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Integrating Artificial Intelligence Literacy into Mathematics Teacher Education: an Integrative Conceptual Framework for AI-Supported Classroom Practice

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Abstract

The rapid advancement of artificial intelligence (AI) is transforming mathematics education and creating new opportunities for enhancing teaching and learning. However, effective AI integration depends on teachers' ability to use AI critically, ethically, and pedagogically. This conceptual paper examines the integration of AI literacy and AI tools into mathematics teacher education and classroom practice and proposes an integrative framework for preparing future-ready mathematics teachers. Drawing on a comprehensive review of contemporary literature, the paper explores the concept and dimensions of AI literacy, the pedagogical applications of AI tools, and the theoretical foundations underpinning AI integration. The proposed framework synthesizes the Technological Pedagogical Content Knowledge (TPACK) framework, the UNESCO AI Competency Framework for Teachers, Self-Determination Theory, and Diffusion of Innovations Theory, positioning AI literacy as the central competency linking mathematics teacher education, AI-supported classroom practice, and improved learning outcomes. The paper argues that AI technologies can enhance mathematics education only when teachers possess the knowledge, ethical awareness, and pedagogical competence required for their responsible use. It further highlights implications for teacher education, professional development, educational policy, and future research, while emphasizing the need to embed AI literacy within mathematics teacher education to support effective and responsible AI integration.

Keywords: artificial intelligence literacy, mathematics teacher education, artificial intelligence tools, mathematics education, TPACK, teacher competence, conceptual framework

1 Introduction

The twenty-first century has witnessed unprecedented technological advances that continue to reshape education. Among these innovations, artificial intelligence (AI) has emerged as one of the most transformative technologies, transforming how teaching, learning, assessment, and educational management are conceptualized and implemented (Holmes et al., 2021; Luckin & Cukurova, 2019; Zawacki-Richter et al., 2019). Unlike earlier educational technologies, AI systems can analyse data, recognize patterns, generate human-like content, and support adaptive decision-making and personalized learning, positioning AI as a key catalyst for educational transformation (Russell & Norvig, 2021). The growing adoption of AI in education is transforming teachers' professional roles. Rather than replacing teachers, AI increasingly supports lesson planning, personalized instruction, assessment, learning analytics, and differentiated teaching (Holmes et al., 2021; Miao & Holmes, 2023; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2023). Consequently, effective AI integration depends not only on access to AI technologies but also on teachers' ability to understand, critically evaluate, and pedagogically apply them. Reflecting this shift, UNESCO's AI Competency Framework for Teachers identifies AI competence as an essential component of contemporary teacher professionalism (UNESCO, 2024).

Mathematics education is particularly well suited to AI integration because of its emphasis on problem solving, logical reasoning, adaptive practice, and immediate feedback. AI-powered tools, including intelligent tutoring systems, generative AI, automated assessment, dynamic visualization, and learning analytics, can enhance conceptual understanding, procedural fluency, and learner engagement while supporting teacher lesson planning, assessment, and instructional

decision-making (Chen et al., 2020; Holmes et al., 2021; Kasneci et al., 2023; Ouyang et al., 2022). These developments reinforce the importance of integrating technological knowledge with pedagogy and mathematical content, consistent with the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006). The emergence of generative AI has further expanded opportunities for mathematics teachers by enabling the rapid generation of lesson plans, instructional materials, worked examples, and assessment tasks (Kasneci et al., 2023; Lo, 2023). However, because AI systems may also generate inaccurate mathematical explanations or flawed reasoning, teachers require sufficient disciplinary knowledge and professional judgement to evaluate AI-generated outputs before using them in instruction (Kasneci et al., 2023; UNESCO, 2023). These developments have elevated AI literacy from a desirable digital skill to a core professional competency encompassing AI knowledge, critical evaluation, ethical awareness, prompt design, and pedagogical integration (Long & Magerko, 2020; Ng et al., 2021; UNESCO, 2024).

Despite growing interest in the educational applications of AI, teacher education programmes have generally struggled to keep pace with the rapid evolution of AI technologies, leaving many educators insufficiently prepared to integrate AI effectively into teaching and learning (Crompton & Burke, 2023; Kohnke et al., 2023). This challenge is particularly pronounced in mathematics education, where teachers require specialized competencies to critically evaluate AI-generated mathematical content, ensure its accuracy, and integrate AI pedagogically to support conceptual understanding and mathematical reasoning (Kasneci et al., 2023; Mishra & Koehler, 2006; UNESCO, 2024). The situation is further compounded in many developing countries, including Nigeria, where efforts to integrate AI literacy into teacher education and continuous professional development are hindered by inadequate training opportunities, limited institutional support, and infrastructural constraints, thereby affecting teachers' readiness for AI-supported pedagogy (UNESCO, 2024; Ogbu, 2024). There is therefore a pressing need to reconceptualize mathematics teacher education by embedding AI literacy alongside pedagogical, technological, and ethical competencies, while providing a coherent framework that explains how AI literacy supports the effective integration of AI into mathematics teaching and learning. Against this background, this paper examines the integration of AI literacy and AI tools into mathematics teacher education and classroom practice. It synthesizes current literature and proposes an integrative conceptual framework that positions AI literacy as a core component of mathematics teacher competence necessary for future-ready mathematics education.

2 Artificial Intelligence Literacy: Concept, Dimensions, and Relevance for Mathematics Teacher Education

As AI becomes increasingly integrated into education, AI literacy has emerged as an essential professional competency for teachers. Building upon traditional digital literacy, AI literacy equips teachers to understand AI technologies, critically evaluate their outputs, and apply them responsibly within pedagogical contexts (Long & Magerko, 2020; Ng et al., 2021). Although definitions vary, there is broad consensus that AI literacy encompasses the knowledge, skills, attitudes, and ethical dispositions required to understand, evaluate, interact with, and responsibly use AI technologies (Long & Magerko, 2020; UNESCO, 2022, 2024). Within mathematics teacher education, AI literacy extends beyond the ability to use AI applications such as ChatGPT or intelligent tutoring systems. It represents a specialized professional competence that combines mathematical knowledge, pedagogy, technological expertise, and ethical responsibility. Mathematics teachers must be able to evaluate AI-generated mathematical explanations, identify computational or logical errors, determine the suitability of AI-supported instructional strategies, and ensure that AI enhances rather than replaces mathematical reasoning (Kasneci et al., 2023). In this respect, AI literacy complements the TPACK framework by extending teachers' technological competence to include AI-specific knowledge and skills (Mishra & Koehler, 2006).

Drawing on Long and Magerko (2020), Ng et al. (2021), Holmes et al. (2021), and UNESCO (2024), AI literacy may be conceptualized as comprising five interrelated dimensions: foundational knowledge of AI concepts, critical evaluation of AI-generated information, ethical and responsible AI use, pedagogical competence for AI integration, and effective human–AI collaboration through prompt design and reflective professional judgement. Collectively, these dimensions enable teachers to select appropriate AI tools, verify AI-generated content, address issues of bias, privacy, and academic integrity, and design learning experiences that strengthen conceptual understanding and learner engagement. These competencies are especially important in mathematics education, where conceptual precision, logical consistency, and procedural accuracy are essential. Inaccurate AI-generated explanations can reinforce misconceptions if they are not critically evaluated. Consequently, mathematics teachers require sufficient disciplinary expertise to validate AI-generated content and use AI as an instructional partner rather than a substitute for professional judgement (Kasneci et al., 2023; Lo, 2023). Accordingly, embedding AI literacy within both pre-service teacher education and continuing professional development is therefore essential. Beyond familiarizing teachers with AI tools, mathematics teacher education should develop the knowledge,

critical thinking, ethical awareness, and pedagogical competence necessary for responsible AI integration (UNESCO, 2024). These competencies provide the foundation for examining the pedagogical applications of AI tools in mathematics education, discussed in the next section.

3 AI Tools and their Pedagogical Applications in Mathematics Education

The rapid development of AI-powered educational technologies has expanded opportunities for mathematics teaching and learning. Unlike conventional digital technologies that primarily support content delivery and communication, AI tools can generate instructional content, provide adaptive feedback, analyse learner data, automate assessment, and support evidence-informed instructional decision-making (Holmes et al., 2021; Ouyang et al., 2022). Consequently, AI is increasingly recognised as a pedagogical resource capable of enhancing mathematics instruction. Recent literature identifies several AI applications relevant to mathematics education, including generative AI, intelligent tutoring systems, adaptive learning platforms, automated assessment, and learning analytics (Holmes et al., 2021; Ouyang et al., 2022; Zawacki-Richter et al., 2019). Among these, generative AI has attracted particular attention because it can rapidly generate lesson plans, instructional materials, worked examples, assessment tasks, and differentiated learning resources while supporting teachers' instructional planning and creativity (Kasneci et al., 2023; Lo, 2023). Likewise, intelligent tutoring systems and adaptive learning platforms personalize instruction by diagnosing misconceptions, adjusting task difficulty, and providing immediate feedback, whereas AI-powered assessment and learning analytics enable teachers to monitor learner progress, identify learning gaps, and make timely instructional decisions (Holmes et al., 2021; Siemens & Baker, 2012).

Despite these benefits, AI cannot replace the professional expertise required for effective mathematics teaching. Because mathematics learning depends on conceptual understanding, logical reasoning, and problem solving, teachers must critically evaluate AI-generated content for mathematical accuracy and pedagogical suitability before integrating it into instruction (Kasneci et al., 2023). The effectiveness of AI therefore depends largely on teachers' AI literacy and their ability to integrate AI within pedagogical frameworks such as TPACK (Mishra & Koehler, 2006; UNESCO, 2024). Rather than substituting teacher expertise, AI should function as an instructional partner that complements teachers' mathematical knowledge, pedagogical judgement, and ethical decision-making, with effective integration grounded in frameworks such as TPACK (Holmes et al., 2021; Kasneci et al., 2023; Mishra & Koehler, 2006). Overall, AI offers significant opportunities to enhance personalized learning, adaptive instruction, formative assessment, and evidence-informed teaching. However, its educational value depends fundamentally on teachers' ability to integrate AI critically, ethically, and pedagogically. This consideration underscores the relevance of the theoretical perspectives discussed in the next section.

4 Theoretical Foundations for Integrating AI Literacy into Mathematics Teacher Education

Integrating AI into mathematics teacher education requires a theoretical foundation that explains how teachers develop the knowledge, competencies, motivation, and institutional support necessary for effective AI integration. Since no single theory adequately captures these interrelated dimensions, this paper draws on four complementary frameworks: the Technological Pedagogical Content Knowledge (TPACK) framework, the UNESCO AI Competency Framework for Teachers, Self-Determination Theory (SDT), and Diffusion of Innovations Theory (DOI). Together, these frameworks provide a comprehensive basis for conceptualizing AI literacy as a key component of mathematics teacher competence.

4.1 Technological Pedagogical Content Knowledge (TPACK)

The TPACK framework (Mishra & Koehler, 2006) provides the principal theoretical foundation for this paper. It argues that effective technology integration depends on the interaction of technological, pedagogical, and content knowledge. Within mathematics education and technology-enhanced teaching more broadly, TPACK has become one of the most widely adopted frameworks for understanding teachers' readiness to integrate digital technologies and for informing teacher professional development (Chai et al., 2013; Kholid et al., 2023; Mishra & Koehler, 2006; Niess, 2005; Voogt et al., 2013). However, the emergence of generative AI extends TPACK beyond conventional ICT competencies by requiring teachers to evaluate AI-generated content, formulate effective prompts, address ethical concerns, and make informed pedagogical decisions (Kasneci et al., 2023; UNESCO, 2024). AI literacy therefore extends rather than replaces the technological dimension of TPACK.

4.2 UNESCO AI Competency Framework for Teachers

The UNESCO AI Competency Framework for Teachers (UNESCO, 2024) complements TPACK by specifying the competencies required for responsible AI integration. It emphasizes five domains: human-centred values, AI ethics, AI foundations and applications, AI pedagogy, and AI-supported professional learning. Within mathematics teacher education, these competencies enable teachers to evaluate AI-generated mathematical content critically, ensure ethical AI use, protect learner privacy, and maintain professional judgement throughout instructional decision-making.

4.3 Self-Determination Theory

Self-Determination Theory (Deci & Ryan, 1985; Ryan & Deci, 2020) explains teachers' motivation to adopt AI by emphasizing the roles of autonomy, competence, and relatedness. Teachers are more likely to integrate AI into mathematics instruction when they possess confidence in their AI competencies, retain autonomy over instructional decisions, and receive adequate institutional and collegial support. Conversely, inadequate preparation, low self-efficacy, and limited organizational support may discourage AI adoption despite the availability of AI technologies (Ryan & Deci, 2020; Kohnke et al., 2023).

4.4 Diffusion of Innovations Theory

Diffusion of Innovations Theory (Rogers, 2003) explains how AI adoption spreads within educational institutions. Adoption is influenced by teachers' perceptions of an innovation's relative advantage, compatibility, complexity, trialability, and observability. In mathematics education, AI tools are more likely to be adopted when teachers perceive clear instructional benefits, have opportunities to experiment with the technologies, and receive adequate professional support (Kohnke et al., 2023; Rogers, 2003).

4.5 Integrating the Frameworks

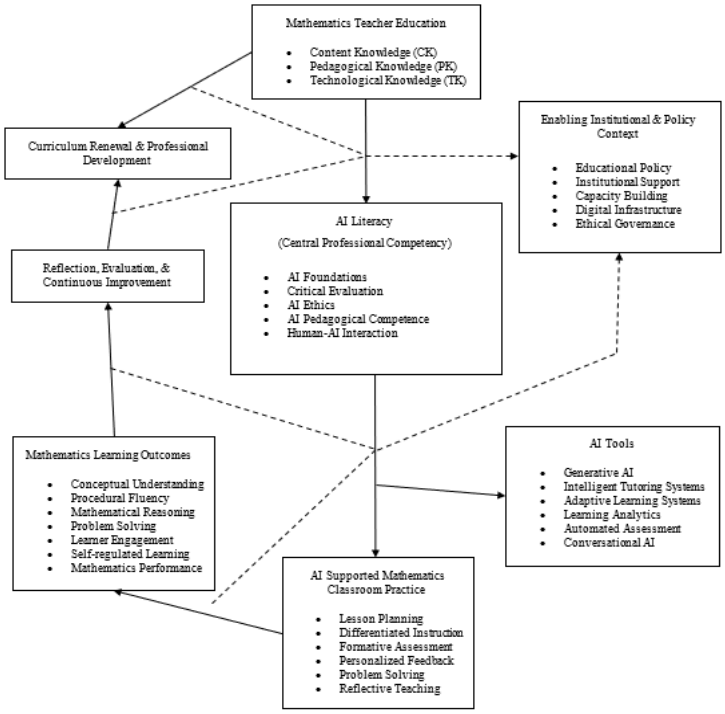
Collectively, these frameworks provide complementary explanations for AI integration in mathematics teacher education. TPACK explains the integration of technological, pedagogical, and content knowledge within mathematics teaching; the UNESCO AI Competency Framework specifies the AI-related competencies required for responsible educational practice; Self-Determination Theory explains teachers' motivation to adopt AI; and Diffusion of Innovations Theory highlights the organizational factors that influence AI implementation. Within this paper, AI literacy serves as the connecting construct that links these perspectives by extending TPACK, operationalizing UNESCO's competencies, strengthening teachers' confidence and motivation, and facilitating effective AI adoption. Together, they provide a coherent theoretical foundation for understanding how AI literacy can strengthen mathematics teacher competence and support effective AI-enabled mathematics instruction.

5 Proposed Integrative Conceptual Framework for AI Literacy Integration in Mathematics Teacher Education

Existing frameworks provide valuable perspectives on technology integration, teacher competence, AI literacy, and innovation adoption. However, no single framework sufficiently explains how mathematics teacher education, AI literacy, AI tools, classroom practice, and learner outcomes interact to support AI-enabled mathematics teaching. While the TPACK framework explains the integration of technological, pedagogical, and content knowledge (Mishra & Koehler, 2006), it was developed before the emergence of generative AI and therefore does not explicitly address AI-specific competencies such as prompt engineering, critical evaluation of AI-generated outputs, and ethical AI use. Similarly, the UNESCO AI Competency Framework for Teachers identifies the competencies required for AI-enabled education but does not explicitly illustrate how these competencies translate into mathematics classroom practice and improved learner outcomes (UNESCO, 2024). To address these limitations, this paper proposes an integrative conceptual framework that positions AI literacy as the central professional competency linking mathematics teacher education, AI tools, AI-supported classroom practice, and mathematics learning outcomes.

Figure **1**

Proposed Integrative Conceptual Framework for AI Literacy Integration in Mathematics Teacher Education.



Source: Developed by the authors based on Mishra and Koehler (2006), UNESCO (2024), Ryan and Deci (2020), and Rogers (2003).

The framework illustrates how mathematics teacher education develops AI literacy as the central professional competency that enables the effective pedagogical use of AI tools in mathematics classroom practice, leading to improved learning outcomes. Continuous reflection, evaluation, curriculum renewal, and professional development create a feedback cycle for ongoing improvement, while educational policy, institutional support, digital infrastructure, ethical governance, and capacity building provide the enabling context for successful implementation.

Theoretical Foundation: Technological Pedagogical Content Knowledge (TPACK), UNESCO AI Competency Framework for Teachers, Self-Determination Theory (SDT), and Diffusion of Innovations Theory (DOI). Figure 1 presents the proposed framework. Mathematics teacher education provides the foundation by developing teachers' content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK), while simultaneously cultivating AI literacy. This builds on the TPACK perspective of mathematics teacher competence by extending teachers' technological knowledge to include AI-specific competencies required for contemporary mathematics teaching (Kholid et al., 2023; Mishra & Koehler, 2006; UNESCO, 2024). At the center of the framework is AI literacy, comprising AI foundations, critical evaluation of AI-generated outputs, AI ethics, AI pedagogical competence, and effective human–AI interaction. As the central professional competency, AI literacy enables teachers to evaluate AI-generated content critically, make informed pedagogical decisions, and integrate AI responsibly into mathematics instruction. AI literacy facilitates the effective use of AI tools, including generative AI, intelligent tutoring systems, adaptive learning systems, learning analytics, automated assessment, and conversational AI. These tools support AI-enhanced classroom practices such as lesson planning, differentiated instruction, formative assessment, personalized feedback, problem solving, and reflective teaching. Through these practices, teachers enhance learners' conceptual understanding, procedural fluency, mathematical reasoning, problem-solving ability, learner engagement, self-regulated learning, and mathematics performance.

The framework further recognizes that AI integration occurs within an enabling institutional and policy context, including educational policy, institutional support, capacity building, digital infrastructure, and ethical governance, all of which influence teachers' ability to implement AI effectively. Equally important is the framework's continuous improvement

cycle, whereby evidence from classroom practice and learner outcomes informs teachers' reflection, evaluation, curriculum renewal, and professional development. This feedback process continuously informs improvements in mathematics teacher education and AI literacy, emphasizing that AI integration is an ongoing process of professional learning rather than a one-time technological adoption. Overall, the framework synthesizes the complementary perspectives of TPACK, the UNESCO AI Competency Framework for Teachers, Self-Determination Theory, and Diffusion of Innovations Theory into a coherent model in which AI literacy serves as the central professional competency through which mathematics teachers translate AI technologies into effective, ethical, and pedagogically meaningful classroom practice (Mishra & Koehler, 2006; Rogers, 2003; Ryan & Deci, 2020; UNESCO, 2024). The principal contribution of the proposed framework lies in its integration of teacher knowledge, AI literacy, AI-enabled pedagogy, institutional support, and continuous professional learning into a single conceptual model. Unlike existing frameworks, which address these elements separately, the proposed framework explains how they interact to support effective AI integration in mathematics teacher education and classroom practice.

6 Implications for Mathematics Teacher Education and Classroom Practice

The proposed conceptual framework has important implications for mathematics teacher education, professional development, classroom practice, educational policy, and future research. Its central proposition is that effective AI integration depends not simply on access to AI technologies but on the systematic development of teachers' AI literacy. Consequently, AI literacy should be recognised as a core dimension of mathematics teacher competence rather than an optional extension of digital literacy. For mathematics teacher education, the framework underscores the need to redesign pre-service and in-service programmes so that AI literacy is embedded across mathematics methods, educational technology, teaching practice, and professional ethics courses rather than being taught as an isolated topic. Such integration would enable future mathematics teachers to develop the knowledge, skills, and professional judgement required to critically evaluate AI-generated mathematical content, address ethical concerns, and integrate AI effectively into classroom instruction, consistent with the competencies outlined in the UNESCO AI Competency Framework for Teachers (UNESCO, 2024). It also responds to growing evidence that many teachers remain insufficiently prepared for AI-supported pedagogy (Kohnke et al., 2023). Equally important is the provision of authentic learning experiences that allow teachers to experiment with AI tools during lesson planning, assessment design, microteaching, and reflective practice.

Because AI technologies continue to evolve rapidly, continuous professional development (CPD) is equally essential. Professional learning should extend beyond traditional ICT training to include AI-specific competencies such as prompt engineering, critical evaluation of AI-generated mathematical explanations, ethical and responsible AI use, adaptive learning technologies, and AI-assisted assessment. Collaborative professional learning communities, mentoring, and practitioner inquiry can further strengthen teachers' confidence, pedagogical competence, and capacity to integrate AI effectively across diverse mathematics classroom contexts (Kohnke et al., 2023; Tunjera & Chigona, 2025; UNESCO, 2024). The framework also has significant implications for mathematics classroom practice. AI should be viewed as a pedagogical partner that enhances, rather than replaces, teacher expertise. When used appropriately, AI can support lesson planning, differentiated instruction, formative assessment, personalized feedback, and learning analytics, enabling more learner-centred and evidence-informed mathematics instruction. Nevertheless, teachers retain responsibility for ensuring mathematical accuracy, facilitating classroom discourse, and promoting learners' conceptual understanding and reasoning (Kasneci et al., 2023; Holmes et al., 2021). Accordingly, AI-generated resources should always be critically evaluated and adapted to learners' needs, curriculum objectives, and contextual realities.

At the institutional level, successful implementation of AI literacy requires supportive educational policies, institutional leadership, and governance. Policymakers should establish teacher competency standards, curriculum guidelines, ethical frameworks, and quality assurance mechanisms that promote the responsible integration of AI within teacher education programmes (UNESCO, 2022, 2024). Teacher education institutions should support these initiatives through investment in digital infrastructure, faculty development, and institutional policies that promote responsible AI use while addressing challenges such as limited internet connectivity, inadequate infrastructure, and unequal access to AI technologies, particularly in developing countries. Finally, the framework provides a useful foundation for future empirical research. Subsequent studies should validate the proposed relationships among AI literacy, AI-supported classroom practice, and mathematics learning outcomes across different educational settings. Future research should also examine contextual influences such as institutional support, teachers' experience, digital infrastructure, and educational policy, as well as emerging issues including prompt engineering, AI-assisted assessment, algorithmic bias, and human–AI collaboration. Such studies would not only strengthen the evidence base for AI integration but also refine the proposed framework and enhance its applicability across diverse mathematics education contexts. Overall, the framework highlights AI literacy as

the critical competency through which mathematics teachers can integrate AI responsibly, ethically, and pedagogically. By embedding AI literacy within teacher education, professional development, educational policy, and classroom practice, mathematics teacher education can better prepare teachers to harness AI technologies in ways that enhance teaching quality and improve learners' mathematical understanding.

7 Challenges and Future Directions for AI Integration in Mathematics Teacher Education

Despite its transformative potential, the effective integration of artificial intelligence (AI) into mathematics teacher education is constrained by several pedagogical, ethical, institutional, and technological challenges. AI can support lesson planning, adaptive instruction, and assessment, but mathematics teaching requires conceptual understanding, mathematical reasoning, and meaningful classroom interaction that cannot be delegated to AI alone (Holmes et al., 2021; Mishra & Koehler, 2006). Moreover, generative AI may produce inaccurate or misleading mathematical explanations, making it essential for teachers to verify AI-generated content before using it in instruction (Kasneci et al., 2023). Excessive dependence on AI may also limit learners' opportunities to develop independent reasoning and problem-solving skills (Kasneci et al., 2023; UNESCO, 2024). Ethical concerns further complicate AI integration. Issues relating to algorithmic bias, learner privacy, data security, and academic integrity require teachers to use AI responsibly and establish clear guidelines for its educational use (UNESCO, 2022, 2024). These responsibilities highlight the importance of AI literacy in enabling mathematics teachers to critically evaluate AI outputs, protect learners' interests, and ensure that AI enhances rather than undermines learning (UNESCO, 2024).

Teacher preparedness remains another major challenge. Many mathematics teachers have received limited training in AI-supported pedagogy because teacher education programmes have traditionally focused on general ICT competencies rather than AI literacy (Kohnke et al., 2023). Continuous professional development is therefore essential to equip teachers with competencies in AI pedagogy, prompt engineering, ethical AI use, and the evaluation of AI-generated mathematical content (Kohnke et al., 2023; UNESCO, 2024). At the same time, inadequate infrastructure, unreliable internet connectivity, insufficient funding, and the absence of coherent institutional policies, particularly in many low- and middle-income countries, including Nigeria, where infrastructure and institutional capacity continue to pose challenges (UNESCO, 2024). Looking ahead, mathematics teacher education should move beyond teaching educators how to use AI tools toward developing AI-literate professionals capable of integrating AI critically, ethically, and pedagogically into mathematics instruction. This requires embedding AI literacy across teacher education curricula, teaching practice, assessment, and professional development while fostering collaboration among mathematics educators, AI specialists, educational technologists, and policymakers. Future research should also validate the conceptual framework proposed in this paper, examine the relationships among AI literacy, teacher competence, classroom practice, and learner outcomes, and develop reliable instruments for assessing AI literacy in mathematics teacher education. Addressing these challenges through sustained professional learning, supportive policies, and empirical research will be essential for ensuring that AI contributes meaningfully to mathematics teaching and learning.

8 Conclusion

Artificial intelligence is transforming education and redefining the professional competencies required of mathematics teachers. This paper has argued that the successful integration of AI into mathematics education depends not merely on access to AI technologies but on teachers' ability to use them critically, ethically, and pedagogically. Accordingly, AI literacy is conceptualized as a core professional competency that extends traditional technology integration frameworks by enabling teachers to critically evaluate AI-generated outputs, address ethical issues, design AI-supported learning experiences, and make informed instructional decisions. Drawing on the Technological Pedagogical Content Knowledge (TPACK) framework, the UNESCO AI Competency Framework for Teachers, Self-Determination Theory, and Diffusion of Innovations Theory, the paper proposed an integrative conceptual framework that positions AI literacy as the central mechanism linking mathematics teacher education, AI tools, AI-supported classroom practice, and mathematics learning outcomes. The framework emphasizes that meaningful AI integration arises from the interaction of professional knowledge, pedagogical expertise, ethical responsibility, institutional support, and continuous professional learning, with AI functioning as a pedagogical partner that complements rather than replaces teacher expertise. The paper further underscores the importance of embedding AI literacy across pre-service teacher education, continuous professional development, educational policy, and institutional practice to prepare mathematics teachers for increasingly AI-enabled learning environments. Future empirical research should validate the proposed framework and examine the relationships among AI

literacy, teacher competence, AI-supported classroom practice, and mathematics learning outcomes across diverse educational contexts. By positioning AI literacy at the centre of mathematics teacher education, this paper provides a conceptual foundation for preparing future-ready mathematics teachers who can harness AI responsibly to enhance the quality of mathematics teaching and learning.

9 Declarations

Ethical and Artificial Intelligence Declaration: This study is a conceptual paper based entirely on published literature and did not involve human participants, animals, or the collection of primary data. Consequently, ethical approval and informed consent were not required. Artificial intelligence (AI) tools were used only to assist with language editing, organization, and refinement of the manuscript. The authors independently conducted the literature review, critically evaluated all sources, developed the conceptual framework, interpreted the evidence, and prepared the final manuscript. The authors accept full responsibility for the accuracy, originality, and integrity of the work.

Conflict of Interest: The authors declare neither financial nor non-financial conflict of interest.

Author Contributions: **Author 1:** Conceptualization, literature review, theoretical synthesis, conceptual framework development, writing−original draft, visualization, and manuscript preparation. **Author 2:** Literature validation, critical review, writing−review and editing, and methodological guidance. **Author 3:** Supervision, critical revision of the manuscript, validation of the conceptual framework, and final approval of the manuscript. All authors read and approved the final manuscript.

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