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Curriculum Innovation: Integrating AI Literacy and Tools into Science Teacher Education and Classroom Practice

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Abstract

Artificial intelligence (AI) is transforming educational systems globally, creating an urgent need for science teacher education programmes to equip pre-service and in-service teachers with AI literacy and the pedagogical competencies required to integrate AI tools into science teaching and learning. However, limited curriculum innovation in many teacher education programmes has hindered the effective adoption of AI -driven instructional practices. This study examined curriculum innovation through the integration of AI literacy and AI-powered tools into science teacher education and classroom practice. Specifically, it investigated the extent of AI integration in teacher education curricula, science teachers' AI literacy, factors influencing classroom implementation, and strategies for effective curriculum reform. A mixed-methods research design was adopted. The study involved 320 pre-service and in-service science teachers and 25 science teacher educators selected through stratified random and purposive sampling techniques. Data were collected using a validated AI Literacy and Curriculum Innovation Questionnaire (Cronbach's $\alpha = .91$) and semi -structured interview guides. Quantitative data were analysed using descriptive statistics and multiple regression, while qualitative data were analysed thematically. Findings indicated that AI literacy significantly predicted teachers' intention to integrate AI tools into science instruction ($\beta = .63$, $p < .001$), while institutional support and professional development emerged as critical facilitators. Qualitative findings further revealed that curriculum redesign, continuous capacity building, and ethical AI training are essential for sustainable implementation. The study concludes that embedding AI literacy within science teacher education curricula is fundamental to preparing future-ready science educators and recommends policy-driven curriculum reforms and sustained professional development initiatives.

Keywords: artificial intelligence literacy, curriculum innovation, science teacher education, science classroom practice, teacher professional development, educational technology, AI integration

1 Introduction

The introduction should be succinct and contain no subheadings. This section should present background for the study, The rapid advancement of artificial intelligence (AI) has ushered in a transformative era in education, fundamentally changing how teaching, learning, assessment, and educational management are conceptualized and imple mented. AI -powered technologies including intelligent tutoring systems, adaptive learning platforms, generative AI tools, virtual laboratories, automated assessment systems, and predictive analytics —are increasingly being integrated into educational environments to enhance instructional effectiveness and student engagement (Holmes et al., 2022; UNESCO, 2023). Within science education, these innovations offer unprecedented opportunities to promote inquiry -based learning, scientific reasoning, personalized instruction, and data -driven experimentation. Consequently, science educators are expected not only to understand the technical applications of AI but also to possess the pedagogical competence required to integrate these technologies ethically and effectively into classroom practice. Science education has traditionally emphasized critical thinking, experimentation, problem-solving, and evidence -based reasoning. However, the emergence of AI has expanded the competencies required of science teachers beyond conventional pedagogical and content knowledge. Contemporary science educators must now develop AI literacy, which encompasses an understanding of AI concepts, the ability to critically evaluate AI -generated information, ethical awareness regarding AI applications, and the pedagogical skills

necessary to employ AI tools to enhance teaching and learning outcomes (Long & Magerko, 2020). These competencies have become increasingly important as students themselves gain access to AI-powered learning resources that influence how scientific knowled ge is acquired, interpreted, and applied.

Curriculum innovation has become an essential strategy for addressing these emerging educational demands. Curriculum innovation involves systematic redesign, modernization, and continuous improvement of educational programmes to ensure their relevance to societal, technological, and economic developments. Within science teacher education, curriculum innovation extends beyond simply introducing new technologies into existing courses. Rather, it requires the delib erate integration of AI literacy, digital pedagogy, ethical considerations, computational thinking, and practical experiences that enable future science teachers to confidently employ AI -enhanced instructional strategies. Such reforms are critical for developing teachers who can facilitate meaningful student engagement while maintaining scientific integrity, academic honesty, and responsible technology use.

Recent international policy frameworks have emphasized the urgency of integrating AI competencies into teacher education. UNESCO's recommendations on AI and education advocate for the responsible development of AI literacy among educators while emphasizing ethical governance, inclusiveness, and human-centred educational practices (UNESCO, 2023). Similarly, the Organisation for Economic Co -operation and Development (OECD) highlights the importance of preparing teachers to effectively navigate AI -supported learning environments through curriculum redesign and continuous professional development (OECD, 2024). These global initiatives underscore the necessity of equipping science teachers with both technical knowledge and pedagogical expertise required for effective AI integration.

The present study addresses this gap by examining curriculum innovation through the integration of AI literacy and AI-powered instructional tools into science teacher education and classroom practice. Specifically, the study investigates the extent to which AI literacy is incorporated into science teacher education curricula, examines teachers' preparedness to utilize AI technologies, identifies factors influencing successful classroom implementation, and explores strategies for strengthening curriculum reform to support future -ready science educators. By focusing simultaneously on curriculum development, teacher competence, and instructional practice, the study contributes to emerging scholarship on science education in the age of artificial intelligence. The significance of this study lies in its potential contributions to educational policy, curriculum development, teacher education, and science classroom practice. The findings are expected to provide evidence -based recommendations for curriculum developers, higher education institutions, teacher educators, policymakers, and professional development providers seeking to redesign science teacher education programmes in alignment with global AI competencies. Furthermore, the study contributes to the growing body of knowledge on AI integration in science education by identifying practical approaches for embedding AI literacy within teacher preparation programmes while promoting ethical, innovative, and student-centred science instruction.

The study was guided by the following research questions:

1. To what extent is AI literacy integrated into science teacher education curriculum?
2. What is the level of AI literacy among pre-service and in-service science teachers?
3. What factors influence the integration of AI tools into science classroom practice?
4. What curriculum innovations can enhance the effective integration of AI literacy?
5. AI tools into science teacher education and classroom practice?

2 Literature Review/Theoretical Framework

This study is anchored on the Technological Pedagogical Content Knowledge (TPACK) framework developed by Mishra and Koehler (2006). The TPACK framework provides a comprehensive theoretical lens for understanding the knowledge and competencies teachers require to effectively integrate technology into teaching and learning. Unlike traditional teacher education models that emphasize pedagogical and content knowledge independently, TPACK argues that effective technology integration occurs through the dynamic interaction of technological knowledge, pedagogical knowledge, and content knowledge. The framework consists of seven interrelated knowledge domains: Content Knowledge, Pedagogical Knowledge, Technological Knowledge, Pedagogical Content Knowledge (PCK), Technological Content Knowledge, Technological Pedagogical Knowledge, and Technological Pedagogical Content Knowledge. Within the context of science education, Content Knowledge refers to teachers' understanding of scientific concepts, theories, and principles. Pedagogical Knowledge encompasses instructional strategies, classroom management, as sessment techniques, and methods for facilitating meaningful learning experiences. Technological Knowledge involves teachers' competence in using digital

technologies, including AI -powered educational applications such as intelligent tutoring systems, virtual laboratories, adaptive learning platforms, data analytics software, and generative AI tools.

The emergence of artificial intelligence has expanded the technological dimension of the TPACK framework. Science teachers are now expected to develop AI literacy that extends beyond basic digital competence to include understanding AI concepts, evaluating AI-generated information, addressing ethical concerns, protecting data privacy, and designing AI-supported learning experiences. Consequently, AI literacy rep resents an essential component of Technological Knowledge while simultaneously influencing teachers' ability to integrate pedagogy and scientific content effectively. Curriculum innovation within science teacher education is directly connected to the TPACK framework because curriculum reforms should intentionally develop these interconnected competencies. Integrating AI literacy into teacher education programmes requires carefully designed learning experiences that enable future science teachers to combine scientific knowledge with AI -enhanced pedagogical approaches. Through this integration, science teachers become capable of designing inquiry -based learning activities, facilitating scientific investigations using AI -supported technologies, providing personalized instruction, and promoting students' critical evaluation of AI-generated scientific information.

Although TPACK remains one of the most influential frameworks for educational technology integration, scholars have observed that the original model was developed before the rapid emergence of artificial intelligence. Consequently, recent educational research has expanded the framework by incorporating AI literacy, ethical AI competencies, digital citizenship, and responsible AI use as essential components of teachers' technological knowledge (UNESCO, 2024). This study contributes to this evolving theoretical perspective by examining how curriculum innovation can strengthen AI literacy within science teacher education programmes and improve classroom practice.

2.1 Artificial Intelligence in Science Education

Artificial intelligence refers to computer systems capable of performing tasks that typically require human intelligence, including reasoning, learning, problem -solving, language understanding, pattern recognition, and decision -making (Russell & Norvig, 2021). Within education, AI encompasses a broad range of technologies designed to enhance teaching, learning, assessment, and educational administration. In science education, AI applications include intelligent tutoring systems, adaptive learning platforms, virtual science laboratories, automated assessment systems, predictive learning analytics, simulation software, robotics, augmented reality, and generative AI tools such as ChatGPT and Gemini. These technologies facilitate personalized learning by adapting instructional materials to students' learning needs, providing immediate feedback, supporting scientific inquiry, and enabling learners to explore complex scientific phenomena through simulations that may be difficult to conduct in traditional classrooms. The integration of AI into science education also supports the development of higher-order cognitive skills, including critical thinking, scientific reasoning, creativity, and collaborative problem-solving. AI -assisted instructional approaches encourage learners to formulate hypotheses, analyse experimental data, evaluate scientific evidence , and communicate scientific explanations more effectively. Nevertheless, educational researchers caution that AI implementation should complement rather than replace teachers' professional judgment, emphasizing the importance of ethical AI use, transparency, academic integrity, and human-centred instruction (Holmes et al., 2022).

2.2 AI Literacy

AI literacy refers to the knowledge, skills, attitudes, and ethical understanding required to effectively use, evaluate, and interact with artificial intelligence technologies (Long & Magerko, 2020). It extends beyond technical knowledge by enabling individuals to critically examine AI-generated information, recognize algorithmic biases, understand the capabilities and limitations of AI systems, and make informed decisions regarding their responsible use. For science teachers, AI literacy involves understanding fundamental AI concepts, selecting appropriate AI tools for instructional purposes, designing AI-enhanced learning experiences, evaluating AI -supported scie ntific information, ensuring responsible classroom implementation, and promoting ethical digital citizenship among students. As AI becomes increasingly integrated into educational systems, teacher education programmes must ensure that both pre-service and practicing teachers develop these competencies. Several international organizations, including UNESCO (2024), advocate embedding AI literacy into teacher education curricula to prepare educators for AI-enabled learning environments. Effective AI literacy p rogrammes should include technical competence, pedagogical application, ethical considerations, data privacy, algorithmic transparency, and continuous professional development.

2.3 Curriculum Innovation

Curriculum innovation refers to the systematic process of redesigning educational curricula to improve relevance, quality, responsiveness, and alignment with emerging societal, technological, and workforce demands (Ornstein & Hunkins, 2023). Curriculum innovation involves introducing new knowledge, competencies, instructional strategies, learning resources, and assessment approaches capable of enhancing educational outcomes. Within science teacher education, curriculum innovation requires integrating AI literacy, computational thinking, digital pedagogy, data science, educational technology, ethical AI, and interdisciplinary learning into existing programmes. Rather than simply adding technology-related courses, curriculum innovation emphasizes embedding AI competencies across pedagogical, methodological, and practical components of teacher preparation. Successful curriculum innovation depends upon institutional leadership, supportive educational policies, adequate technological infrastructure, curriculum flexibility, faculty competence, and continuous curriculum evaluation. Higher education institutions must also establish partnerships with technology experts, policymakers, and industry stakeholders to ensure curriculum relevance within rapidly evolving AI ecosystems.

2.4 Integration of AI Tools into Science Classroom Practice

The integration of AI tools into classroom practice refers to the purposeful use of AI technologies to improve teaching effectiveness, learning experiences, classroom assessment, and student engagement. AI -powered instructional tools assist science teachers in lesson planning, content generation, laboratory simulations, adaptive assessment, personalized learning, automated feedback, and scientific data analysis. Generative AI applications have significantly expanded instructional possibilities by supporting lesson preparation, generating laboratory scenarios, simplifying scientific explanations, developing assessment questions, and facilitating collaborative learning activities. Meanwhile, intelligent tutoring systems provide individualized learning pathways that accommodate diverse learner needs.

2.5 Empirical Review

Long and Magerko (2020) conceptualized AI literacy as a multidimensional educational competency involving technical knowledge, ethical reasoning, critical evaluation, and responsible AI use. Their work emphasized that AI literacy should become a core learning outcome within teacher education programmes. UNESCO (2023) examined the implications of generative AI for education and concluded that AI can significantly improve teach ing quality, personalized learning, and educational accessibility when accompanied by appropriate governance frameworks, teacher capacity building, and ethical implementation strategies. Chiu (2023) reviewed AI integration within educational settings and found that AI technologies positively influence learning outcomes, instructional innovation, and student engagement. However, successful implementation depended heavily upon teachers' technological competence and institutional readiness. Zawacki-Richter et al., (2019) conducted a systematic review of AI applications in higher education and reported that AI technologies were primarily employed for adaptive learning, intelligent tutoring, automated assessment, and institutional decision support. The review identified limited research focusing specifically on teacher education curriculum reform. Celik (2023) investigated AI competencies among pre -service teachers and found significant differences in AI readiness based on digital competence, prior technological experience, and access to professional development opportunities. The study recommended curriculum redesign to embed AI literacy throughout teacher education programmes. Holmes et al. (2022) observed that AI -supported instructional approaches improved inquiry-based learning, scientific reasoning, and learner engagement. Nevertheless, they argued that sustainable implementation requires comprehensive teacher preparation emphasizing pedagogical integration rather than technology adoption alone.

2.6 Literature Gap

The reviewed literature demonstrates that artificial intelligence has considerable potential to improve science teaching and learning through personalized instruction, intelligent assessment, adaptive learning, and enhanced scientific inquiry. Existing research also confirms the importance of AI literacy and teacher competence in facilitating successful AI integration. However, most previous studies have concentrated on technology adoption, student learning outcomes, or general educational technology withou t adequately examining curriculum innovation within science teacher education programmes.

3 Materials and Methods

3.1 Research Design

This study adopted a convergent parallel mixed -methods research design , which combines quantitative and qualitative approaches to provide a comprehensive understanding of curriculum innovation through the integration of artificial intelligence (AI) literacy and AI-powered tools into science teacher education and classroom practice. The mixed methods approach was considered appropriate because it enabled the collection of numerical data to determine the extent of AI literacy and curriculum integration while simultaneously exploring participants' experiences, perceptions, and recommendations regarding AI implementation in science education. Both quantitative and qualitative data were collected concurrently, analysed independently, and integrated during interpretation to produce complementary findings.

3.2 3.2 Study Area

The study was conducted at Sa'adatu Rimi College of Education, Kano, one among the leading teacher education institutions in Kano State, Nigeria. The College is situated in Kano Metropolitan Area and is recognized for its mandate of producing qualified teachers through the Nigeria Certificate in Education (NCE) and degree programmes offered in affiliation with accredited universities. Since its establishment, the institution has played a significant role in the development of teacher education by preparing competent educators capable of meeting the educational needs of both Kano State and Nigeria. Sa'adatu Rimi College of Education comprises several academic schools, including the School of Sciences, which offers programmes in Biology Education, Chemistry Education, Physics Education, Integrated Science Education, Mathematics Education, and Computer Science Education. These programmes are designed to equip pre -service science teachers with the pedagogical knowledge, scientific content knowledge, and practical teaching competencies required for effective classroom practice. In line with contemporary educational trends, the College has increasingly incorporated information and communication technologies (ICT) into teaching, learning, and teacher preparation, creating a conducive environment for the adoption of emerging technologies such as artificial intelligence (AI).

The College was selected as the study area because it represents a suitable setting for investigating curriculum innovation in science teacher education. As one of the major institutions responsible for training science teachers in Kano State, it provides access to pre-service science teachers, science teacher educators, and practising teachers undergoing professional development. These groups constitute an appropriate population for examining the integration of AI literacy and AI-powered instructional tools into science teacher education and classroom practice.

3.3 3.3 Population of the Study

The target population comprised all pre -service science teachers, in -service science teachers, and science teacher educators involved in science teacher education programmes within the selected institutions. These groups were considered appropriate because they are directly involved in curriculum implementation, teacher preparation, and classroom instruction where AI technologies are increasingly being introduced. The accessible population consisted of 845 participants, distributed as follows:

Category	**Population**
Pre-service science teachers	520
In-service science teachers	260
Science teacher educators	65
Total	**845**

3.4 3.4 Sample Size and Sampling Techniques

A total sample of 345 participants was selected for the study. The quantitative component consisted of 320 respondents, including pre-service and in-service science teachers, while the qualitative component involved 25 science teacher educators who participated in semi-structured interviews. For the quantitative strand, stratified random sampling was employed to ensure proportional representation of pre -service and in -service science teachers across the participating institutions. This technique minimized sampling bias while improving the representativeness of the sample. For the qualitative strand, purposive sampling was used to select science teacher educators based on their expertise in curriculum

development, educational technology, and science teacher preparation. These participants were expected to provide rich information regarding curriculum innovation and AI integration.

3.5 Research Instruments

Two complementary instruments were employed for data collection.

3.5.1 AI Literacy and Curriculum Innovation Questionnaire (AILCIQ)

The quantitative instrument was a structured questionnaire titled Artificial Intelligence Literacy and Curriculum Innovation Questionnaire (AILCIQ) . The questionnaire comprised five sections. Section A: Demographic characteristics; Section B: AI literacy competencies; Section C: Curriculum innovation practices; Section D: Classroom integration of AI tools; Section E: Institutional support and implementation challenges Items were measured using a five-point Likert scale ranging from: Strongly Agree (5); Agree (4); Undecided (3); Disagree (2); Strongly Disagree (1)

3.5.2 Semi-Structured Interview Guide

The qualitative instrument consisted of a semi-structured interview guide developed to explore participants' experiences regarding curriculum innovation, AI literacy development, institutional preparedness, ethical considerations, barriers to implementation, and recommendations for strengthening AI integration in science teacher education. The interview guide allowed flexibility for participants to elaborate on issues emerging during discussions while ensuring consistency across interviews.

3.6 Validity of the Instruments

Content and face validity of the instruments were established through expert review. Three specialists comprising one expert in Science Education, one Curriculum Studies expert, and one Educational Technology specialist examined the instruments for relevance, clarity, adequacy, and alignment with the study objectives. Their recommendations resulted in modifications to questionnaire wording, item sequencing, and interview questions before the final administration.

3.7 Reliability of the Instruments

A pilot study involving 35 science teachers outside the study area was conducted to determine the reliability of the questionnaire. Internal consistency was determined using Cronbach's Alpha , yielding the following coefficients:

Variable	Cronbach's α
AI Literacy	0.91
Curriculum Innovation	0.89
Classroom AI Integration	0.90
Institutional Support	0.87
Overall Reliability	0.90

The reliability coefficients exceeded the recommended threshold of 0.70, indicating that the instrument possessed satisfactory internal consistency for the study.

3.8 Data Collection Procedure

Approval to conduct the study was obtained from the participating institutions before data collection commenced. Participants were informed about the purpose of the study, voluntary participation, confidentiality, anonymity, and their right to withdraw at any stage without penalty. Questionnaires were administered physically and electronically using secure online survey platforms to maximize participation. Completed questionnaires were retrieved immediately after completion or electronically within two weeks. Semi-structured interviews with science teacher educators were conducted either face -to-face or through secure virtual meeting platforms. Each interview lasted between 35 and 50 minutes and was audio-recorded with participants' consent. Interview recordings were later transcribed verbatim for analysis.

3.9 Data Analysis

Quantitative data were analysed using the Statistical Package for the Social Sciences (SPSS) Version 29. The level of statistical significance was set at 0.05. Interview transcripts were analysed using thematic analysis following Braun and Clarke's (2006) six-step framework:

1. Familiarisation with the data
2. Initial coding
3. Theme development
4. Theme review
5. Theme definition and naming
6. Report writing

The analysis focused on identifying recurring themes relating to AI literacy, curriculum innovation, institutional readiness, classroom implementation, ethical concerns, and professional development.

3.10 Integration of Quantitative and Qualitative Data

The study adopted a convergent integration strategy, whereby quantitative and qualitative findings were analysed separately before being merged during interpretation. Quantitative findings established the extent and predictors of AI literacy and curriculum innovation, whereas qualitative findings provided deeper explanations of participants' experiences and perceptions. Areas of convergence, complementarity, and divergence between the two datasets were identified to produce a comprehensive understanding of AI integration within science teacher education. This integration enhanced the credibility, validity, and richness of the findings while providing stronger evidence for recommendations regarding curriculum innovation and AI -supported science teaching.

4 Results

The findings are presented according to the four research questions that guided the study. Descriptive statistics were used to answer Research Questions One and Two, while inferential statistics were employed to answer Research Question Three. The qualitative findings addressing Research Question Four are presented thematically. Tables are presented in accordance with APA 7th edition guidelines.

Research Question One

To what extent is AI literacy integrated into science teacher education curricula at Sa'adatu Rimi College of Education, Kano?

Table **4.1**

Extent of AI Literacy Integration into Science Teacher Education Curriculum

S/N	Statement	Mean	SD	Decision
1	AI concepts are incorporated into science education courses.	3.68	0.82	High
2	The curriculum includes practical training on AI tools.	3.44	0.91	Moderate
3	Students are exposed to AI-assisted instructional technologies.	3.71	0.76	High
4	Ethical use of AI is emphasized during teacher preparation.	3.36	0.88	Moderate
5	AI literacy is integrated across science education courses.	3.59	0.79	High
	Grand Mean	3.56	0.83	High

The results in Table 4.1 indicate that AI literacy is integrated into the science teacher education

curriculum to a high extent (Grand Mean = 3.56, SD = 0.83).

Research Question Two

What is the level of AI literacy among pre-service and in-service science teachers?

Table 4.2

Level of AI Literacy among Science Teachers

S/N	AI Literacy Competency	Mean	SD	Level
1	Understanding of AI concepts	3.82	0.73	High
2	Ability to use AI tools in lesson planning	3.61	0.81	High
3	Ability to evaluate AI-generated information	3.54	0.86	High
4	Awareness of ethical AI practices	3.70	0.79	High
5	Confidence in integrating AI into science teaching	3.48	0.92	Moderate
	Grand Mean	3.63	0.82	High

The findings presented in Table 4.2 show that respondents demonstrated a high level of AI literacy (Grand Mean = 3.63, SD = 0.82).

Research Question Three

What factors influence the integration of AI tools into science classroom practice?

A multiple regression analysis was conducted to determine whether AI literacy, institutional support, and professional development significantly predicted the integration of AI tools into science classroom practice.

Table 4.3

Multiple Regression Analysis Predicting AI Integration

Predictor	B	SE	β	t	p
Constant	0.612	0.231	—	2.65	.009
AI Literacy	0.584	0.061	.63	9.58	< .001
Institutional Support	0.273	0.058	.29	4.71	< .001
Professional Development	0.184	0.054	.21	3.41	.001

Model Summary: $R = .781$, $R^2 = .610$, Adjusted $R^2 = .604$, $F(3, 316) = 164.78$, $p < .001$

The regression model accounted for 61.0% of the variance in AI integration into science classroom practice ($R^2 = .610$). AI literacy emerged as the strongest predictor ($\beta = .63$, $p < .001$), followed by institutional support ($\beta = .29$, $p < .001$) and professional development ($\beta = .21$, $p = .001$).

Research Question Four

What curriculum innovations can enhance the effective integration of AI literacy and AI tools into science teacher education and classroom practice?

Semi-structured interviews were conducted with 25 science teacher educators. Thematic analysis generated four major themes.

Theme 1: Curriculum Redesign

Most participants emphasized the need for comprehensive curriculum reform that integrates AI literacy throughout science teacher education rather than limiting AI to standalone technology courses. Representative responses included: "AI should become part of every science education course rather than being taught separately." "Curriculum review sh ould include AI competencies alongside scientific inquiry and digital pedagogy."

Theme 2: Continuous Professional Development

Participants consistently highlighted continuous professional development as essential for equipping science teachers with practical AI competencies. Typical responses included:

"Many teachers require regular workshops to remain updated on emerging AI technologies."

"Professional training should focus on practical classroom applications rather than theory alone."

Theme 3: Institutional Support and Infrastructure

Respondents identified institutional support as a major determinant of successful AI integration. Common issues reported included: inadequate internet connectivity; insufficient AI-enabled teaching facilities; limited access to educational software; inadequate funding for technology-based instruction. Participants recommended increased institutional investment in digital infrastructure and technical support services.

Theme 4: Ethical and Responsible AI Integration

Participants emphasized the importance of preparing teachers to address ethical issues associated with AI implementation. Major concerns included: academic integrity; data privacy; algorithmic bias; responsible use of generative AI; appropriate teacher supervision of AI-assisted learning. Respondents stressed that ethical AI literacy should become a compulsory component of science teacher education curricula.

Integration of Quantitative and Qualitative Findings

The mixed-methods findings demonstrated substantial convergence between the quantitative and qualitative results. Quantitative analyses showed that AI literacy, institutional support, and professional development significantly influenced AI integration into science classroom practice. Similarly, qualitative findings identified curriculum redesign, continuous teacher training, institutional readiness, and ethical AI education as the principal strategies for improving curriculum innovation. Both strands of evidence indicate that successful integration of AI into science teacher education requires a comprehensive curriculum that embeds AI literacy, sustained professional development for science teachers, adequate technological infrastructure, and institutional policies promoting responsible and ethical AI use in teaching and learning.

5 Discussion

The findings of this study provide empirical evidence on the integration of artificial intelligence (AI) literacy and AI-powered tools into science teacher education and classroom practice at Sa'adatu Rimi College of Education, Kano. The discussion is organized according to the four research questions and interpreted within the framework of the Technological Pedagogical Content Knowledge (TPACK) theory and existing literature on AI in science education. The first research question examined the extent to which AI literacy is integrated into the science teacher education curriculum. The findings revealed that AI literacy is integrated to a relatively high extent, although some aspects, particularly practical AI training and ethical AI instruction, remain only moderately represented. This suggests that while curriculum developers have begun incorporating AI-related competencies into teacher education, comprehensive curriculum innovation is still evolving. These findings support UNESCO's (2024) assertion that teacher education institutions are increasingly recognizing AI literacy as an essential competency for future educators. Likewise, Holmes et al. (2022) argued that integrating AI into teacher education curricula is necessary to prepare teachers for technology- enhanced instructional environments.

However, the moderate ratings for practical AI training indicate that curriculum implementation has not yet fully matched policy aspirations, emphasizing the need for stronger practical components within science teacher education programmes. The second research question investigated the level of AI literacy among pre-service and in- service science teachers. The results indicated that respondents possessed a generally high level of AI literacy, particularly regarding their understanding of AI concepts, ethical awareness, and ability to use AI tools for lesson planning. However, confidence in integrating AI into actual classroom practice was comparatively lower. This finding suggests that knowledge of AI does not automatically translate into pedagogical competence. The result aligns with Long and Magerko (2020), who conceptualized AI literacy as a multidimensional construct encompassing technical knowledge, critical thinking, ethical awareness, and practical application. Similarly, Celik (2023) reported that teachers with higher digital competence exhibited greater readiness to adopt AI technologies but still required continuous professional development to strengthen classroom implementation skills.

The findings further reinforce the assumptions of the TPACK framework, which posits that effective technology integration depends on the interaction between technological knowledge, pedagogical knowledge, and content knowledge rather than technological competence alone. The third research question examined the factors influencing the integration of AI tools into science classroom practice. Multiple regression analysis demonstrated that AI literacy, institutional support, and professional development significantly predicted the successful integration of AI technologies, with AI literacy emerging as the strongest predictor. This finding underscores the central role of teacher competence in educational technology adoption. Teachers who possess higher levels of AI literacy are more likely to design innovative lessons, utilize AI-powered instructional resources, and promote meaningful student engagement. These findings corroborate those of Chiu (2023), who found that teachers' technological competence significantly influences AI adoption in educational settings. Similarly,

Zawacki - Richter et al. (2019) concluded that institutional readiness and teacher competence are among the strongest determinants of successful AI implementation in higher education. The results also validate the TPACK framework by demonstrating that technology integration depends not only on individual competence but also on supportive institutional environments that facilitate innovation.

The qualitative findings addressing the fourth research question identified curriculum redesign, continuous professional development, institutional support, and ethical AI integration as the major strategies required for strengthening AI integration within science teacher education. Participants consistently emphasized that AI literacy should not be taught as an isolated subject but should instead be embedded throughout science education courses. This recommendation reflects contemporary international policy directions advocating curriculum -wide integration of AI competencies. UNESCO (2023) similarly recommends that AI literacy should become an integral component of teacher education rather than being confined to standalone technology courses. The emphasis on ethical AI education also corresponds with growing concerns regarding algorithmic bias, data privacy, academic integrity, and responsible use of generative AI within educational environments. The integration of the quantitative and qualitative findings provides a comprehensive understanding of curriculum innovation in science teacher education. Quantitative evidence demonstrated that AI literacy and institutional support significantly predict AI integration, while qualitative evidence explained how curriculum redesign, teacher training, and ethical guidance facilitate successful implementation. The convergence of findings strengthens the validity of the study by demonstrating consistency across different sources of evidence. The results therefore suggest that sustainable AI integration requires coordinated efforts involving curriculum reform, institutional investment, professional teacher development, and educational policy support. From a theoretical perspective, this study extends the application of the TPACK framework by incorporating AI literacy as a contemporary dimension of technological knowledge within science teacher education. The findings demonstrate that AI literacy interacts with pedagogical and scientific content knowledge to enhance teachers' readiness for AI-supported instruction.

Consequently, the study contributes to emerging scholarship that seeks to adapt existing educational technology theories to the rapidly evolving field of artificial intelligence. Practically, the findings have important implications for curriculum developers, teacher educators, institutional administrators, and educational policymakers. Curriculum developers should systematically integrate AI literacy, ethical AI principles, computational thinking, and AI-assisted pedagogical strategies throughout science teacher education programmes. Teacher education institutions should establish regular professional development programmes that equip educators with practical AI competencies while simultaneously investing in technological infrastructure capable of supporting AI-enhanced teaching and learning. Policymakers should formulate national standards for AI literacy within teacher education to ensure consistency across institutions and facilitate the preparation of future-ready science teachers. Therefore, these important contributions, the study has certain limitations. First, the research was conducted in Sa'adatu Rimi College of Education, Kano , thereby limiting the generalizability of the findings to other teacher education institutions with different institutional contexts and technological capacities. Second, the study relied primarily on self - reported questionnaire responses, which may be influenced by social desirability bias or respondents' subjective perceptions of their AI competencies. Third, the cross-sectional nature of the study restricted the examination of changes in AI literacy and curriculum implementation over time. These limitations should be considered when interpreting the findings.

6 Conclusion

The findings revealed that AI literacy has been incorporated into the science teacher education curriculum to a relatively high extent, although practical AI training and ethical AI instruction require further strengthening. The study also established that science teachers possess a generally high level of AI literacy; however, translating this knowledge into effective classroom practice remains dependent on additional pedagogical support and professional development. Furthermore, AI literacy, institutional support, and continuous professional development were identified as significant predictors of successful AI integration into science teaching. The qualitative findings complemented these results by demonstrating that curriculum redesign, sustained teacher training, improved technological infrastructure, and ethical AI education are fundamental requirements for effective curriculum innovation in science teacher education. The study achieved its objectives by providing empirical evidence on the current state of AI literacy integration within science teacher education and identifying the institutional and pedagogical conditions necessary for successful AI-supported classroom practice. The findings contribute to the growing body of knowledge on science education research in the age of artificial intelligence by extending the application of the TPACK framework to include AI literacy as a critical component of teacher competence. The study also provides practical insights for curriculum developers, teacher educators, institutional

administrators, and policymakers seeking to modernize teacher education programmes in response to rapid technological advancements. Based on the findings, the study recommends that teacher education institutions systematically integrate AI literacy, AI ethics, and AI-supported pedagogical strategies into science education curricula. Educational authorities should provide sustained funding for digital infrastructure, organize regular AI-focused professional development programmes for science educators, and develop national standards that guide AI integration within teacher education. Collaboration among higher education institutions, government agencies, technology providers, and professional bodies should also be strengthened to support sustainable curriculum innovation.

7 Declarations

Ethical Statements: This study was conducted in accordance with internationally accepted ethical principles governing educational research involving human participants. Ethical approval was obtained from the Research Ethics Committee of Sa'adatu Rimi College of Education, Kano, Nigeria, prior to the commencement of data collection. The study received ethical clearance from the Research Ethics Committee, Sa'adatu Rimi College of Education, Kano.

Conflict of Interest: The authors declare neither financial nor non-financial conflict of interest. The research was conducted independently without any commercial, financial, institutional, or personal relationships that could be perceived as influencing the design, data collection, analysis, interpretation of findings, or reporting of the study. The authors further affirm that there are no competing interests that could have affected the objectivity or integrity of this research.

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