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Research article

Preparing future STEM educators: investigating artificial intelligence literacy among pre-service STEM teachers

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Abstract: Artificial Intelligence (AI) has emerged as a transformative tool capable of revolutionizing teaching and learning processes. However, the successful integration of AI in education depends largely on the AI literacy of pre-service Science, Technology, Engineering, and Mathematics (STEM) teachers, who will shape the future of education. While researchers have explored the role of AI in education, there is a significant gap in understanding the levels of AI literacy among pre-service STEM teachers, particularly in the Nigerian context. In this study, we addressed this gap by examining AI literacy among pre-service STEM teachers, and the differential impact of gender on their AI literacy. We employed a quantitative approach for data collection, adopting a descriptive-correlational research design. The sample included 541 pre-service STEM teachers from Lagos State, Nigeria, with 345 females and 196 males. An Artificial Intelligence Literacy Questionnaire with a reliability level of 0.84 was used for data collection. It was validated by experts in test and measurement and an expert in computer education. Data were analyzed using IBM SPSS Statistics (Version 23) with percentage, mean, standard, t-tests, and regression analysis to examine variable relationships. The findings revealed a relatively high self-reported AI literacy among these pre-service STEM teachers, indicating their readiness to understand and manage AI technologies.

Additionally, knowing and understanding AI significantly predicted the use and application of AI. We identified a statistically significant difference in AI literacy levels between male and female students, favoring the male students. Moreover, we recommend that educational institutions and teacher preparation programs build on this strong foundation by further integrating AI into their curricula and teaching practices.

Keywords: pre-service teachers, STEM, artificial intelligence literacy, gender

1. Introduction

The contemporary world is experiencing a significant technological disruption characterized by breakthroughs such as cybersecurity, robotics, machine learning, the Internet of Things (IoT), deep learning, and Artificial Intelligence (AI) [1,2]. These technological innovations, particularly AI, have had a widespread impact across sectors, including education. According to a report by Tractica [3], AI is projected to impact nearly every industry, with its annual global revenue expected to rise significantly from $643.7 million in 2016 to $36.8 billion by 2025. To comprehend AI, it is essential to define it. Although AI is multifaceted, researchers generally agree that it encompasses a set of sciences, theories, and techniques concerned with developing intelligent machines capable of learning, adapting, synthesizing, and self-correcting like humans [4]. Ali [5] highlighted that the education sector is actively embracing the opportunities and challenges introduced by technology, particularly focusing on enhancing teaching and learning through AI. This transformation is part of the fourth industrial revolution (IR 4.0) in education.

Advances in AI are reshaping education by driving a shift from traditional methods to technology-enhanced, learner-centered approaches. Schools and universities are increasingly integrating technologies that are AI-enabled to develop personalized and tailored learning pathways for students. This integration of AI is gradually transforming conventional teaching methods into more modern, student-centered approaches [6]. AI is now applied to improve the quality of teaching and learning, track instructional processes, and support academic evaluation and diagnosis [7]. Through personalized learning platforms and AI-driven assessment tools, institutions are reshaping education by customizing instruction, streamlining administrative tasks, and generating valuable insights into student performance. Expanding access to AI-based learning equips students with the skills and knowledge necessary to thrive in a technology-driven society [8].

However, despite these advancements, research on AI literacy among pre-service Science, Technology, Engineering, and Mathematics (STEM) teachers in Nigeria remains limited. This gap restricts the ability of policymakers and educators to design evidence-based strategies for effectively embedding AI into teacher training and classroom practice. Addressing this shortfall is particularly important for the future of STEM education in Nigeria, where emerging technologies are redefining the skills needed for global competitiveness [8]. Without adequate AI knowledge and competencies, pre-service teachers may find it difficult to nurture digital literacy among their students, thereby weakening efforts to build a technology-oriented workforce.

In light of this, we seek to examine AI literacy among pre-service STEM teachers in Nigeria. Specifically, we investigate the overall levels of AI literacy, explore potential gender-based differences, and analyze whether knowledge of AI significantly predicts its application in teaching.

The outcomes of this study are expected to inform teacher preparation programs and guide policy development aimed at advancing AI integration in STEM education.

1.1. Genesis of AI

The origins of AI date back to the 1950s and 1960s when researchers aimed to create machines that could replicate human intelligence. This era introduced fundamental AI concepts, focusing on symbolic reasoning, logic, and problem-solving. Although early AI systems were limited, they laid the foundation for advancements in machine learning, natural language processing, and expert systems. However, technical constraints and reduced funding led to what Haenlein and Kaplan [9] describe as the "AI winter," a period of stagnation in AI research.

The resurgence in the 1980s and 1990s was driven by expert systems, which aimed to replicate human decision-making in specialized fields [10]. These systems relied on rule-based reasoning, integrating a knowledge base and inference engine to process expert knowledge. Researchers later explored combining expert systems with machine learning, laying the groundwork for future advancements [11]. However, their complexity and high maintenance costs led to a shift toward alternative AI approaches by the late 1990s. A turning point came in the late 1990s and early 2000s with the rise of machine learning and neural networks. Researchers embraced statistical methods such as Bayesian networks and support vector machines to enhance AI capabilities [12]. By the 2010s, deep learning, powered by big data and advanced processing capabilities, revolutionized AI. This led to breakthroughs in image recognition, speech processing, and autonomous systems [13]. Inspired by the structure of the human brain, deep learning enabled machines to recognize complex patterns from vast datasets [14]. The convergence of AI, big data, and increased processing power enabled innovations across industries, from personalized recommendation systems to advanced medical diagnostics. The rapid evolution of AI during this period marked the beginning of its widespread integration into daily life [15].

1.2. AI in education

The mention of AI often brings to mind the image of a supercomputer, a powerful machine capable of exhibiting human-like cognition and adaptive behavior through sensors and advanced processing. This portrayal, often depicted in popular media, emphasizes AI’s capacity to enhance human interaction by mimicking human thought and decision-making. Various motion pictures have depicted the capabilities of AI in smart buildings, demonstrating abilities such as managing air quality, regulating temperatures, and playing music based on based on occupants' emotions [16]. While these portrayals may be exaggerated, they reflect the growing role of AI in everyday life. However, the application of AI in education has evolved beyond this narrow image of supercomputers. AI now encompasses a broader range of technologies, including embedded systems within robots and educational tools, which enhance the learning experience, even for young children. Collaborative robots (or cobots) work alongside teachers to help children with tasks like spelling and pronunciation [17].

The use of AI in web-based learning systems is a case in point. What began as simple online platforms for accessing materials has evolved into dynamic, adaptive systems capable of learning from teachers and students to personalize the learning experience [16,18]. The integration of AI into Nigerian educational institutions is progressively reshaping the academic landscape. A study by

Ngonso et al. [19] indicated that a significant number of Nigerian students are utilizing AI tools, notably ChatGPT, to enhance their academic performance. In secondary education, AI applications are being piloted to personalize learning experiences and streamline administrative tasks. Adaptive learning systems have been introduced in select urban schools to tailor instruction to individual student needs, resulting in improved engagement and outcomes [20]. AI technologies like intelligent tutoring systems and multimedia e-learning platforms are being explored to supplement traditional teaching methods. These tools aim to provide students with interactive and personalized learning experiences [21]. Olatunde-Aiyedun [22] posits that AI serves as a catalyst for improved learning outcomes and a deeper understanding of academic concepts among Nigerian students. AI supports the implementation of science education in Nigerian tertiary institutions in several ways. It enhances lecture delivery in science education, assists lecturers in conducting research, and facilitates the provision of community services [23]. Ngonso et al. [19] found that most Nigerian students use AI and benefit from its positive impact on their academic performance. The study also revealed that students receive training on AI for educational purposes and are particularly familiar with ChatGPT. While these applications highlight AI's potential to transform education, they also bring attention to a significant gap in the literature. The application of advanced AI techniques, such as deep learning and data mining, holds promise for solving complex educational challenges, these technologies have yet to be fully integrated into teacher training programs. Existing studies in the Nigerian context rarely evaluate how well these future educators are prepared to incorporate AI into their teaching practices. This limitation is critical, as without a strong understanding of AI, pre-service teachers may struggle to implement AI-driven methodologies, hindering their ability to foster digital competencies among their students.

1.3. AI literacy

Literacy is an evolving concept shaped by social and technological changes [24]. Over time, it has expanded to include competencies in information and communication technology (ICT), media, and global citizenship. AI literacy follows this trend, emerging alongside other technology-driven literacies such as digital literacy, media literacy, and data literacy. Burgsteiner et al. [25] and Kandlhofer et al. [26] introduced the term "AI literacy," defining it as the ability to understand AI's basic principles. Magerko and Long [27] extended this definition to include skills for evaluating, communicating, and working with AI in various settings.

In some cases, AI literacy has been conceptualized as an extension of data literacy or digital literacy [28,29]. This perspective is reflected in several national AI curricula that focus on AI applications such as machine learning and natural language processing. However, AI differs from other digital technologies in its ability to operate autonomously and adapt to different contexts. Teaching AI should go beyond technical concepts to include ethical considerations, data biases, and its impact on employment and sustainable development. In education, AI literacy also involves understanding how AI-driven tools collect data and influence learning processes [30]. Without this, educators may struggle to integrate AI effectively into teaching and learning.

Ng et al. [31] highlighted ethical concerns in AI, warning that poor design or misuse could have serious consequences. Issues such as algorithmic bias, legal accountability, and intellectual property rights emphasize the need for ethical guidelines in AI education [32]. Lee et al. [33] stressed the importance of human-centered AI education to develop responsible users and designers. While AI tools like chatbots and translation apps have made AI more accessible [34], access alone does not ensure AI literacy. Educators must be equipped to teach AI literacy effectively; yet, studies on their literacy level remains scarce, especially in a Nigerian context.

1.4. AI in African education

Education across Africa places strong emphasis on practicality, relevance, and real-world experiences while nurturing individual growth and community well-being. Culture, tradition, and spirituality are highly valued, and teaching often adopts a hands-on, experiential orientation [8]. Within this context, technology is viewed as a vital tool for improving the quality of life for individuals and communities. Nonetheless, the integration of technology across Africa is hindered by limited resources and weak infrastructure. Despite these barriers, educators across the continent remain hopeful about the role of technology in bridging gaps between urban and rural communities as well as across socioeconomic groups [35].

AI, as a rapidly developing technology, presents new opportunities for transforming education in Africa. Its potential lies in reshaping learning processes and expanding access to quality education. Examples of its application include AI-driven conversational agents that provide personalized mentoring and platforms that deliver customized learning experiences. AI also supports teachers by automating tasks such as homework evaluation, enabling them to dedicate more time to core instructional activities [36].

Beyond these uses, AI offers solutions tailored to Africa's unique educational challenges, such as delivering content in indigenous languages. It stands to exert a significant positive influence on education in Africa by furnishing tailored learning experiences, enhancing efficiency, and tackling challenges endemic to educational systems on the continent. Additionally, the rise of remote learning platforms and virtual classrooms further facilitates AI integration, overcoming geographical limitations and promoting equitable access to quality education. This broadening of educational opportunities enables learners from underserved communities to pursue academic goals and contribute meaningfully to societal progress. Importantly, AI not only reshapes learning approaches but also strengthens educators' capacity to fulfil their teaching roles effectively.

A major area of alignment lies in the use of AI to broaden access to education. Across Africa, as in many other regions, AI-powered platforms and virtual classrooms are increasingly used to reduce geographical barriers and promote inclusivity. Tools such as AI-driven chatbots and adaptive learning systems are being employed to provide personalized learning experiences, similar to developments in North America, Europe, and Asia [37]. These technologies are particularly valuable in resource-limited settings, especially rural and underserved areas. However, unlike developed countries where stable internet connectivity and widespread device availability facilitate AI adoption, Africa continues to face significant digital divides [38], limiting the reach of these innovations.

Another point of convergence is the growing recognition of the importance of AI literacy among teachers. Globally, countries are embedding AI competencies into teacher education programs, making AI training a central priority. In Nigeria, initiatives such as the Experience AI Program and the DeepTech Ready Upskilling Program reflect efforts to build teacher capacity in this area. Yet, these initiatives are largely short-term and have not been systematically integrated into teacher education curricula. In contrast, nations like China, Finland, and the United States have incorporated AI literacy into national education policies, ensuring long-term preparedness for teachers [39].

Without similar policy-driven, sustained investment, Africa risks falling behind in preparing its teaching workforce for the future.

Globally, AI has drawn significant attention for its potential to enhance instruction and create interactive learning opportunities in African classrooms [40]. Yet, its adoption among pre-service teachers remains uneven, largely due to varying levels of readiness. Preparing to integrate AI into STEM education extends beyond understanding AI concepts; it requires confidence in using AI tools, access to technological resources, and institutional support [41]. Successful AI integration therefore depends not only on technical competence but also on teachers' ability to adapt instructional strategies to AI-supported learning. Readiness is influenced by factors such as professional development, technical assistance, and attitudes toward AI [8,42–44]. Pre-service teachers with prior experience using digital technologies often display greater confidence and willingness to apply AI in their practice. Those who perceive AI as effective for engaging learners and improving outcomes are also more likely to embrace its use [43].

Conversely, limited technical support, insufficient resources, and inadequate training frequently discourage AI adoption [41]. Many pre-service teachers report feeling ill-prepared to use AI, especially when they view it as complex or difficult to apply in classroom settings [45]. Teachers' perceptions, ranging from anxiety about adopting new technologies to confidence in teaching AI-related content, play a critical role in shaping readiness [8,42,44]. Addressing these barriers through targeted training, access to resources, and supportive policies is therefore essential to equipping future teachers with the skills needed to integrate AI effectively into STEM education.

1.5. AI literacy among pre-service teachers

AI literacy is increasingly recognized as a crucial competency in today's digital landscape. Traditionally, literacy referred to reading and writing skills [46], but the concept has expanded to include media, digital, information, and AI literacy [47]. AI literacy is particularly vital for pre-service STEM teachers, equipping them to integrate AI tools into classrooms. AI-literate teachers serve as role models, preparing students for an AI-driven future. Celik [43] emphasized that teachers proficient in AI can reshape instructional roles, improve efficiency, and make data-driven decisions. Similarly, Daxing [48] highlighted how AI enhances pre-service teachers' professional development by improving adaptability and personalized learning experiences. Nurzhanova et al. [49] found that pre-service STEM teachers generally possess strong AI literacy and digital skills. Xue and Wang [50] highlighted that teachers recognize the potential of AI to ease instructional workload and improve information literacy. However, Attwood et al. [51] found that while pre-service teachers recognize AI potential for classroom management and instruction, many lack the necessary training to use AI effectively.

Historically, AI education was confined to university computer science departments, limiting accessibility for pre-service teachers [8]. The requirement for advanced programming skills posed a barrier to widespread AI literacy among teachers. However, the emergence of user-friendly AI tools has created opportunities for pre-service STEM teachers to adopt AI in education. Despite these advancements, there is a gap in AI literacy training within Nigeria's teacher education programs, making it necessary to examine existing frameworks aimed at addressing this gap [8].

Several initiatives have been introduced to improve AI literacy among educators in Nigeria. One notable effort is the Experience AI Program, which aims to equip 25,000 educators with AI teaching tools, enabling them to educate 125,000 students. This program is part of Google.org's broader commitment to advancing digital skills across Sub-Saharan Africa. Similarly, the DeepTech Ready Upskilling Program seeks to train 20,000 young Nigerians in AI and data science, preparing them for careers in emerging tech fields [52]. These initiatives highlight a shift toward large-scale AI literacy efforts, but their impact on pre-service STEM teachers remains unclear, as most training programs focus on in-service educators.

The Federal Government of Nigeria also launched a five-week AI training program targeting 6,000 senior secondary school teachers. This initiative, in collaboration with the National Senior Secondary Education Commission (NSSEC) and Google Research, aims to integrate AI into Nigeria's educational system [53]. While these programs mark significant progress, their long-term impact on AI literacy among pre-service teachers in Nigeria remains unclear. Unlike countries that have embedded AI literacy frameworks into teacher education curricula, Nigeria's approach has primarily focused on short-term training for in-service teachers [8]. This has left a significant gap in preparing pre-service teachers, who will soon be responsible for navigating AI-driven classrooms. Without structured AI training, many of these future educators may enter the profession unprepared for the challenges of integrating AI into teaching and learning. As AI continues to reshape education, pre-service teachers must develop technical proficiency and adapt AI tools to learning environments.

1.6. Gender bias in AI

The underrepresentation of girls in STEM remains a persistent issue, with implications for AI advancement in Nigeria. According to the Financial Institutions Training Center (FITC), females constitute only 22% of STEM graduates from Nigerian universities, highlighting a substantial gender gap in these critical disciplines [54]. Deeply ingrained social and cultural norms often discourage girls from pursuing STEM careers, reinforcing the misconception that these fields are more suited for boys. Despite growing global advocacy for gender inclusivity in technology, Nigeria continues to face challenges in bridging this gap. Even with the emergence of AI-based tools such as ChatGPT, questions remain about whether male and female students in higher education have equal awareness and access to AI tools for academic and research purposes [55].

While digital technology has become more accessible worldwide, gender disparities persist, particularly in developing regions. In low- and middle-income countries, an 8% gap exists in phone ownership between men and women, which rises to 20% for smartphone ownership [56]. In Africa, women lag behind men by 25% in Internet adoption [57], and globally, women are 21% less likely than men to own a mobile device, which is the primary means of Internet access in many developing nations [58]. Dai et al. [59] found that male students tend to exhibit greater confidence and higher readiness for AI adoption. Although digital access has improved over time, studies suggests that men and women interact with AI tools differently [60]. While women may download AI applications, men are more likely to actively engage with and utilize them for productivity and learning [61].

Nigeria reflects these global trends, with structural barriers limiting women's participation in AI-related education. Although government initiatives and advocacy efforts have sought to bridge the gap, deep-rooted social norms and limited access to resources continue to restrict women's engagement in AI literacy programs [62]. Compared to developed nations where gender-focused policies and initiatives have been implemented to close the digital divide, Nigeria's approach remains fragmented. Several countries have implemented gender-inclusive digital literacy programs, including Rwanda with its Digital Ambassador Program [63], Kenya with the Ajira Digital Program [64], and initiatives in EU countries like France, Germany, and others. These programs were designed to ensure that girls receive equal exposure to AI and other emerging technologies from an early stage. In contrast, Nigeria lacks a coordinated national strategy for AI literacy among female students, leaving many at a disadvantage. Limited access to digital tools, combined with socio-economic barriers, further restricts women's participation in AI-driven education and career paths [65,66].

Women represent one of the fastest-growing population segments [67], and issues affecting their use of technology can significantly impact national investments in educational technologies. Thus, if educational stakeholders understand the differential impact of gender on pre-service STEM teachers' AI literacy, appropriate measures can be taken to create a more inclusive and equitable learning environment. This is essential for preparing a diverse and competent future workforce in the rapidly evolving field of AI. Therefore, we examine whether gender is a significant determinant of AI literacy among pre-service STEM teachers.

Although research on AI in education continues to expand, there is limited empirical evidence on the AI literacy levels of pre-service STEM teachers in the Nigerian context, as well as insufficient understanding of how gender may influence these competencies, even though their preparedness is central to the effective integration of AI in future classrooms. In this study, we seek to fill this gap.

1.7. Problem statement

AI has emerged as a transformative tool with the potential to revolutionize teaching and learning. However, its successful integration into education largely depends on the AI literacy of pre-service STEM teachers, who serve as the future architects of educational systems. While numerous studies in Africa have explored AI in education, the focus has mostly been on AI implementation and student engagement. For instance, Oyelere et al. [68] evaluated AI adoption in African schools, emphasizing the need for contextualized educational materials to enhance effective teaching and learning. Ayanwale [1] examined secondary school students' intentions to learn AI, reporting a generally positive attitude and confidence in AI knowledge acquisition. Similarly, Sanusi et al. [69] investigated AI competencies among K-12 learners, highlighting the importance of collaborative activities in AI curricula. Despite these advancements, there is a critical gap in the literature regarding AI literacy among pre-service STEM teachers in Nigeria. This gap limits education stakeholders' ability to design evidence-based policies that effectively integrate AI into teacher education and classroom practice. Without adequate AI literacy, pre-service teachers may struggle to implement AI-driven pedagogies, potentially widening the digital divide in STEM education.

From a theoretical standpoint, this study contributes to the understanding of AI literacy through the lens of technological pedagogical content knowledge (TPACK) and constructivist learning theories, which emphasize the role of teachers' technological proficiency in fostering meaningful learning experiences. Practically, the study informs teacher education programs by identifying the AI literacy needs of pre-service STEM teachers, guiding curriculum reforms and professional development initiatives. Addressing these gaps is essential to ensuring that future STEM educators are adequately prepared to leverage AI technologies in ways that enhance student learning and engagement. Therefore, we aim to investigate the level of AI literacy among pre-service STEM teachers in Nigeria, assess gender differences in AI literacy, and determine whether understanding AI significantly predicts its application in educational contexts.

1.8. Theoretical framework

The TPACK framework provides a robust foundation for understanding how pre-service STEM teachers integrate AI into their instructional practices. At its core, TPACK emphasizes the dynamic interplay between technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) in shaping effective teaching and learning experiences [70]. In the context of this study, AI literacy is examined through the lens of TPACK, focusing on three key components: TK, Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK).

TK serves as a strong foundation to address the level of AI literacy among pre-service STEM teachers in Nigeria. TK reflects teachers' ability to understand, evaluate, and apply technological tools in educational contexts [71]. Within this study, TK is seen as pre-service teachers' foundational understanding and critical awareness of artificial intelligence. As reflected in the Know & Understand AI (KU) and Detect AI (DA) constructs, TK encompasses knowledge of core AI concepts and definitions, the ability to evaluate its opportunities and limitations, and the capacity to anticipate current and future applications. It also includes the competence to recognize AI-based systems and distinguish them from non-AI technologies. A strong foundation in TK enables teachers to critically assess AI's role in education and determine its practical benefits and limitations.

The TPACK framework acknowledges that knowledge acquisition and technological competence may vary based on individual experiences and contextual factors. TCK, which examines how technology interacts with subject-specific content [72], helps explain why differences in AI literacy may emerge. Gender-based disparities in technology access, exposure, and confidence may influence how pre-service teachers engage with AI tools [57]. TPACK, particularly TK and TPK, provides a lens to examine these differences by assessing whether pre-service teachers' AI knowledge and application vary based on gender. Since TPK involves understanding how technology supports different teaching methodologies, gender-based disparities in AI literacy could signal broader challenges in equitable access to AI training and resources. TCK and TPK highlight that for AI to be meaningfully applied in teaching, educators must understand its content relevance and pedagogical potential [72]. Simply knowing about AI is insufficient; teachers must also recognize how it can enhance subjects and instructional strategies.

The survey instrument is designed to reflect the key dimensions of the TPACK framework that guided this study. The KU and DA constructs primarily capture aspects of TK. Items such as knowing the core concepts and definitions of AI, identifying its advantages and limitations, distinguishing AI-based systems from non-AI systems, and recognizing whether one is interacting with AI or a human reflect foundational technological understanding. Within the TPACK framework, TK refers to the ability to comprehend, evaluate, and work with technological tools. Therefore, these items assess participants' conceptual grasp of AI and their ability to critically interpret its presence and functionality in real-world contexts.

The Use & Apply AI (UA) construct extends beyond basic awareness and reflects the practical dimension of TK and elements of TPK. Items measuring the ability to operate AI applications, communicate effectively with AI systems, and use AI to achieve goals assess participants' confidence and competence in applying AI tools. While these items are framed in everyday contexts, they are relevant to TPK because the ability to meaningfully use AI tools is a prerequisite for integrating them into teaching strategies. In other words, practical engagement with AI forms the basis for later pedagogical application [73]

The AI Ethics (AE) construct aligns closely with TCK and TPK. Evaluating the societal consequences of AI use, incorporating ethical considerations when using AI-generated data, and analyzing ethical implications require participants to connect technological understanding with broader disciplinary and instructional considerations. TCK is reflected in the ability to relate AI to subject-specific and societal contexts, while TPK is evident in the capacity to make informed decisions about when and how AI should be used responsibly. Ethical awareness is therefore not treated as an isolated competence but as part of the broader integration of technology with content and pedagogy.

Taken together, the four survey constructs operationalize the dimensions of TPACK by moving from foundational understanding (TK) to contextual and critical awareness (TCK), and toward meaningful and responsible application (TPK). This alignment ensures that AI literacy in this study is not limited to technical familiarity but is examined as an integrated competence consistent with the TPACK framework's emphasis on the interconnectedness of technology, pedagogy, and content knowledge.

1.9. Our objectives of the study

In this study, we aim to investigate AI literacy among pre-service STEM teachers in Nigeria and examine factors influencing its application in educational contexts. Specifically, we seek to:

1. Assess the level of AI literacy among pre-service STEM teachers in Nigeria.
2. Determine whether statistically significant differences exist in AI literacy levels between male and female pre-service STEM teachers.
3. Examine whether knowledge and understanding of AI significantly predict its use and application among pre-service STEM teachers.

1.10. Research questions

1. What is the level of AI literacy among pre-service STEM teachers in Nigeria?
2. Are statistically significant differences evident in the level of AI literacy between male and female pre-service STEM teachers?
3. Does knowing and understanding AI significantly predict using and applying AI among pre-service STEM teachers?

1.11. Null hypotheses

1. There are no statistically significant differences evident in the level of AI literacy between male and female pre-service STEM teachers.
2. Knowing and understanding AI does not significantly predict use and application of AI among pre-service STEM teachers.

2. Methodology

2.1. Study context

The sample was selected from a tertiary institution in Lagos State, one of Nigeria's 36 states, known for its cosmopolitan characteristics, including a diverse student and staff population. Lagos

State, the economic capital of Nigeria, is distinguished by its rich diversity of ethno-linguistic groups and a broad spectrum of school ownership.

2.2. Research design

We employed a descriptive survey of the non-experimental research design to investigate the level of AI literacy among pre-service STEM teachers. This design was considered appropriate because, in the context of this study, it was essential to capture and understand the levels of AI literacy among pre-service STEM teachers without manipulating variables or conditions. Moreover, a descriptive research design enables researchers to systematically describe the characteristics of the population being studied [74]. This makes it suitable for aiming to understand the state of a phenomenon without altering the natural setting [75].

2.3. Sample and sampling technique

The population of this study included all pre-service STEM teachers in Lagos state, Nigeria. A convenience sampling technique was used to select 541 pre-service STEM teachers from three public universities for the study. This included 399 from Lagos State University, 33 from the University of Lagos, and 109 from Lagos State University College of Education. All participants voluntarily completed an AI literacy survey through an online Google Form. This approach was chosen due to its accessibility and efficiency in reaching a large number of participants within a limited timeframe. Given our study's objective of assessing AI literacy levels and examining gender differences, convenience sampling enabled the recruitment of respondents who were readily available and willing to participate. While convenience sampling did not ensure full representativeness, steps were taken to enhance data credibility. These included preventing multiple responses to maintain data integrity, ensuring voluntary participation to minimize response bias, and including a diverse sample of male and female pre-service teachers. This approach aligned with other studies [42,76] that have entailed convenience sampling to investigate pre-service teachers' perspectives. Of the collected survey responses, 345 were from female participants, constituting 63.8 % of the total sample, while 196 responses were from male pre-service STEM teachers, representing 36.2 % of the surveyed population. The age range of the pre-service STEM teachers included in the study ranged from 25 to 40 years, indicating that most belonged to the younger generation, known for their proficiency in 21st-century technology. While the we encompassed pre-service STEM teachers from all academic levels, ranging from year 1 to year 4, the predominant representation was observed among year 4 students (331).

2.4. Instrumentation

A questionnaire titled "Artificial Intelligence Literacy Questionnaire (AILQ)" was used to collect data for the study. Specifically, the facets on utilization and application of AI, comprehension of AI, and ethical considerations of AI was adopted from Ng et al. [31], while the facet of detection of AI was adopted from Ayanwale, et al, [8]. Ayanwale et al. [8] assessed the validity of the scale by having it reviewed by two academic experts in the field of educational research. The reliability coefficient was calculated using Cronbach's alpha, resulting in a value of 0.70. The AILQ was organized into two sections, Section A and Section B. Section A gathered demographic information on pre-service STEM teachers, including gender and age. Section B consisted of 13 items subdivided into four sections: Section one focused on usage and application of AI, section two on knowledge of AI applications, section three on Detecting AI, and section four on AI ethics. The instrument was validated by two experts in test and measurement and an expert in computer education. To ensure the validity of the research instrument, the survey underwent expert validation by two specialists in test and measurement and one expert in computer education. The two experts in test and measurement evaluated the survey to confirm that it effectively measured the intended constructs. They assessed the alignment of the items with our objectives, ensuring that the questions were clear, unbiased, and capable of accurately capturing AI literacy levels. Their review also focused on the structure of the Likert-scale items to enhance reliability and consistency in responses. An expert in computer education reviewed the instrument to verify its technical accuracy and relevance to AI concepts. This specialist examined whether the questions appropriately addressed key aspects of AI literacy, including knowledge, application, and ethical considerations. Following the expert reviews, their feedback led to the removal and restructuring of some items to improve the clarity and validity of the instrument. The reliability of the instrument was determined using a Cronbach's (α) reliability, yielding a reliability level of 0.84. This surpassed the 0.80 threshold, indicating the instrument's acceptable reliability. The survey instrument was converted into an online format using Google Forms and subsequently distributed to undergraduate pre-service STEM teachers via their online platform (WhatsApp) for data collection. The design of the Google Forms survey ensured that respondents could not complete it more than once. The survey link was shared with the students and monitored by lecturers. Participants were thoroughly informed about our objectives and understood that their participation was voluntary. They were assured that withdrawing during the data collection process or before its commencement would not result in any negative repercussions. Voluntary participation was emphasized, and explicit consent, along with the ethical guidelines, was communicated to the students, who provided their consent before participating in the study. The survey link remained open for three weeks before being closed for data collection. At the end of this period, 541 pre-service STEM teachers had completed the survey. Data were analyzed using IBM SPSS Statistics (Version 23). The analysis involved descriptive statistics, including simple percentages, mean, and standard deviation, as well as inferential statistical techniques such as t-tests and regression analysis to examine the relationships between variables.

3. Results

The first question examined the level of AI literacy among pre-service STEM teachers in Lagos State, Nigeria. The pre-service STEM teachers surveyed indicated their level of AI literacy on a five-point scale of strongly disagree, disagree, neutral, agree, and strongly disagree. The percentages, mean, and standard deviation for each item in the AI literacy section of the questionnaire on a five-point Likert scale of strongly disagree (SD), disagree (D), neutral (N), agree (A), and strongly agree (SA) are shown in Table 1.

From Table 1, pre-service STEM teachers indicated a relatively high level of agreement with the thirteen measures of AI literacy identified in the study. The top five skills with the highest levels of agreement (with the percentages of respondents in parentheses) were: (a) I know definitions of AI. (87.6%), (b) In everyday life, I can work together gainfully with an AI (87.8%), (c) I can operate AI applications in everyday life (84.3%), (d) I can communicate gainfully with AI in everyday life (83.1%), and (e) In everyday life, I can interact with AI in a way that makes my tasks easier (87.3%).

Table 1. Level of AI literacy among pre-service STEM teachers.

s/n	ITEMS	SD	D	N	A	SA	Mean	Std
1.	I can operate AI applications in everyday life.	0.6%	3.3%	11.9%	55.2%	29.1%	4.09	.77
2.	In everyday life, I can interact with AI in a way that makes my tasks easier.	0.4%	2.2%	10.2%	52.9%	34.4%	4.19	.73
3.	In everyday life, I can work together gainfully with an AI	0.2%	1.5%	10.5%	54.0%	33.8%	4.20	.69
4.	I can communicate gainfully with AI in every-day life.	0.4%	2.4%	14.0%	54.3%	28.8%	4.09	.74
5.	I know definitions of AI.	0.0%	2.0%	10.4%	61.9%	25.7%	4.11	.67
6.	I can assess what the limitations and opportunities of using an AI are.	0.0%	4.1%	17.7%	56.4%	21.8%	3.96	.75
7.	I can assess what advantages and disadvantages the use of an AI entails.	0.2%	4.6%	12.8%	59.1%	23.3%	4.01	.75
8.	I can tell if I am dealing with an application based on AI	0.2%	5.9%	14.4%	55.5%	24.0%	3.97	.79
9.	I can incorporate ethical considerations when deciding whether to use data provided by an AI.	0.4%	3.9%	23.8%	52.7%	19.2%	3.98	.78
10.	I can weigh the consequences of using AI for society	0.4%	6.3%	18.5%	53.8%	21.1%	3.89	.82
11.	I can analyze AI-based applications for their ethical implications.	0.9%	6.7%	23.8%	50.3%	18.3%	3.78	.85
12.	I can use AI meaningfully to achieve my everyday goals.	0.4%	5.2%	14.4%	49.2%	30.9%	4.05	.83
13.	I can imagine possible future uses of AI	0.2%	3.7%	17.9%	49.4%	28.8%	4.03	.79

The second research question addressed whether or not there was a statistically significant difference in the level of AI literacy between male and female pre-service STEM teachers in Lagos State, Nigeria. The results are shown in Table 2

Table 2. T-test showing differences between male and female pre-service STEM teachers AI literacy level.

Gender	N	Mean	Std	t	P (sig. level)	Cohen's d
Female	345	3.91	0.45	5.62	0.00	0.50
Male	196	4.14	0. 51			

Table 2 shows that there was a statistically significant difference in AI literacy between male and female students, $t(539) = 5.62$ and $p < .05$. The effect size ($d = 0.50$) indicated a moderate difference between the two groups. Although the mean score of the male students was higher than that of the female students, suggesting greater AI literacy among males in this sample, the magnitude of the difference reflected a meaningful but not large practical effect.

The third research question sought to establish if knowing and understanding AI (KUAI) significantly predicted using and applying AI (UAAI) among pre-service STEM teachers in Lagos

State, Nigeria.

A linear regression was conducted to determine if KUAI could significantly predict UAAI. A scatterplot shows that the relationship between the variables was positive and linear and without bivariate outliers (Figure 1).

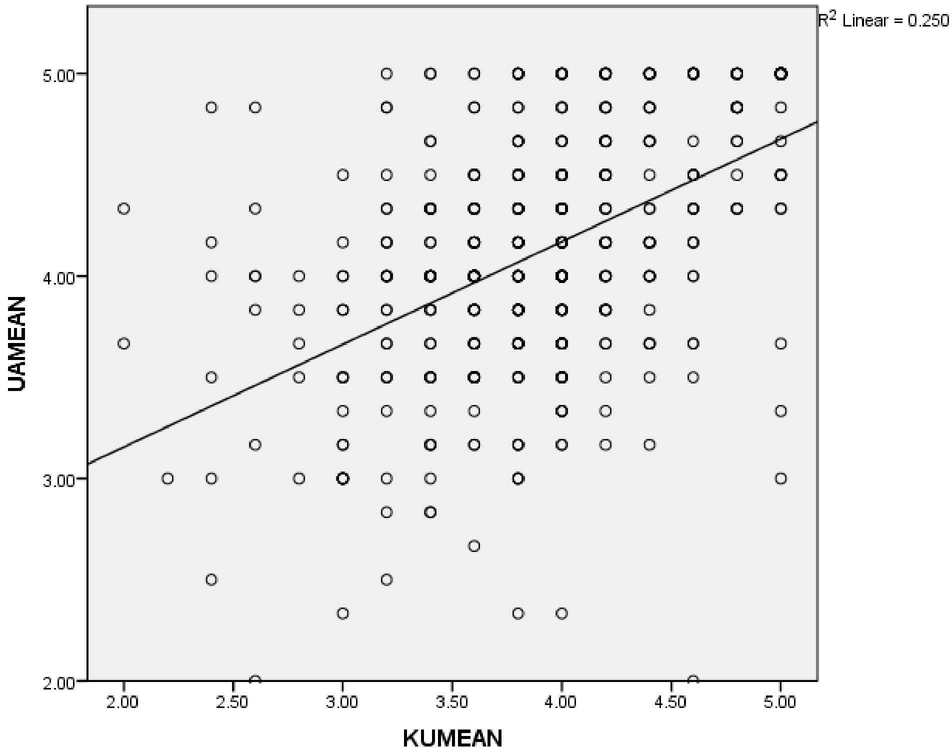

Figure 1. A scatterplot showing the relationship between variables.

An analysis of standard residuals showed that the data contained no outliers (Std. Residuals Min. = - 4.89, Std. Residuals Max. = 2.91). The independence of residual errors was confirmed with a Durbin-Watson (DW) test (d = 1.99). According to Kenton [77], a rule of thumb is that DW test statistic values in the range of 1.5 to 2.5 are relatively normal; hence, the normality of the population.

Table 3. Model summary table.

Model	R	R Square	Adjusted R-Square	Std. Error of the Estimate
1	.50[a]	.25	.23	.50

a. Predictors: (Constant), KUAI

Table 4. ANOVA table.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	46.11	1	46.11	180.02	.00[b]
Residual	138.05	539	.26		
Total	184.16	540			

a. Dependent variable; AUAI

b. Independent carriable; KUAI

Table 5. Coefficient table.

Model	B	Std. Error	Beta	t	Sig.
	(Constant)	2.14	.15		14.25
	Knowing AI	.50	.03	.500	13.41

a. Dependent variable; UAAI

Simple linear regression was used to assess whether knowing and understanding AI significantly predicted using and applying AI. The results revealed that knowing and understanding AI significantly predicted using and applying AI, F (1,539) = 180.02 and p< .001 (Table 4), indicating that KUAI played a significant role in shaping UAAI (B =.50, t = 13.41, p< .001) (see Table 5); therefore, the null hypothesis is rejected. The R2 = .25 (Table 3) depicted that the model explained 25% of the variance in the use and application of AI. This was a moderate-to-large relationship [78]. Moreover, the model demonstrated meaningful predictive power, although it explained a portion of the variance in UAAI.

4. Discussion

For the first research question, we aimed to determine the level of AI literacy among pre-service STEM teachers in Nigeria. Our findings indicated a relatively high level of self-reported AI literacy among pre-service STEM teachers. This suggests that these pre-service STEM teachers self-reported relatively high preparedness to comprehend and manage the complexities associated with AI technologies. Xue and Wang [50] highlighted that teachers recognize the potential of AI to ease instructional workload and improve information literacy, with over half of their study participants acknowledging its benefits for professional growth. This study supports these perspectives and extends them within the Nigerian context, demonstrating that AI literacy is not only high among pre-service teachers but also suggests a readiness to integrate AI into educational practices. This challenges assumptions that teachers in developing regions may struggle with AI adoption due to technological limitations.

Our findings contribute to the evolving field of AI in teacher education by shifting the focus from AI awareness to practical preparedness. While many researchers have examined in-service teachers' attitudes toward AI [44], this study highlights that pre-service teachers are developing essential AI competencies before entering the profession. This insight is crucial for curriculum developers and educational policymakers seeking to design AI-focused teacher training programs that go beyond theoretical knowledge to hands-on application. Recognizing pre-service teachers as early adopters of AI-driven education enables institutions to design structured learning experiences that incorporate AI tools into teacher training. This ensures that future educators develop hands-on AI competencies, facilitating a seamless transition into AI-integrated classrooms.

For the second question, we sought to establish whether there is a statistically significant difference in the level of AI literacy between male and female pre-service STEM teachers. Our findings revealed that there is a statistically significant difference in the level of AI literacy between male and female students. The higher mean score among male students suggests that they have higher levels of AI literacy than female students.

This aligns with the study of Dai et al. [59], who found that male students tend to exhibit greater confidence, a stronger sense of relevance, and higher readiness for AI adoption. The study further noted that males often report greater self-perceived control over AI applications and possess stronger programming skills compared to females. These findings raise important questions about gender disparities in technological education and proficiency. One plausible explanation for the elevated levels of AI literacy among male pre-service STEM teachers could be attributed to the persistence of gender stereotypes and societal norms regarding technology and STEM disciplines. Throughout history, males have traditionally received more encouragement to pursue interests and careers in technology and engineering fields closely associated with AI [59]. This societal inclination may result in greater exposure and involvement in AI-related activities, resources, and educational prospects for males from a young age. Consequently, male pre-service STEM teachers may have had increased opportunities to cultivate their AI literacy over time compared to their female counterparts.

At this point, it is important to discuss the effect size. The effect size of d = 0.50 indicates a moderate difference between male and female pre-service teachers in AI literacy. In educational research, this magnitude suggests that the difference is meaningful in practice, although it is not large. While males scored higher on average, the effect size shows that the overlap between the two groups is substantial, meaning many female participants also demonstrated strong AI literacy levels. Therefore, the finding points to a gender-related variation that warrants attention, but it should not be interpreted as evidence of a wide or deterministic gap.

These findings contribute to the growing body of knowledge on gender disparities in AI literacy within teacher education. While researchers have explored gender differences in technology use [59], we extend that conversation to pre-service STEM teachers, a group responsible for shaping the next generation of learners. Understanding these disparities is crucial, as it underscores the need for targeted interventions that address gender-specific barriers to AI adoption in education.

For the third research question, we sought to establish if knowing and understanding AI significantly predicts the use and application of AI. The regression analysis showed that knowing and understanding AI significantly predicts using and applying AI, with the model explaining 25% of the variance (R^2 = .25). This indicates a meaningful relationship between the two constructs. However, the model represents only a partial explanation of AI application, as 75% of the variance remains accounted for by other factors not included in the analysis, as other factors influence the use of AI in educational contexts.

This finding agrees with that of Ayanwale et al. [8], which revealed that KUAI serves as a significant predictor, positively impacting different facets of AI literacy. Notably, KUAI positively influences UAAI, indicating that a solid understanding of AI concepts enhances pre-service teachers' ability to effectively use and apply AI technologies. The significant predictive relationship between KUAI and UAAI underscores the pivotal role that foundational knowledge and understanding play in the utilization and application of AI technologies. Understanding the intricacies of AI enables these educators to better appreciate its potential benefits and limitations, enabling them to make more informed decisions about effectively integrating AI into the curriculum. Such integration is crucial in STEM education, where AI can offer transformative tools for instruction, assessment, and personalized learning. However, realizing these benefits requires teachers who are comfortable with AI technologies and capable of ethically integrating these tools into their pedagogical practices.

Another reason for the significant prediction of UAAI by KUAI is the framework of TPACK. The TPACK model posits that effective technology integration in education requires an understanding of the interplay between technology, pedagogy, and content. In this context, AI literacy (KUAI) serves as a critical component of technological knowledge, enhancing individuals' ability to integrate AI effectively into their practices. These findings contribute to the growing body of knowledge on AI literacy, particularly in the context of teacher education. Moreover, this study provides empirical evidence supporting the role of AI knowledge in shaping pre-service teachers' ability to utilize AI technologies. This insight is particularly valuable as education systems increasingly integrate AI-driven tools into teaching and learning. The study shows that knowledge is a key predictor of AI applications, highlighting the need for AI literacy programs that extend beyond theoretical instruction to include hands-on experiences that strengthen application skills.

In relation to the theoretical framework, in the regression model, KUAI was treated as the predictor variable, while UAAI served as the outcome variable. Within the TPACK framework, KUAI corresponds to TK, as it reflects participants' conceptual understanding of AI, including its definitions, principles, opportunities, and limitations. UAAI represents the applied dimension of TK and moves toward Technological Pedagogical Knowledge (TPK) by capturing participants' ability to operate with and meaningfully engage with AI tools. Therefore, we examined whether foundational technological knowledge predicts practical technological application. The significant findings indicated that stronger AI knowledge (TK) is associated with greater use and application of AI. This is consistent with TPACK emphasis on the progression from technological understanding to practical integration.

5. Conclusions

The rapid progression of AI technology has significantly transformed educational frameworks, with institutions increasingly adopting AI-enabled tools to deliver personalized learning experiences. This transformation is evident in the emergence of smart classrooms and adaptive learning systems that are reshaping how students interact with content. As AI continues to take a central role in global education, assessing the AI literacy of pre-service STEM teachers, who will be at the forefront of future teaching innovations, has become increasingly critical. Our findings reveal that pre-service STEM teachers possess a relatively high self-reported AI literacy, indicating that they are well-prepared to understand and engage with AI technologies. However, we also uncovered a notable gender disparity in AI literacy, with male pre-service teachers demonstrating significantly relatively higher levels of proficiency than their female counterparts. This gap suggests that male pre-service STEM teachers are more familiar with AI concepts and better equipped to apply them in educational contexts. Such a disparity carries important implications for the future, as these pre-service teachers' AI literacy will likely influence how they integrate AI into their teaching practices and impact student learning outcomes.

6. Recommendations

Given our findings, several recommendations emerge for educational policy and practice. The relatively high self-reported AI literacy among pre-service STEM teachers provide a solid foundation for deeper integration of AI content into teacher training programs. Educational institutions should build on this foundation by embedding more AI-related content and practical experiences into their curricula. This can be achieved through lab-based learning, AI-driven projects, and partnerships with technology companies or research institutions that provide real-world exposure to AI applications.

The observed gender disparity in AI literacy calls for targeted interventions to support female pre-service teachers. Educational programs should intentionally cultivate inclusive learning environments that actively promote the participation of female students in AI and STEM-related activities. Strategies may include mentorship programs, the presence of female role models in AI fields, and the equitable distribution of learning resources and opportunities. Efforts must be made to address broader societal and cultural norms that reinforce gender biases in STEM education. This can be accomplished by encouraging girls from an early age to engage with technology and AI, and by promoting gender-neutral teaching approaches across educational settings.

Professional development initiatives should also be designed with a gender-sensitive lens, offering female pre-service STEM teachers the support and confidence necessary to build their AI competencies. Workshops, training sessions, and collaborative projects focusing on AI in education can provide valuable opportunities for female teachers to enhance their understanding and application of AI in the classroom. The predictive relationship observed between knowledge and use of AI underscores the importance of strategic policymaking. Policymakers should prioritize the integration of AI literacy into the broader educational agenda by investing in curriculum development, funding AI research, teacher training, and increasing public awareness about AI’s role in society. Such policies will help prepare future educators and learners for the demands of an AI-driven world and contribute to a more ethically aware and technologically competent society.

7. Study limitations and future work

Our study has provided meaningful insights into the AI literacy levels of STEM pre-service teachers. However, certain limitations should be acknowledged to provide proper context for interpreting the findings. One notable limitation is the geographic scope of the study. Data were collected solely from pre-service teachers in Lagos State, Nigeria, which may limit the generalizability of the results to other regions with different educational systems, infrastructures, or socio-cultural dynamics. Expanding future research to include participants from multiple states or countries would offer a more comprehensive and comparative understanding of AI literacy across contexts. In addition, we focused exclusively on pre-service teachers and did not include in-service teachers, whose experiences and levels of AI readiness may differ. Moreover, while we identified a significant gender gap in AI literacy in favor of male pre-service teachers, we did not deeply explore the institutional, cultural, or pedagogical factors that may contribute to this disparity. Additionally, factors such as curriculum content, access to digital tools, mentorship, and societal expectations were not investigated but are likely to shape students' exposure and confidence in working with AI. Thus, in future studies, researchers should adopt a more holistic approach that incorporates these contextual influences, possibly through mixed-method designs that include interviews or focus groups alongside quantitative measures. While we examined the relationship between key variables like knowledge and application of AI, we did not include an in-depth exploration of the ethical dimensions of AI use in education or the readiness of teacher preparation programs to equip future teachers for an AI-integrated classroom. These areas remain underexplored and are increasingly critical as AI technologies continue to evolve and reshape educational practices. Thus, researchers should investigate how pre-service and in-service teachers perceive and respond to the ethical challenges of AI, as well as how teacher education programs can adapt their curricula to foster responsible and equitable AI integration in schools.

Author contribution

All authors contributed to the study's conception and design. Umar Adam conceptualized the study and led the writing of the original draft. Adekunle Oladejo was involved in reviewing related literature, editing and refining the manuscript. Bamiro Nurudeen was involved in reviewing related literature and data analysis. Olasunkanmi Gbeleyi co-conceptualized the study and was involved in writing the methodology. Tunde Owolabi contributed to data curation and the development of the study instruments. Mariam Usman assisted in data collection and investigation.

Use of Generative-AI tools declaration

The authors declare the use of Artificial Intelligence (AI) tools in preparation of this article, exclusively for refining the grammar, structure and spelling. All intellectual content, data interpretation, and critical analysis were conceived and developed by the human author.

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Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

Ethics declaration

The instrument and methodology were reviewed by the Department of Science and Technology Education Research and Ethics Committee at Lagos State University. The study was granted an approval (Approval No: STE/REC/010). All participants in this study provided their informed consent before participating. Consent was obtained through a question on the first page of the Google form used to collect data, where participants indicated their agreement to participate in the study. Only those who consented were able to proceed with completing the form. This ensured that all data collected was done so with the full knowledge and voluntary participation of the respondents.

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