various areas of university students AIL based on multiple authors and dimensions

(Ajzen, 1985; Carolus et al., 2023; Long & Magerko, 2020; Ng et al., 2022). These include the use and application of AI, knowledge and comprehension of AI, detection of AI, ethics of AI, creation of AI, AI self-efficacy (AI problem-solving), and AI self-competency (AI persuasion literacy & AI emotion regulation). Face and content validity of the instrument were established by three education specialists, and their feedback and input helped to enhance the items. Thirty PSSTs from another institution participated in the PSSTAILCSQ trial test, with a strong internal consistency of 0.82 obtained using Cronbach's alpha.

Creswell and Guetterman's (2019) theme analysis was employed to analyse the qualitative data. To ensure accuracy, the interview data were meticulously transcribed and subsequently subjected to multiple readings and theme-based categorisation. We underlined passages according to student comments and patterns. The interview guide was developed after an extensive literature review.

The questions were designed to explore the experiences, challenges, and possible strategies to improve PSSTs' AIL. Three experts also reviewed the guide to ensure clarity and alignment with the research questions. Afterwards, the themes were examined to ensure they were pertinent to the study objectives and reflected their core. The participants reviewed the thematic accuracy, while two independent coders confirmed the consistency and credibility of the themes. During interpretation, data were integrated, and qualitative data were used to explain and expand the quantitative findings through participants' narratives and insights.

4.4 Data Analysis

Using SPSS Version 25, mean and standard deviation statistics and bar charts were used to respond to the research questions. A mean rating of 2.5 was set as the criterion. Positive agreement with the items was indicated by mean ratings >2.5, while a negative response or disagreement was indicated by mean ratings of 2.49 and lower. The mean rankings for the level of AIL are low (2.49 and below), moderate (2.50–3.49), and high (3.50–4.00), while the standard deviation score ranges are: 0.00–0.49 (low variability), 0.50–0.79 (moderate variability), and 0.80 and above (high variability). Theme analysis was employed to analyse the qualitative data. This required transcribing the interviews, reading the transcripts several times, coding them, and classifying them according to themes to represent their essence and relevance to the research topics.

4.5 Ethical Considerations

Before data collection, the participants willingly filled out and signed informed consent forms. The participants received guarantees regarding the study's confidentiality, identity anonymity, and freedom to discontinue participation at any moment. The Department of Science Education, Nnamdi Azikiwe University, Awka, Nigeria, Ethics Committee granted the study ethical approval.

5. Results

5.1 Levels of AI Literacy of Pre-Service Science Teachers

Table 1 presents the mean and standard deviation results of respondents AIL levels.

Table 1: Mean and standard deviation scores of the AI literacy levels of respondents

N	Item	Mean	SD	Decision
1.	I can operate AI applications in everyday life	2.16	0.95	Low
2.	I can use AI applications to make my everyday life easier	2.74	0.65	Moderate
3.	In everyday life, I can interact with AI in a way that makes my tasks easier	2.95	0.53	Moderate
4.	In everyday life, I can work together gainfully with an artificial intelligence	2.71	0.92	Moderate
5.	I can communicate with artificial intelligence in everyday life	3.87	0.33	High
6.	I know the most important concepts of the topic "artificial intelligence"	1.87	0.82	Low
7.	I can assess the limitations and opportunities of using an AI	1.92	0.83	Low
8.	I can assess what advantages and disadvantages the use of artificial intelligence entails	2.71	0.97	Moderate
9.	I can imagine possible future uses of AI	2.43	0.98	Low
10.	I can tell if I am dealing with an application based on artificial intelligence	1.89	0.84	Low
11.	I can distinguish devices that use AI from devices that do not	2.08	0.87	Low
12.	I can incorporate ethical considerations when deciding whether to use data provided by an AI	2.06	0.91	Low
13.	I can analyse AI-based applications for their ethical implications	1.83	0.82	Low
14.	I can design new AI applications	1.89	0.71	Low
15.	I can program new applications in the field of "artificial intelligence"	1.87	0.77	Low
16.	I can develop new AI applications	1.58	0.63	Low
17.	I can select useful tools (e.g., frameworks, programming languages) to program an AI	1.51	0.71	Low
18.	I can rely on my skills in difficult situations when using AI	2.33	0.94	Low
19.	I can handle most problems in dealing with artificial intelligence well on my own	2.11	0.97	Low
20.	I can also usually solve strenuous and complicated tasks when working with artificial intelligence well	2.17	0.99	Low
21.	I don't let AI influence my everyday decisions	2.99	0.99	Moderate

22.	I can prevent an AI from influencing me in my everyday decisions	3.77	0.47	High
23.	I keep control over feelings like frustration and anxiety while doing everyday things with AI	2.91	0.97	Moderate
24.	I can handle it when everyday interactions with AI frustrate or frighten me	3.12	0.91	Moderate
25.	I can control my euphoria that arises when I use artificial intelligence for everyday purposes	2.60	0.95	Moderate
	Cluster mean	**2.40**	**0.35**	**Low level**

Table 1 shows that items 1, 6, 7, and 9–20 have mean ratings in the range of 2.49 and below, which indicates that respondents have a low level of AIL for these items. The mean ratings of items 2–4, 8, 21, and 23–25 are in the range of 2.50 to 3.49, showing a moderate AIL level for these items, while items 5 and 22 have mean ratings in the range of 3.50 to 4.00, showing a high level of AIL.

However, the cluster mean reveals that respondents have low AIL levels, which is also illustrated in Figure 1 below. The standard deviation values in Table 1 show that items 5 and 22 have low variability, while items 2, 3, and 14–17 have moderate variability, and items 1, 4, 6–13, 18–21, and 23–25 have high variability. This indicates that while respondents have a common opinion on a few items, significant variation exists in more items, suggesting differences in experience and exposure. Moreover, the cluster standard deviation of 0.35 indicates that respondents have a similar opinion on their low level of AIL.

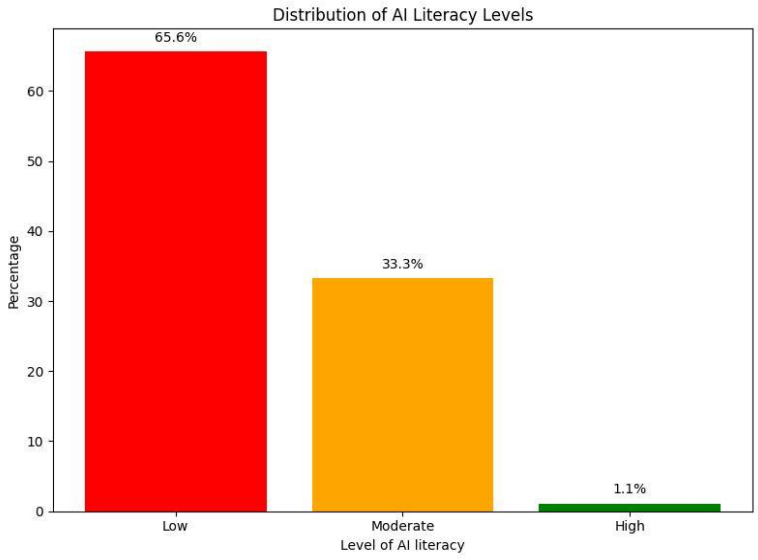

Figure 1: Levels of AI literacy of respondents

Figure 1 shows that 65.6% of the respondents have a low level of AI literacy, 33.3% have a moderate level of AI literacy, and 1.1% have a high level of AI literacy.

5.2 Challenges Encountered by the Pre-Service Science Teachers in Developing Their AI Literacy

Table 1 presents the mean and standard deviation results related to challenges encountered by the respondents in developing their AIL.

Table 2: Mean and standard deviation scores related to the challenges encountered by respondents in developing their AI literacy

N	Item	Mean	SD	Decision
1.	Poor understanding of AI concepts	3.63	0.78	Agreed
2.	Limited access to AI-driven tools	3.87	0.33	Agreed
3.	Limited support from the institution	3.77	0.53	Agreed
4.	Insufficient AI-related coursework	3.61	0.49	Agreed
5.	High cost of AI tools	3.82	0.39	Agreed

As seen in Table 2, the challenges encountered by the respondents in developing their AIL include a poor understanding of AI concepts (M = 3.63, SD = 0.78), limited access to AI-driven tools (M = 3.87, SD = 0.33), limited support from the institution (M = 3.77, SD = 0.53), insufficient AI-related coursework (M = 3.61, SD = 0.49), and high cost of AI tools (M = 3.82, SD = 0.39). The standard deviation values in Table 2 show that respondents have low variability in items 2, 4, and 5, and moderate variability in items 1 and 3. This indicates that respondents share a common opinion on the formal items, compared to the latter, with varied views.

In the interviews, participants revealed other challenges that affect PSSTs' AIL:

> P1: *"Electricity challenges, for example, frequent power outages; unreliable power supply can disrupt access to digital learning tools like computers, Internet modems, and mobile devices. This prevents my engagement with AI tools in online classes."*
>
> P3: *"The problem I encountered has already been stated out... It is the embedding of AI literacy into our curriculum. Many government-owned universities are yet to accept the utilisation of AI in their studies, thus making AI usage in schools very limited, as well as discouraging."*
>
> P4: *"I am a science student and need practical experience, without which I cannot connect the theoretical knowledge I may have acquired through AI-driven tools to real-life problems. This affects my science process skills acquisition. … I believe this lack of practical experience has a great impact on my literacy level in using AI."*
>
> P5: *"I always find it hard to search for certain questions on AI; this may be due to my inability to engage with the AI tools and my poor knowledge of prompts in phrasing the necessary questions."*

These qualitative responses align with the low mean scores of some items (i.e., items 1, 6–7, & 9–20) in Table 1, which deal with poor conceptual understanding of AI and limited practical engagement. Also, the quantitative findings in Table 2 and responses on poor infrastructure, insufficient AI content in the curriculum, unreliable power supply, and limited institutional support explain the low AIL level, as shown in Figure 1.

5.3 Strategies Identified by the Pre-Service Science Teachers for Improving Their AI Literacy

Table 1 presents the mean and standard deviation results related to strategies identified by the respondents for improving their AIL.

Table 3: Mean and standard deviation scores related to the strategies identified by respondents for improving their AI literacy

N	Item	Mean	SD	Decision
1.	Integrating AI into existing courses	3.48	0.81	Agreed
2.	Provision of mentorship for the students	2.86	0.96	Agreed
3.	Training lecturers and students through workshops to improve their knowledge and understanding of AI	3.62	0.78	Agreed
4.	Developing new AI-related courses	3.86	0.35	Agreed
5.	Ensuring easy access to AI-related resources	3.16	0.97	Agreed
6.	Provision of funds for AI-driven tools	3.82	0.39	Agreed

As seen in Table 3, the strategies identified by the respondents for improving PSSTs' AIL include integrating AI into existing courses (M = 3.48, SD = 0.81), the provision of mentorship for the students (M = 2.86, SD = 0.96), training lecturers and students through workshops to improve their knowledge and understanding of AI (M = 3.62, SD = 0.78), developing new AI-related courses (M = 3.86, SD = 0.35), ensuring easy access to AI-related resources (M = 3.16, SD = 0.97), and the provision of funds for AI-driven tools (M = 3.82, SD = 0.39).

The standard deviation values in Table 3 show that respondents have low variability in items 4 and 6, suggesting uniform agreement between respondents. In contrast, item 3 has moderate variability, which indicates some divergence of views, and items 1, 2, and 5 have high variability, indicating mixed opinions on these items.

The interviews yielded specific views on strategies for improving AIL:

> P2: *"I think the government should do more by providing scholarships in AI-related courses to encourage students to explore the field. This will help to ensure access to AI-driven tools."*

> P3: *"Teaching the students how to harness AI resources in the presentation of their numerous data, thesis, and project defences can help boost the use of AI in our school system, especially in scientific analysis and visualisation."*

> P4: *"… after one of our departmental courses titled Laboratory Organisation and Management, I decided to gain more understanding of some of the concepts I didn't understand through ChatGPT. My experience shows that a lot of knowledge can be gained in AI, and I suggest that our teachers use AI together with our normal physical classroom lectures."*

The quantitative findings and interview responses cover how access to resources, curriculum integration, and government support can address the challenges identified. The interview response to blend AI tools with physical classroom teaching aligns with item 1, with a mean score of 3.48 (Table 3), highlighting the need to integrate AI into the existing courses.

6. Discussion

The study results show that PSSTs have a low degree of AIL. The data show that 1.1% of respondents had a high level of AIL, 33.3% had a moderate level, and 65.6% had a low level (Figure 1). The inadequate infrastructure in most of the universities in Nigeria may be the cause of this outcome. Additionally, in many Nigerian universities, a lot of the teaching materials that are currently available are out of date, and funding is not adequately allocated for AI research and development. Furthermore, some PSTs train themselves and are concerned with passing the courses that are part of their curriculum; they do not seek to improve themselves through study and collaboration.

These findings lend credence to Vygotsky's (1978) socio-cultural theory, which emphasises that learning is a social procedure in which knowledge is acquired by interaction with peers and cultural tools. In the context of this study, the lack of AI-driven tools and inadequate infrastructure led to a low level of AIL among PSSTs. When properly integrated into the curriculum, Vygotsky (1978) maintained that these cultural tools mediate learning and ensure knowledge acquisition. However, when these tools are inaccessible, PSSTs cannot progress through their ZPD.

The study results are consistent with a previous study by Funda and Piderit (2024), who found that South Africans lack the necessary digital literacy and AI abilities, impacting their access to and involvement in digital economies. The results are also consistent with those of Ndung'u and Signe (2020), who found that teachers are not AI-literate, which lowers the likelihood that students would acquire the necessary AI abilities. However, the findings of the study oppose those of Kong et al. (2021), who found that a high level of AIL existed among university students in China, and of Lérias et al. (2024), who found a moderate AIL level among students in Portugal.

The difference between the measurement techniques (pre- and post-course surveys) and the intervention may cause discrepancies in improvement. Mansoor et al. (2024) acknowledged that AIL can vary by country. In addition, some other factors not found in the location of the present study, such as improved infrastructure, better attitude towards AI, and structured educational policies and their practical implementation strategies, could have played a significant role in impacting these results.

Poor comprehension of AI concepts, limited access to AI-driven tools, limited support from institutions, insufficient AI-related coursework, and expensive AI tools are some challenges PSSTs encounter in developing AIL. Though limited to five participants, the semi-structured interviews provided more profound insight

into challenges such as unstable power supply to power AI-driven tools, the inability to connect theoretical knowledge acquired through AI tools to real-life experience, and students' inability to engage with AI tools. The results corroborate the findings of Hart (2023) that some of the barriers to incorporating AI in schools are limited access to AI tools and cultural resistance.

Correspondingly, the results align with previous findings by Nsoh et al. (2023) and Ayanwela et al. (2024) that poor awareness, inadequate exposure to and comprehension of AI concepts, and limited support from institutions are the difficulties that affect university students AIL level. Also, Vazhayil et al. (2019) found that insufficient financing, undeveloped AI courses, and poor infrastructure are among the difficulties educators confront in teaching and improving AIL. Therefore, teacher education programmes should advance to include the practical training of teachers in AI concepts and the use of collaborative learning models.

The PSSTs identified several strategies for increasing their AIL, such as incorporating AI into already-existing courses, offering mentorship to students, educating lecturers and students through workshops to expand their knowledge and comprehension of AI, creating new courses related to AI, making sure that resources associated with AI are easily accessible, and allocating funds for AI-driven tools. The interviews revealed more details on the strategies to improve AIL, including utilising AI tools with face-to-face learning, providing scholarships in AI-related courses by the government, and applying AI in data analysis.

This aligns with the assertion by Thomas and Gambari (2021) that mentorship programmes, cooperative research initiatives, and AI training workshops are the key tactics for successful AI integration in schools. Moreover, the finding is congruent with that of Cross and Feldman (2025), who showed that government action is urgently needed to promote AIL in South Africa by funding teacher training, ensuring accessibility to AI in education (AIEd) in areas lacking resources, and protecting data. Hence, there is a need to redesign the curricula of PST programmes and promote the ethical considerations in AI implementations through capacity-building for educators.

7. Conclusions, Implications, and Recommendations

The study provides empirical evidence on the levels of AIL among PSSTs in developing countries, particularly Nigeria. It reveals that PSSTs have limited AIL and contributes to the growing body of literature highlighting challenges hindering AIL development among PSTs in under-resourced settings. The challenges encountered by PSTs in developing their AIL are unstable electricity, a lack of institutional support, a poor understanding of AI concepts, and limited AI-related courses. Moreover, strategies for improving PSSTs' AIL, such as mentorship, access to AI-related resources, and training of lecturers and students, were highlighted. This underscores the need for professional development and training for PSSTs towards effective AI integration.

Theoretically, this study significantly reinforces Vygotsky's (1978) socio-cultural theory, which postulates that learning occurs through social interaction with peers, mediated by cultural tools. These tools, which can be AI-driven tools, enhance learning when effectively integrated into the PST programmes, but when inaccessible, they tend to hinder knowledge acquisition; hence, PSTs cannot progress through their ZPD. However, through strategies such as mentorship, collaborative learning, and institutional support, AI tools can serve as scaffolds to improve the literacy levels of PSSTs from low to high.

The findings imply that the development of course materials that explicitly address all facets of AIL without undermining AI ethics is apparent in PST programmes. This is because, to improve PSSTs' AI awareness and proficiency, instructors and education policymakers must integrate AI into the modules of PSSTs. Additionally, African institutions should be outfitted with AI tools to address AI practices and biases while promoting improved AI knowledge and comprehension.

Thus, we suggest that the government and education ministries in Africa and the world at large should increase and sustain PSTs' awareness of the use of AI in education. This can be done with adequate funding to guarantee the provision of AI tools along with other cutting-edge technologies. In addition, PSST curricula should be reformed to ensure that AI and other emerging technologies are included to promote the use of blended learning models, which can enhance engagement and AIL. Teacher education policy holders should also develop an AI policy to guarantee ethical conduct among users.

8. Limitations

The present study has some limitations that can hinder the generalisability of the findings. First, the study participants were restricted to one university in Nigeria, limiting generalisation of the findings to other states or countries. Second, while the study focused on AIL levels, challenges encountered by PSSTs in developing their AIL, and strategies for improving their AIL, it did not address the influence of other variables such as gender, age, socio-economic status, and area of specialisation.

Despite these drawbacks, the findings of the study are not subverted. Future research can thus investigate the correlation between AIL and PSTs' achievement and how PSTs understand and implement AI ethics in the school environment. Research can also utilise samples from various universities, disciplines, and countries, and explore patterns based on area of specialisation to offer broader insights into the variables of the study.

9. References

Ahmad, S. F., Rahmat, M. K., Mubarik, M. S., Alam, M. M., & Hyder, S. I. (2021). Artificial intelligence and its role in education. *Sustainability, 13*(22), Article 12902. https://doi.org/10.3390/su132212902

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Al Darayseh, A. (2023). Acceptance of artificial intelligence in teaching science: Science teachers' perspective. *Computers and Education: Artificial Intelligence, 4*, Article 100132. https://doi.org/10.1016/j.caeai.2023.100132

Ali, S., DiPaola, D., Lee, I., Sindato, V., Kim, G., Blumofe, R., & Breazeal, C. (2021). Children as creators, thinkers, and citizens in an AI-driven future. *Computers and Education: Artificial Intelligence, 2*, Article 100040. https://doi.org/10.1016/j.caeai.2021.100040

Ali, S., Payne, B. H., Williams, R., Park, H. W., & Breazeal, C. (2019). Constructionism, ethics, and creativity: Developing primary and middle school artificial intelligence education [Conference session]. *International Workshop on Education in Artificial Intelligence K-12 (EduAI'19),* Palo Alto, CA, USA (pp. 1–4). Association of Computing Machinery. https://www.media.mit.edu/publications/constructionism-ethics-and-creativity/

Almasri, F. (2024). Exploring the impact of artificial intelligence in teaching and learning of science: A systematic review of empirical research. *Research in Science Education, 54,* 977–997. https://doi.org/10.1007/s11165-024-10176-3

Arkorful, V., Arthur, F., Boateng, E., Ofosu-Koranteng, M., Salifu, I., Attom, E. R., Tetteh, S. A., Quayson, E., Asare-Bediako, S., & Nortey, S. A. (2025). Exploring artificial intelligence literacy among basic school teachers in Ghana. *Discover Education, 4*, Article 250. https://doi.org/10.1007/s44217-025-00630-3

Asghar, M. Z., Duah, K. A., Iqbal, J., & Järvenoja, H. (2025). Evidence from West Africa on the interplay of affective, behavioral, cognitive, and ethical dimensions of AI literacy in Ghanaian and Nigerian universities. *Discover Computing, 28*, Article 169. https://doi.org/10.1007/s10791-025-09691-2

Ayanwale, M. A., Adelana, O. P., Molefi, R. R., Adeeko, O., & Ishola, A. M. (2024). Examining artificial intelligence literacy among pre-service teachers for future classrooms. *Computers and Education Open, 6*, Article 100179. https://doi.org/10.1016/j.caeo.2024.100179

Benjamin, R. (2019). *Race after technology: Abolitionist tools for the New Jim Code*. Polity.

Burgsteiner, H., Kandlhofer, M., & Steinbauer, G. (2016). Irobot: Teaching the basics of artificial intelligence in high schools. *Proceedings of the AAAI Conference on Artificial Intelligence, 30*(1), 4126–4127. https://doi.org/10.1609/aaai.v30i1.9864

Carolus, A., Koch, M. J., Straka, S., Latoschik, M. E., & Wienrich, C. (2023). MAILS – Meta AI Literacy Scale: Development and testing of an AI literacy questionnaire based on well-founded competency models and psychological change- and meta-competencies. *Computers in Human Behavior: Artificial Humans, 1*(2), Article 100014. https://doi.org/10.1016/j.chbah.2023.100014

Chenqi, L., Guoqing, L., & Xiangchun, H. (2023). Measuring artificial intelligence literacy of pre-service teachers at a university in northwest China [Conference session]. *2023 Twelfth International Conference of Educational Innovation through Technology (EITT)*, December 15–17, 2023, Fuzhou, China, (pp. 100–105). IEEE. https://doi.org/10.1109/EITT61659.2023.00027

Chigwada, J. (2024). A proposed framework for a digital literacy course for artificial intelligence in academic libraries. *South African Journal of Libraries and Information Science, 90*(2), 1-8. https://doi.org/10.7553/90-2-2388

Chiu, T. K. F., Moorhouse, B. L., Chai, C. S., & Ismailov, M. (2023). Teacher support and student motivation to learn with artificial intelligence (AI) based chatbot. *Interactive Learning Environments, 32*(7), 3240–3256. https://doi.org/10.1080/10494820.2023.2172044

Cleopas, B. C. (2023). Advent of artificial intelligence: Prospects and challenges in Nigeria education system. *GPH-International Journal of Educational Research, 6*(6), 1–9. https://doi.org/10.5281/zenodo.8114160

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed). Sage Publications.

Creswell, J. W., & Guetterman, T. C. (2019). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (6th ed.). Pearson.

Cross, S., & Feldman, J. (2025). Artificial intelligence in education: Considerations for South African schooling. *Journal of Education, 98*, 27–41. http://dx.doi.org/10.17159/2520-9868/i98a02

Dai, Y., Lin, Z., Liu, A., & Wang, W. (2024). An embodied, analogical and disruptive approach of AI pedagogy in upper elementary education: An experimental study. *British Journal of Educational Technology, 55*(1), 417–434. https://doi.org/10.1111/bjet.13371

Egara, F. O., & Mosimege, M. (2024). Exploring the integration of artificial intelligence-based ChatGPT into mathematics instruction: Perceptions, challenges, and implications for educators. *Education Sciences, 14(7),* Article 742. https://doi.org/10.3390/educsci14070742

Funda, V., & Piderit, R. (2024). A review of the application of artificial intelligence in South African higher education [Conference session]. *2024 Conference on Information Communications Technology and Society (ICTAS),* March 7–8, 2024, Durban, South Africa (pp. 44–50). IEEE. https://doi.org/10.1109/ICTAS59620.2024.10507113

Gillani, N., Eynon, R., Chiabaut, C., & Finkel, K. (2023). Unpacking the "Black Box" of AI in education. *Educational Technology & Society, 26*(1), 99–111. https://doi.org/10.30191/ETS.202301_26(1).0008

Hart, S. A. (2023). Identifying the factors impacting the uptake of educational technology in South African schools: A systematic review. *South African Journal of Education, 43*(1), Article 2174. https://doi.org/10.15700/saje.v43n1a2174

Holmes, W., Persson, J., Chounta, I., Wasson, B., & Dimitrova, V. (2022). *Artificial intelligence and education: A critical view through the lens of human rights, democracy, and the rule of law*. Council of Europe Publishing. https://rm.coe.int/1680a956e3

Ibrahim, A. B. (2024). Assessing the knowledge and perception of artificial intelligence for teaching and research among lecturers in the faculties of arts in Nigeria. *Journal of Global Research in Education and Social Science, 18*(2), 25–33. https://doi.org/10.56557/JOGRESS/2024/v18i28671

Kamalov, F., Santandreu Calonge, D., & Gurrib, I. (2023). New era of artificial intelligence in education: Towards a sustainable multifaceted revolution. *Sustainability, 15*, Article 12451. https://doi.org/10.3390/su151612451

Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016). Artificial intelligence and computer science in education: From kindergarten to university [Conference session]. *2016 IEEE Frontiers in Education Conference (FIE),* October 12–15, 2016, Erie, PA, USA (pp. 1–9). IEEE. https://doi.org/10.1109/FIE.2016.7757570

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

Kong, S.-C., Cheung, W. M.-Y., & Zhang, G. (2021). Evaluation of an artificial intelligence literacy course for university students with diverse study backgrounds. *Computers and Education: Artificial Intelligence, 2*, Article 100026. https://doi.org/10.1016/j.caeai.2021.100026

Lérias, E., Guerra, C., & Ferreira, P. (2024). Literacy in artificial intelligence as a challenge for teaching in higher education: A case study at Portalegre polytechnic university. *Information, 15*(4), Article 205. https://doi.org/10.3390/info15040205

Long, D., & Magerko, B. (2020). What is AI literacy? Competencies and design considerations [Conference session]. *2020 CHI conference on Human Factors in Computing Systems* (pp. 1–16). Association for Computing Machinery. https://doi.org/10.1145/3313831.3376727

Mansoor, H. M. H., Bawazir, A., Alsabri, M. A., Alharbi, A., & Okela, A. H. (2024). Artificial intelligence literacy among university students: A comparative transnational survey. *Frontiers in Communication, 9*, Article 1478476. https://doi.org/10.3389/fcomm.2024.1478476

Mertala, P., Fagerlund, J., & Calderon, O. (2022). Finnish 5th and 6th Grade students' pre-instructional conceptions of artificial intelligence (AI) and their implications for AI literacy education. *Computers and Education: Artificial Intelligence, 3*, Article 100095. https://doi.org/10.1016/j.caeai.2022.100095

Nahar, N., Howard, D., Akeren, K., Ngele, E., Hollins, P., & Prescott, G. (2025). Cultivating AI literacy in higher education students: A four-step conceptual framework. In A. I. Cristea, E. Walker, Y. Lu, O. C. Santos, & S. Isotani (Eds.), *Artificial intelligence in education* (pp. 16–29). Lecture Notes in Computer Science (15879). Springer. https://doi.org/10.1007/978-3-031-98420-4_2

Ndung'u, N., & Signe, L. (2020). *The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse.* Brookings Institution.

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). Conceptualizing AI literacy: An exploratory review. *Computer Education: Artificial Intelligence, 2*, Article 100041. https://doi.org/10.1016/j.caeai.2021.100041

Ng, D. T. K., Leung, J. K. L., Su, M. J., Yim, I. H. Y., Qiao, M. S., & Chu, S. K. W. (2022). AI literacy education in primary schools. In *AI literacy in K-16 classrooms (*pp. 75–86). Springer International Publishing. https://doi.org/10.1007/978-3-031-18880-0

Nsoh, A. M, Joseph T., & Adablanu, S. (2023). Artificial intelligence in education: Trends, opportunities and pitfalls for institutes of higher education in Ghana. *International Journal of Computer Science and Mobile Computing, 12*(2), 38–69. https://doi.org/10.47760/ijcsmc.2023.v12i02.004

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

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research, 42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* Basic Books. https://worrydream.com/refs/Papert_1980_-_Mindstorms%2C_1st_ed.pdf

Park, J., Teo, T. W., Teo, A., Chang, J., Huang, J. S., & Koo, S. (2023). Integrating artificial intelligence into science lessons: Teachers' experiences and views. *International Journal of STEM Education, 10*, Article 61. https://doi.org/10.1186/s40594-023-00454-3

Pedro, F., Subosa, M., Rivas, A., & Valverde, P. (2019). *Artificial intelligence in education: Challenges and opportunities for sustainable development.* UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000366994

Ravindran, S. (2023). Frustrated that AI tools rarely understand their native languages, thousands of African volunteers are taking action. *Science, 381*(6655), 262–265. https://www.science.org/doi/epdf/10.1126/science.adj8519

Rosling, A., & Littlemore, K. (2011). Improving student mental models in a new university information setting: Digitisation perspectives. In R. Rikowski (Ed.), *Improving student mental models in a new university information setting* (pp. 89–101). Sense Publishers. https://doi.org/10.1007/978-94-6091-299-3_5

Selwyn, N. (2022). The future of AI and education: Some cautionary notes. *European Journal of Education, 57*(4), 620–631. https://doi.org/10.1111/ejed.12532

Southworth, J., Migliaccio, K., Glover, J., Reed, D., McCarty, C., Brendemuhl, J., & Thomas, A. (2023). Developing a model for AI across the curriculum: Transforming the higher education landscape via innovation in AI literacy. *Computers and Education: Artificial Intelligence, 4,* Article 100127. https://doi.org/10.1016/j.caeai.2023.100127

Su, K. D. (2022). Implementation of innovative artificial intelligence cognitions with problem-based learning guided tasks to enhance students' performance in science. *Journal of Baltic Science Education, 21*(2), 245–257. http://dx.doi.org/10.33225/jbse/22.21.245

Thomas, G., & Gambari, A. I. (2022). A review of artificial intelligence for teaching, assessment and research in Nigerian universities [Conference session]. *Conference Proceedings of Association for Innovative Technology Integration in Education* (pp. 199−207). https://www.academia.edu/81893120/a_review_of_artificial_intelligent_for_teaching_assessment_and_research_in_nigerian_universities

Topal, A. D., Eren, C. D., & Geçer, A. K. (2021). Chatbot application in a 5th Grade science course. *Education and Information Technologies, 26*(5), 6241–6265. https://doi.org/10.1007/s10639-021-10627-8

Vazhayil, A., Shetty, R., Bhavani, R. R., & Akshay, N. (2019). Focusing on teacher education to introduce AI in schools: Perspectives and illustrative findings [Conference session]. *2019 IEEE Tenth International Conference on Technology for Education (T4E),* December 9–11, 2019, Goa, India (pp. 71–77). IEEE. https://doi.org/10.1109/T4E.2019.00021

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wong, G. K., Ma, X., Dillenbourg, P., & Huan, J. (2020). Broadening artificial intelligence education in K-12: Where to start? *ACM Inroads, 11*(1), 20–29. https://doi.org/10.1145/3381884

Xia, Q., Chiu, T. K., & Chai, C. S. (2023). The moderating effects of gender and need satisfaction on self-regulated learning through artificial intelligence (AI). *Education and Information Technologies, 28*(7), 8691–8713. https://doi.org/10.1007/s10639-022-11547-x

Xiao, J., Alibakhshi, G., Zamanpour, A., Zarei, M. A., Sherafat, S., & Behzadpoor, S. F. (2024). How AI literacy affects students' educational attainment in online learning: Testing a structural equation model in higher education context. *International Review of Research in Open and Distributed Learning, 25*(3), 179–198. https://doi.org/10.19173/irrodl.v25i3.7720

Yim, I. H. Y. (2023). *Design of artificial intelligence (AI) education for primary schools: Arts-based approach.* ISTES BOOKS. https://book.istes.org/index.php/ib/article/view/5

Zhang, H., Lee, I., Ali, S., DiPaola, D., Cheng, Y., & Breazeal, C. (2023). Integrating ethics and career futures with technical learning to promote AI literacy for middle school students: An exploratory study. *International Journal of Artificial Intelligence in Education, 33*, 290–324. https://doi.org/10.1007/s40593-022-00293-3

Zhao, L., Wu, X., & Luo, H. (2022). Developing AI literacy for primary and middle school teachers in China: Based on a structural equation modeling analysis. *Sustainability, 14*(21), Article 14549. https://doi.org/10.3390/su142114549