

Artificial Intelligence-Driven Digital Transformation of STEM Education: A Conceptual Framework for Integrating Physics, Chemistry and Mathematics Education in Nigeria

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Abstract

The rapid development of Artificial Intelligence (AI) and digital technologies is transforming educational practices and creating new possibilities for Science, Technology, Engineering and Mathematics (STEM) education. This paper examines the potential of AI-driven digital transformation for integrating Physics, Chemistry and Mathematics education in Nigeria. A conceptual position-paper approach was adopted, drawing on relevant empirical and conceptual studies on AI applications in STEM education, with particular emphasis on Physics, Chemistry and Mathematics. The paper is theoretically anchored on Technological Pedagogical Content Knowledge (TPACK), Constructivist Learning Theory and Connectivism. The reviewed literature indicates that AI and digital technologies can support personalized learning, intelligent tutoring, digital simulation, virtual experimentation, mathematical modelling, automated feedback, scientific inquiry and interdisciplinary problem-solving. Evidence from Nigerian and African studies further indicates that AI adoption is increasing, although its educational application remains constrained by inadequate infrastructure, limited teacher competence, unequal access to technology, ethical concerns, academic integrity and the reliability of AI-generated information. The paper argues that AI should not replace teachers or conventional practical experiences but should complement them through purposeful pedagogical integration. Accordingly, a conceptual framework is proposed that connects AI and digital technologies with AI-enhanced pedagogy, the integration of Physics, Chemistry and Mathematics, interdisciplinary STEM learning, STEM competencies, innovation and sustainable development. The paper concludes that a human-centered, interdisciplinary and context-sensitive approach to AI integration can strengthen STEM education and better prepare Nigerian learners for the demands of the digital economy.

Keywords: Artificial Intelligence; Digital Transformation; STEM Education; Interdisciplinary Learning; Nigeria.

Introduction

Science, Technology, Engineering and Mathematics (STEM) education occupies a central position in national development because it provides the knowledge, skills and competencies required for scientific advancement, technological innovation and economic transformation. Contemporary societies increasingly require individuals who can apply scientific knowledge, mathematical reasoning, digital technologies and problem-solving skills to complex social and economic challenges. Consequently, STEM education is no longer expected to focus exclusively on the acquisition of disciplinary knowledge but also on the development of creativity, critical thinking, computational thinking, collaboration and innovation. The increasing influence of the Fourth Industrial Revolution has further intensified this expectation by introducing technologies such as Artificial Intelligence (AI), machine learning, robotics, cloud computing, big data and immersive digital environments into educational and professional contexts.

Artificial Intelligence has attracted particular attention because of its capacity to process large amounts of information, generate content, provide feedback, personalize learning and support decision-making. Zawacki-Richter et al. (2019), in a systematic review of AI applications in higher education, identified applications involving profiling and prediction, assessment and evaluation, adaptive systems and personalization, and intelligent tutoring systems. Although their review predates the widespread emergence of generative AI, it established an important foundation for understanding the educational potential of AI. More recently, Kasneci et al. (2023) noted that large language models can provide opportunities for personalized learning, feedback, content generation and educational interaction, while simultaneously creating challenges relating to accuracy, bias, academic integrity and overreliance on AI. These developments suggest that AI has moved beyond being simply an emerging technological tool to becoming a significant component of contemporary educational transformation.

The implications are particularly important for STEM education because STEM learning involves abstract concepts, complex relationships, quantitative reasoning, and experimentation, modelling and problem-solving. Within STEM education, Physics, Chemistry and Mathematics occupy interconnected positions because they share concepts, methods and applications that support scientific inquiry and technological innovation. Mathematics provides the quantitative language used to represent and analyze physical and chemical phenomena; Physics explains fundamental principles underlying energy, matter and technological systems; while Chemistry provides knowledge of substances, molecular interactions and materials that contribute to technological and industrial applications. Despite these relationships,

the three disciplines are often taught independently, limiting opportunities for learners to recognize and apply their interdependence.

AI and digital technologies provide opportunities for overcoming some of these limitations. Digital simulations can enable learners to visualize physical and chemical processes that may be difficult to observe directly. AI-supported mathematical platforms can provide feedback and adaptive practice, while computational tools can facilitate modelling and data analysis. These technologies can also support interdisciplinary projects in which students apply knowledge from Physics, Chemistry and Mathematics to authentic problems such as renewable energy, environmental pollution, climate change, energy storage and technological innovation.

However, the availability of AI does not automatically produce meaningful educational transformation. Its effectiveness depends on teacher competence, curriculum design, infrastructure, institutional support and responsible use. Falebita and Kok (2024), in a systematic review of AI integration among STEM academics and undergraduates in African higher education, reported that AI was increasingly being used for learning, teaching, content generation and research, but also observed that the evidence base for African higher education remained relatively limited. In Nigeria, Okoye and Mante (2024) similarly identified considerable opportunities for AI-driven STEM transformation while drawing attention to resource and expertise-related challenges. These findings suggest that Nigeria requires a context-sensitive approach to AI adoption rather than simply transferring models developed in technologically advanced educational systems.

The emergence of generative AI also makes the issue more urgent. Students can now obtain explanations, mathematical solutions, scientific descriptions and laboratory-related information from AI systems within seconds. While this can expand learning opportunities, it can also encourage passive learning if students merely accept AI-generated answers without verification. In Physics, for example, AI systems may generate scientifically plausible but incorrect explanations or calculations. In Mathematics, students may obtain correct answers without developing the reasoning processes required to arrive at those answers. In Chemistry, AI-generated descriptions may simplify complex processes in ways that create misconceptions. Consequently, AI literacy, critical evaluation and teacher guidance must form part of any meaningful digital transformation strategy.

The challenge for Nigerian STEM education, therefore, is not simply whether AI should be introduced into classrooms. Rather, the central issue is how AI and digital technologies can be integrated with

sound pedagogy and disciplinary knowledge to strengthen learning across Physics, Chemistry and Mathematics. This paper addresses this issue by reviewing relevant literature, examining the theoretical foundations of AI-supported STEM education and proposing a conceptual framework for integrating the three disciplines through AI-driven digital transformation.

Conceptual Clarification

Artificial Intelligence

Artificial Intelligence refers broadly to computational systems capable of performing tasks that ordinarily require aspects of human intelligence, including learning, reasoning, prediction, language processing, pattern recognition and decision-making. In education, AI includes intelligent tutoring systems, adaptive learning platforms, automated assessment, learning analytics, recommendation systems and generative AI.

Zawacki-Richter et al. (2019) demonstrated that AI applications in education extend beyond automated tasks to include adaptive learning and personalised educational support. The emergence of generative AI has further expanded these possibilities by enabling systems to generate text, explanations, questions, examples and other forms of educational content. Kasneci et al. (2023) argue that such systems can support learning but require careful management because of concerns relating to misinformation, bias and academic integrity.

For the purpose of this paper, AI is understood as a technological capability that can support teaching, learning, assessment, simulation, modelling, feedback and problem-solving in STEM education.

Digital Technologies

Digital technologies refer to electronic technologies that create, store, process, communicate and analyse information. They include computers, mobile devices, internet-based platforms, digital simulations, virtual laboratories, learning management systems, data analytics tools and AI-enabled applications.

Digital technologies provide the infrastructure through which AI can be incorporated into educational activities. Thus, AI-driven transformation should not be understood independently of the broader digital ecosystem required to support its operation.

Digital Transformation

Digital transformation goes beyond the introduction of electronic devices into classrooms. It involves fundamental changes in educational processes, practices and structures through the strategic use of digital technologies. In STEM education, digital transformation may involve changes in curriculum delivery, assessment, learning environments, teacher roles, student engagement and institutional processes.

The distinction is important because merely providing computers or internet connectivity does not constitute digital transformation. Transformation occurs when technology changes how teaching and learning are designed and experienced.

STEM Education

STEM education integrates knowledge and practices associated with Science, Technology, Engineering and Mathematics to develop learners' capacity to understand and solve real-world problems. Rather than treating the four fields as completely independent, STEM education encourages learners to apply knowledge across disciplinary boundaries.

In this paper, Physics, Chemistry and Mathematics are regarded as interconnected components of the science and mathematics dimensions of STEM. Their integration provides a foundation for addressing complex problems that require scientific understanding, quantitative analysis and technological application.

Interdisciplinary STEM Learning

Interdisciplinary STEM learning involves deliberately connecting concepts and methods from different STEM disciplines around meaningful problems. It differs from simply teaching several subjects within the same programme because learners are expected to transfer knowledge between disciplines.

AI can facilitate this process by providing digital environments for modelling, simulation, data analysis and collaborative problem-solving. Consequently, interdisciplinary STEM learning represents an important pathway through which AI can move STEM education beyond isolated subject teaching.

Theoretical Framework

Technological Pedagogical Content Knowledge

The primary theoretical foundation of this paper is the Technological Pedagogical Content Knowledge (TPACK) framework developed by Mishra and Koehler (2006) from Shulman's (1986) concept of Pedagogical Content Knowledge. TPACK proposes that effective technology integration requires teachers to possess interacting forms of technological, pedagogical and content knowledge.

The framework is particularly relevant to AI-driven STEM education because effective AI integration requires more than technological knowledge. A Physics teacher must understand the Physics concept being taught, select an appropriate pedagogical approach and determine whether an AI-enabled simulation will enhance understanding. Similarly, a Chemistry teacher may need to determine whether AI-supported molecular modelling is appropriate for explaining chemical bonding, while a Mathematics teacher may need to determine whether an AI platform promotes mathematical reasoning or merely provides answers.

TPACK therefore supports the argument that teachers should remain central to AI integration. Technology should serve pedagogical and disciplinary objectives rather than determine them.

Constructivist Learning Theory

Constructivist Learning Theory provides the learner-centered foundation for the proposed framework. Constructivism views learners as active participants in the construction of knowledge through interaction with their environment, prior knowledge, experience and other learners (Piaget, 1972; Vygotsky, 1978).

AI-supported STEM environments can facilitate constructivist learning by allowing students to explore simulations, manipulate variables, investigate problems, generate explanations and receive feedback. For example, learners can use simulations to investigate motion in Physics, molecular structures in Chemistry or mathematical functions through dynamic representations.

Vygotsky's (1978) concept of the Zone of Proximal Development is particularly relevant because AI systems can provide scaffolding through hints, examples and explanations. Nevertheless, such scaffolding should complement teacher and peer interaction rather than replace them.

Connectivism

Connectivism, associated with Siemens (2005), conceptualizes learning as the formation and navigation of connections among information sources, people and digital networks. The theory is particularly relevant to AI-supported education because contemporary learners obtain knowledge from digital libraries, online platforms, simulations, learning management systems and AI applications.

Connectivism also provides a theoretical basis for interdisciplinary learning. A learner investigating renewable energy may connect Physics concepts of energy conversion with Chemistry concepts of batteries and Mathematics concepts of modelling and optimization. AI can facilitate these connections by helping learners locate, organize and analyze information from multiple sources.

However, because digital networks contain both accurate and inaccurate information, learners require critical evaluation skills. Connectivist learning in an AI environment must therefore emphasize verification, comparison and responsible use of information.

Relevance of the Theories

The three theories complement one another. TPACK explains the teacher's capacity to integrate AI appropriately; Constructivism explains how learners can actively construct knowledge through AI-supported experiences; and Connectivism explains how learners can connect information, technologies and disciplinary knowledge across digital networks. Together, these theories provide a suitable foundation for the proposed AI-driven interdisciplinary STEM framework.

Review of Related Literature

AI and STEM Education

Research indicates that AI is increasingly influencing STEM education through adaptive learning, intelligent tutoring, automated feedback, content generation, data analysis and personalised instruction. Zawacki-Richter et al. (2019) established the broad range of AI applications in education, while Kasneci et al. (2023) highlighted the expanded possibilities created by generative AI. However, both the opportunities and risks of AI need to be considered because technological capability does not guarantee educational effectiveness.

African evidence is particularly relevant. Falebita and Kok (2024) reviewed AI integration among STEM academics and undergraduates in African higher education and found applications across learning, teaching, content generation and research. Their review also indicates that African scholarship

in this area remains relatively limited. This reinforces the need for more context-specific conceptual and empirical research.

In Nigeria, Okoye and Mante (2024) reviewed studies concerning AI and STEM education transformation and identified opportunities for improving STEM learning alongside challenges involving resources and expertise. The findings suggest that AI has potential in Nigeria, but effective implementation requires attention to the conditions within which teaching and learning occur.

Artificial Intelligence and Physics Education

Physics education is particularly suited to digital technologies because many physical phenomena are abstract, dynamic or difficult to reproduce in conventional classrooms. Digital simulations can enable students to manipulate variables and observe relationships among physical quantities, while AI-supported systems can provide explanations, feedback and problem-solving assistance.

Yeadon and Hardy (2024) examined the performance of generative AI across Physics examinations and found considerable variation in its ability to solve Physics problems at different educational levels. Their findings demonstrate both the potential and limitations of AI in Physics education. AI may provide useful assistance with explanations and problem-solving, but its outputs cannot automatically be regarded as scientifically correct.

The implication for Physics education is that AI should be integrated with inquiry, experimentation and verification. Students should be encouraged to compare AI-generated explanations with physical laws, experimental evidence and established scientific knowledge. Virtual simulations may also supplement laboratory activities, particularly where equipment is limited, but should not eliminate practical experimentation.

Artificial Intelligence and Chemistry Education

AI and machine learning are increasingly being explored in Chemistry education. Iyamuremye et al. (2024), in a critical review of 62 studies, reported growing applications of AI and machine learning in Chemistry education, including personalized learning, teacher support and improved access to educational resources. At the same time, they identified challenges relating to bias, privacy, security and dependence on available data, emphasizing the importance of teacher preparation, research and appropriate policy.

The potential relevance of AI is particularly strong in Chemistry because students frequently struggle to connect macroscopic observations, symbolic representations and microscopic or molecular explanations. Digital molecular visualization, simulation and virtual laboratory environments can provide additional representations of concepts that may otherwise be difficult to understand. AI can further support these environments by providing explanations and personalized feedback.

However, Chemistry education requires practical competencies that cannot be developed entirely through digital environments. Students must acquire skills in handling apparatus, measuring substances, observing reactions and following laboratory safety procedures. AI-supported Chemistry education should therefore adopt a blended approach that combines digital resources with authentic laboratory experiences.

Artificial Intelligence and Mathematics Education

Mathematics is central to STEM because it provides the quantitative tools required for scientific modelling, measurement, analysis and prediction. AI has introduced opportunities for adaptive learning, automated feedback, intelligent tutoring and mathematical problem-solving.

Independent Nigerian research provides emerging empirical evidence. Ogoke et al. (2025) investigated AI-integrated Mathematics instruction among secondary school students in Owerri, Imo State, using a randomized controlled approach to examine achievement and retention. Such empirical research is important because it moves the discussion beyond claims about the potential of AI and provides evidence concerning its instructional application.

Fawehinmi et al. (2025) also examined the potential of AI for Mathematics learning in Nigeria and emphasized its capacity to address skills gaps while identifying teacher preparedness and curriculum integration as important considerations. Menkiti and Nwodika (2025) further examined undergraduate science education students' perceptions of AI in Mathematics teaching and learning, reinforcing the importance of AI literacy.

These findings suggest that AI-supported Mathematics education should not be reduced to answer generation. Students should be required to explain procedures, justify solutions, identify errors and verify AI-generated responses. Such an approach can preserve mathematical reasoning while benefiting from the efficiency and feedback capabilities of AI.

Interdisciplinary Integration of Physics, Chemistry and Mathematics

Although the three disciplines are closely related, conventional education frequently presents them as separate subjects. Such separation can limit students' ability to transfer knowledge across disciplinary boundaries. Interdisciplinary STEM learning provides an alternative by organizing learning around authentic problems requiring knowledge from several disciplines.

AI and digital technologies can facilitate this integration through simulation, modelling, data analysis and collaborative learning environments. For example, renewable-energy projects can require Physics knowledge of energy and electricity, Chemistry knowledge of batteries and materials, and Mathematics knowledge of statistical analysis and optimization.

The proposed approach therefore differs from simply using AI independently in Physics, Chemistry and Mathematics. It positions AI as a connecting mechanism that enables students to use knowledge from the three disciplines in solving complex problems.

Teacher Competence and AI Adoption

Teacher competence is a critical determinant of successful AI integration. Mishra and Koehler's (2006) TPACK framework demonstrates that effective technology integration requires the interaction of technological, pedagogical and content knowledge. Consequently, teachers need more than basic digital literacy; they must understand how particular AI tools relate to curriculum objectives, disciplinary concepts and appropriate instructional strategies.

Nigerian evidence reinforces this position. Fawehinmi et al. (2025) identified teacher preparedness as an important consideration in AI-supported Mathematics learning, while research on AI and teacher competence in Nigeria has identified digital literacy and infrastructure as important implementation challenges. These findings suggest that professional development should move beyond general awareness of AI to practical competence in selecting, evaluating and integrating AI tools.

Teachers also need to understand the limitations of AI. Because AI-generated content may contain factual errors or misleading explanations, teachers must be able to verify information before using it in instruction. Professional development should therefore incorporate AI literacy, ethical use, assessment redesign, data privacy and strategies for maintaining academic integrity.

Challenges of AI Integration in Nigerian Education

Despite the potential benefits of AI, its implementation in Nigerian education faces significant challenges. Okoye and Mante (2024) identified resource and expertise-related issues as important barriers to STEM transformation. Falebita and Kok (2024) similarly showed that AI integration in African higher education remains an emerging area with limited evidence.

Infrastructure represents a major concern because AI-supported learning requires reliable electricity, internet connectivity, suitable digital devices and access to appropriate software. Unequal access may also widen existing educational inequalities if students from disadvantaged backgrounds cannot benefit from AI-enabled learning environments. Teacher preparedness is another challenge because ineffective use of AI may result in superficial technology adoption rather than meaningful pedagogical transformation.

Ethical issues are equally important. AI-generated information may contain inaccuracies, students may use AI in ways that undermine academic integrity, and digital systems may raise concerns about privacy and data security. These challenges indicate that AI adoption must be accompanied by institutional policies, teacher development, student AI literacy and mechanisms for verifying AI-generated information.

Gap in the Literature

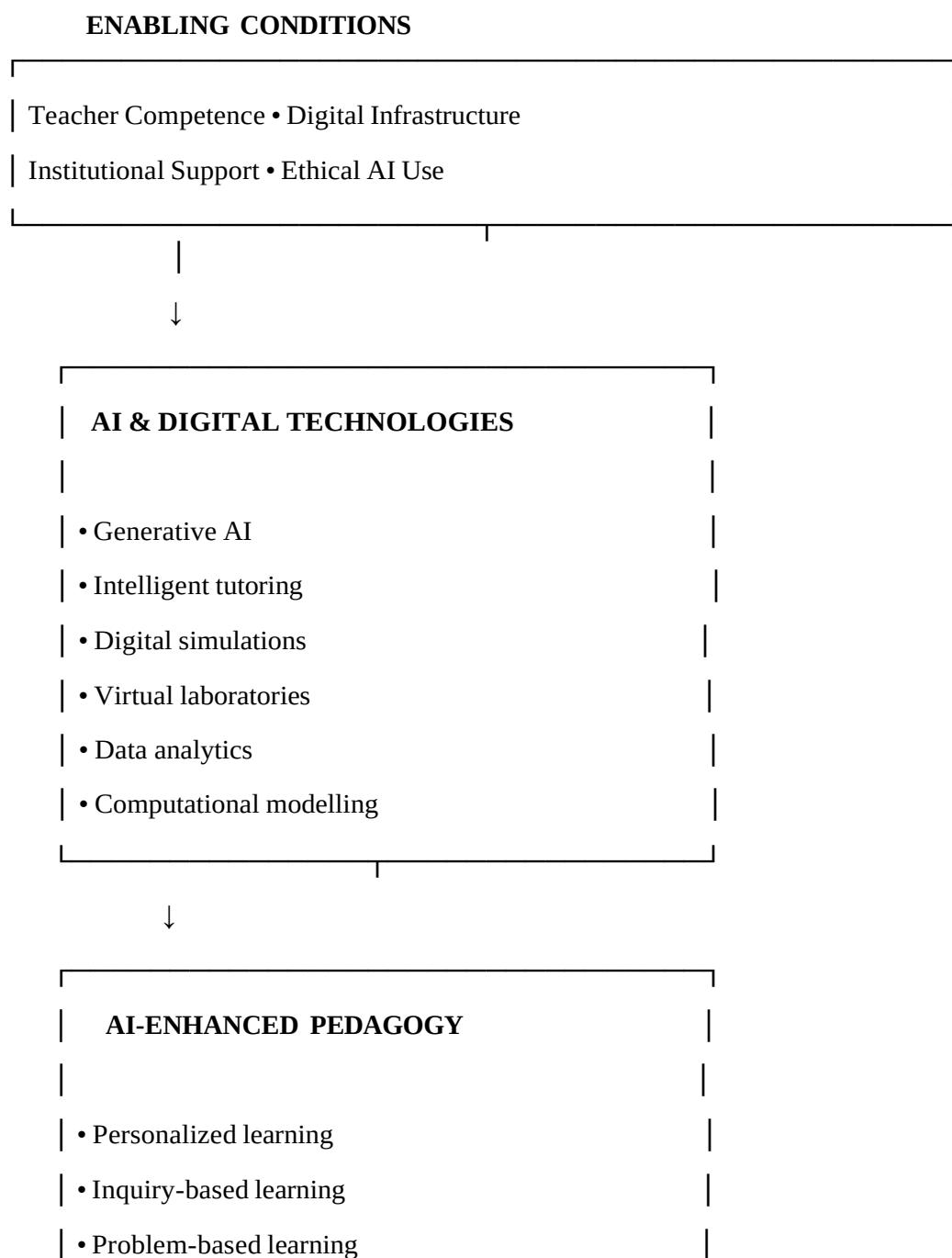
The reviewed literature establishes growing interest in AI across STEM education, including emerging evidence from Nigeria and Africa. However, three major gaps remain. First, much of the literature examines AI within individual disciplines, particularly Mathematics and Chemistry, rather than conceptualizing Physics, Chemistry and Mathematics as an integrated STEM learning system. Second, African and Nigerian evidence remains comparatively limited. Third, relatively little attention has been given to conceptualizing how AI can connect these disciplines to the development of interdisciplinary STEM competencies.

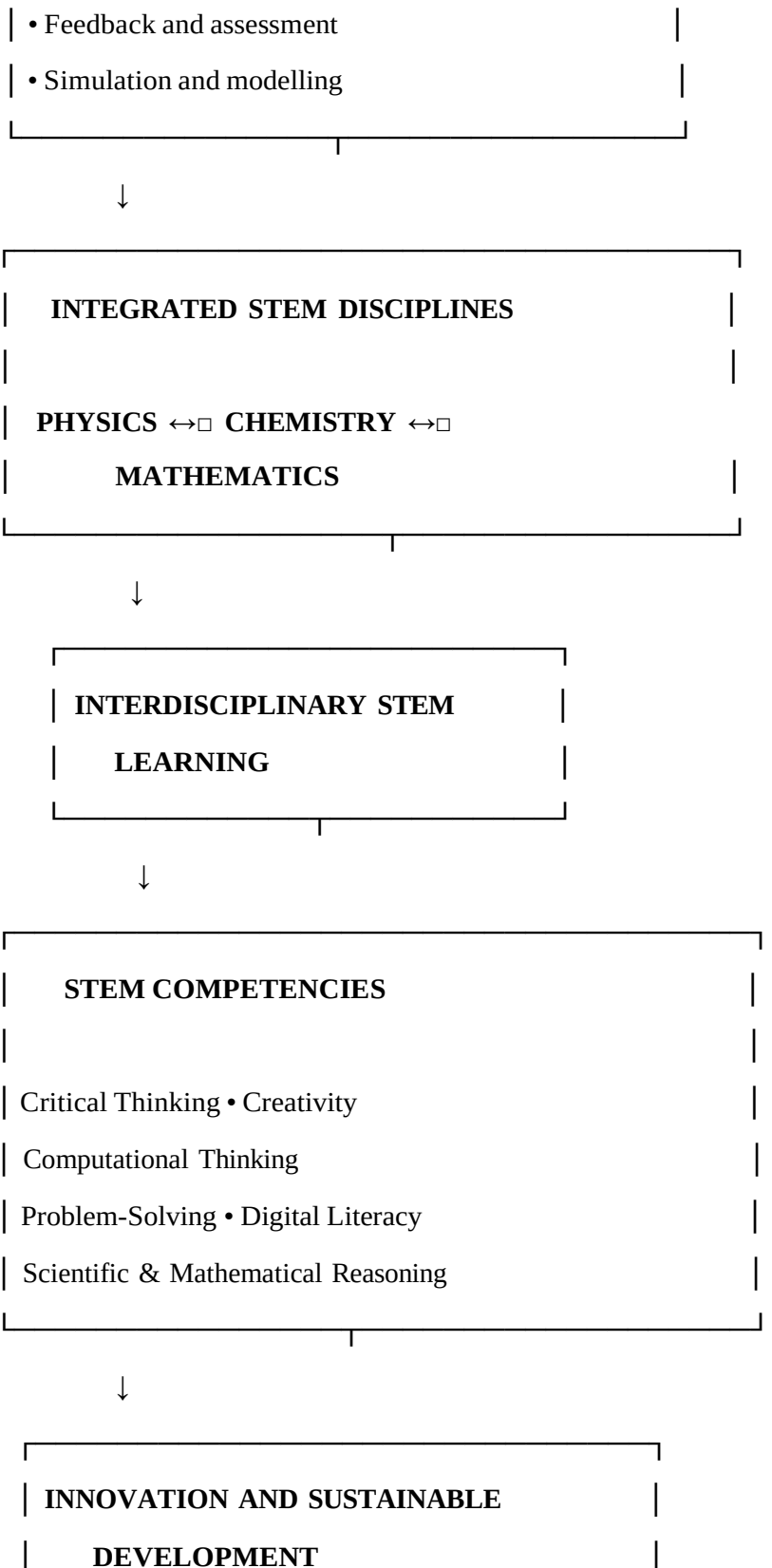
The present paper addresses these gaps by proposing a conceptual framework that positions AI and digital technologies as an enabling mechanism for connecting Physics, Chemistry and Mathematics through AI-enhanced pedagogy and interdisciplinary learning.

Proposed Conceptual Framework

The proposed framework is based on the assumption that AI-driven STEM transformation is most effective when technological resources are connected with appropriate pedagogy, teacher competence and disciplinary knowledge.

Figure 1: AI-Driven Digital Transformation Framework for Integrating Physics, Chemistry and Mathematics Education in Nigeria





Explanation of the Framework

The first component, AI and digital technologies, represents the technological foundation of the framework. It includes generative AI, intelligent tutoring systems, digital simulations, virtual laboratories, data analytics and computational modelling. These technologies provide the resources through which teaching and learning can become more interactive, personalized and data-informed.

The second component is AI-enhanced pedagogy. Technology alone cannot produce meaningful learning. Teachers must deliberately integrate AI into inquiry-based, problem-based, collaborative and learner-centered approaches. This component is grounded in TPACK and Constructivism because it recognizes the importance of teachers' pedagogical and content knowledge and students' active engagement.

The third component is Physics-Chemistry-Mathematics integration. The arrows connecting the three disciplines indicate that knowledge should flow across disciplinary boundaries. Rather than learning concepts independently, students should be provided with opportunities to apply concepts from all three areas to authentic problems.

The fourth component is interdisciplinary STEM learning, which serves as the bridge between disciplinary knowledge and broader STEM competencies. Through interdisciplinary projects, students can apply knowledge from different subjects to investigate and solve real-world problems.

The fifth component comprises STEM competencies, including critical thinking, creativity, computational thinking, problem-solving, digital literacy, scientific reasoning and mathematical reasoning. These competencies represent the immediate educational outcomes expected from the proposed framework.

The final component is innovation and sustainable development. The framework assumes that the ultimate purpose of STEM education is not merely academic achievement but the development of learners capable of applying scientific, mathematical and technological knowledge to societal problems.

The four enabling conditions; teacher competence, digital infrastructure, institutional support and ethical/responsible AI use surround the framework because weaknesses in any of these areas can limit successful implementation.

Discussion

The proposed framework responds to the central challenge identified in the literature: AI is expanding rapidly in education, but its integration is often discussed in terms of individual technologies or individual disciplines. The framework advances a broader perspective by positioning AI as an enabling mechanism for interdisciplinary STEM education.

Evidence from Nigerian and African studies supports the need for this approach. Falebita and Kok (2024) found that AI is increasingly being used by STEM academics and students in Africa, while Okoye and Mante (2024) identified considerable potential for AI-driven STEM transformation in Nigeria. However, the literature also demonstrates that infrastructure, expertise and institutional preparedness remain important constraints. The proposed framework therefore incorporates these factors as enabling conditions rather than assuming that technology can operate independently of the educational environment.

The framework also responds to evidence from the three focal disciplines. In Physics, AI and simulations can support conceptual understanding and problem-solving, but Yeadon and Hardy's (2024) findings demonstrate that AI performance varies across levels of Physics problems. This reinforces the importance of verification and teacher guidance. In Chemistry, Iyamuremye et al. (2024) identified opportunities for personalized learning and teacher support but also highlighted ethical and implementation concerns. In Mathematics, Nigerian studies by Fawehinmi et al. (2025), Menkiti and Nwodika (2025) and Ogoke et al. (2025) demonstrate growing interest in AI-supported learning and the importance of teacher preparedness and responsible use.

The framework's interdisciplinary orientation is particularly significant. Renewable energy, environmental pollution, climate change and energy storage are not problems that can be adequately addressed through one discipline. A learner studying solar energy, for example, may need Physics to understand energy conversion, Chemistry to understand photovoltaic materials or batteries, and Mathematics to analyze efficiency and predict energy output. AI can provide the digital environment through which these forms of knowledge are brought together.

The framework also emphasizes the continuing importance of the teacher. AI may generate explanations, questions and solutions, but it cannot replace the teacher's responsibility to determine whether those outputs are appropriate for the learners, curriculum and context. TPACK therefore

remains highly relevant because teachers need technological, pedagogical and content knowledge to make informed decisions about AI use.

Another important implication concerns assessment. Traditional assessment approaches may become increasingly problematic when students have access to AI systems capable of generating answers. STEM assessment should therefore place greater emphasis on reasoning, application, explanation, practical performance, project work, data interpretation and the ability to critique AI-generated solutions. Such assessment practices can reduce the incentive to use AI merely as an answer-generating mechanism.

The framework consequently positions AI as an augmentation technology rather than a replacement technology. Its purpose is to strengthen teachers' instructional capacity and students' learning opportunities while preserving human judgment, scientific inquiry, practical work and mathematical reasoning.

Conclusion

Artificial Intelligence and digital technologies are creating new possibilities for transforming STEM education, but meaningful transformation requires more than technological adoption. The literature reviewed demonstrates that AI can support personalized learning, intelligent tutoring, simulation, virtual experimentation, mathematical modelling, feedback and problem-solving across Physics, Chemistry and Mathematics. However, the benefits of these technologies depend on appropriate pedagogy, teacher competence, infrastructure, institutional support and responsible use.

This paper proposes an AI-driven digital transformation framework that connects AI and digital technologies with AI-enhanced pedagogy, Physics-Chemistry-Mathematics integration, interdisciplinary STEM learning, STEM competencies, innovation and sustainable development. The framework responds to a gap in the existing literature by moving beyond discipline-specific applications of AI and conceptualizing the three disciplines as interconnected components of an integrated STEM learning environment.

The central argument is that AI should complement rather than replace teachers, practical laboratory experiences and students' independent reasoning. A human-centered and interdisciplinary approach can enable learners to use AI critically and creatively while developing the scientific, mathematical and digital competencies required for contemporary society.

For Nigeria, the successful implementation of this framework will require simultaneous attention to infrastructure, teacher professional development, curriculum reform, ethical guidelines, equitable access and empirical evaluation. Future research should therefore test the proposed framework through experimental, quasi-experimental and longitudinal studies across Nigerian educational institutions. Such evidence will help determine how AI can be responsibly and effectively harnessed to strengthen Physics, Chemistry and Mathematics education and contribute to Nigeria's technological innovation and sustainable development.

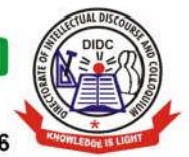
Recommendations

Based on the reviewed literature and proposed framework, the following recommendations are made:

1. AI should be deliberately integrated into Physics, Chemistry and Mathematics curricula as a pedagogical resource rather than treated as a stand-alone technological innovation.
2. Teacher professional development should be strengthened to develop teachers' AI literacy, technological competence and ability to integrate AI with appropriate pedagogical and disciplinary practices.
3. Interdisciplinary STEM projects should be promoted, particularly projects addressing renewable energy, environmental sustainability, climate change, energy storage and other authentic Nigerian problems.
4. Government and educational institutions should improve digital infrastructure, particularly reliable electricity, internet connectivity, digital devices, simulations and laboratory technologies.
5. Institutions should develop responsible-AI policies addressing academic integrity, privacy, assessment, misinformation, ethical use and appropriate student engagement with generative AI.
6. Assessment practices should be redesigned to emphasize reasoning, creativity, problem-solving, scientific inquiry, mathematical justification and practical application rather than answer reproduction.
7. Further empirical research should test the proposed framework across Nigerian secondary schools, colleges of education and universities to establish its effects on STEM achievement and competencies.

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