

AI Literacy in STEM Education: Teachers' Ethical, Pedagogical, and Epistemic Challenges

Nur Choiro Siregar^{1*}, Rahmadani Siregar², Nurhayati³, Arief Herdiansah⁴

^{1,3,4}Universitas Muhammadiyah Tangerang, Indonesia

²Univrsitas Islam Negeri Syekh Ali Hasan Ahmad Addary Padangsidimpuan, Indonesia

E-mail: nur.choiro@umt.ac.id*

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ABSTRACT

This study aims to explore the ethical, pedagogical, and epistemic challenges of STEM teachers in integrating AI literacy into STEM education. An exploratory qualitative double case study design was used. Three STEM teachers were chosen deliberately based on their teaching experience and familiarity with digital or AI-powered learning practices. Data was collected through semi-structured interviews, classroom observations, and analysis of AI-related instructional documents and teaching artifacts. Data were analyzed using thematic analysis, followed by in-case and cross-case analysis to identify recurring and distinct patterns among the three teacher cases. The findings reveal three main themes. First, teachers express ethical concerns related to academic integrity, students' reliance on AI-generated answers, data privacy, and the potential for reproduction bias. Second, pedagogical challenges arise in designing meaningful, AI-powered STEM assignments, aligning the use of GenAI with learning objectives, and developing appropriate assessment strategies. Third, epistemic challenges are seen in students' tendency to overtrust AI outputs, limited ability to verify scientific accuracy, and difficulty distinguishing explanations from evidence. Despite these challenges, teachers view AI literacy as essential to promoting critical, reflective, and responsible STEM learning. This study contributes to the growing study of AI literacy by highlighting teachers' experiences and offering practical insights for designing ethical, pedagogy-grounded, and epistemically minded STEM learning environments.

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INTRODUCTION

Generative artificial intelligence has increasingly become part of contemporary educational practice, including STEM education, where students and teachers may use AI tools to generate explanations, solve problems, design learning activities, and support inquiry-based tasks (Siregar et al., 2023, 2025). The emergence of generative AI marks a significant transformation in the way knowledge is accessed, produced, interpreted, and applied in educational settings (Bahroun et al., 2023). Unlike earlier forms of educational technology that mainly functioned as supplementary tools, GenAI systems are able to interact with users through natural language, respond to complex prompts, produce multimodal content, and assist learners in completing a wide range of academic tasks. In STEM education, this development is particularly important because students are often required to engage with abstract concepts, complex problem-solving processes,

data-based reasoning, and evidence-supported explanations. GenAI can potentially support these learning processes by offering immediate feedback, alternative explanations, simulations of reasoning, examples of problem-solving procedures, and opportunities for students to explore scientific or mathematical concepts from multiple perspectives (Hazzan & Erez, 2025). For teachers, GenAI may also support instructional planning, the development of teaching materials, the design of formative assessments, and the creation of differentiated learning resources that respond to students' diverse needs (Webb & Galamba, 2026).

However, the integration of GenAI into STEM education also changes the nature of digital competence. This shift has expanded the meaning of digital competence beyond basic technology use toward AI literacy, which includes the ability to understand AI concepts, use AI tools appropriately, evaluate AI outputs critically, create or adapt AI-supported products, and recognize ethical issues related to AI use (Ng et al., 2021; Siregar et al., 2025). In the past, digital competence was often associated with students' ability to operate computers, search for information online, use digital applications, and communicate through technological platforms (Zhao et al., 2021). While these abilities remain important, they are no longer sufficient in an educational environment increasingly shaped by intelligent systems. AI literacy requires a deeper and more critical form of competence because users must understand not only how to use AI tools, but also how such tools generate responses, what limitations they have, and what risks may emerge from their use. Students need to recognize that GenAI outputs are not automatically accurate, neutral, or complete (Perkins et al., 2024). They must learn to question the reliability of AI-generated explanations, compare AI responses with credible sources, identify possible errors or biases, and determine whether the information produced by AI is appropriate for the learning task.

AI literacy also requires students to develop responsible and ethical habits when interacting with AI systems (Biagini, 2025). This includes understanding issues of academic integrity, authorship, privacy, transparency, fairness, and accountability. For example, when students use GenAI to solve STEM problems or produce written explanations, they must be able to distinguish between using AI as a learning support and using AI as a substitute for their own thinking. The ethical use of AI in STEM education requires students to acknowledge AI assistance, avoid plagiarism, protect personal data, and remain aware that AI systems may reproduce bias or misinformation (Nagaraj et al., 2023). Teachers therefore have an important role in guiding students to use AI not only effectively, but also responsibly (Kim et al., 2022). They need to design learning activities that encourage students to engage critically with AI-generated content rather than simply accepting or copying it. In this sense, AI literacy becomes a pedagogical concern as well as a technological one.

Recent studies on AI literacy in school education show that AI is no longer only a technical subject but also a pedagogical and social concern because students need to understand how AI systems work, how they influence knowledge practices, and how they should be used responsibly in learning contexts (Casal-Otero et al., 2023; Rahman

et al., 2022). This means that AI literacy should not be limited to computer science or technology-related subjects. Instead, it should be integrated across different areas of learning, including science, mathematics, engineering, and interdisciplinary STEM activities. In STEM classrooms, AI can influence how students formulate questions, test hypotheses, interpret data, construct explanations, and communicate findings. If students rely on AI-generated responses without sufficient critical evaluation, they may develop superficial understanding or become dependent on automated explanations. Conversely, when AI is used with proper guidance, it can support deeper learning by encouraging students to compare answers, test assumptions, refine prompts, evaluate evidence, and reflect on the reasoning process.

The pedagogical challenge for teachers is therefore to determine how AI can be meaningfully integrated into STEM learning without weakening students' conceptual understanding, problem-solving ability, or critical thinking (Lawal et al., 2025). Teachers must make instructional decisions about when AI should be used (Nazaretsky et al., 2022), how students should interact with AI tools, what kinds of tasks are suitable for AI-supported learning, and how learning outcomes should be assessed. For instance, a teacher may ask students to use GenAI to generate an initial explanation of a scientific concept, but then require them to verify the explanation using textbooks, experimental data, or peer-reviewed sources. Similarly, in mathematics or engineering tasks, students may be asked to compare AI-generated solutions with their own calculations and identify differences in reasoning. Such activities can help students understand that AI is not an unquestionable authority, but a tool that must be evaluated through disciplinary knowledge and evidence-based reasoning.

In STEM education, this issue is especially significant because STEM learning requires evidence-based reasoning, problem solving, conceptual accuracy, data interpretation, and critical evaluation of explanations (Siregar et al., 2024; Warsito et al., 2023). These characteristics make STEM education highly dependent on the quality of reasoning and the validity of knowledge claims. Scientific explanations must be supported by evidence, mathematical solutions must follow logical procedures, engineering designs must respond to constraints and testing, and technological decisions must consider function, impact, and context. GenAI can support these processes, but it can also create risks when students treat AI-generated information as correct simply because it appears fluent, coherent, or authoritative. One of the major epistemic challenges in STEM education is that students may struggle to distinguish between a well-written explanation and a scientifically valid explanation. AI-generated text may sound convincing even when it contains inaccuracies, unsupported assumptions, or oversimplified reasoning. Therefore, AI literacy in STEM education must include epistemic vigilance, meaning the ability to examine how knowledge is produced, justified, and validated.

The integration of AI literacy into STEM education also requires attention to the changing role of teachers (Walsh et al., 2023). Teachers are no longer only transmitters of content or facilitators of digital tool use; they are increasingly required to act as critical

mediators between students, AI systems, and disciplinary knowledge. They must help students develop the intellectual habits needed to question AI outputs, evaluate evidence, and maintain responsibility for their own learning. This requires teachers themselves to possess sufficient AI literacy, pedagogical confidence, and ethical awareness. Without teacher readiness, AI integration may remain superficial or even counterproductive. Teachers need professional development that helps them understand GenAI capabilities and limitations, design AI-supported STEM tasks, create assessment strategies that value reasoning rather than mere answers, and establish ethical guidelines for classroom use.

Therefore, integrating AI literacy into STEM education is not merely a matter of introducing new digital tools; it is also a matter of preparing teachers and students to engage with AI as a learning resource that must be questioned, interpreted, and ethically managed (Daher, 2025). AI should not be positioned as a replacement for human reasoning, teacher expertise, or student inquiry. Rather, it should be understood as a socio-technical tool whose educational value depends on how it is used, guided, and critically examined within learning environments. For STEM education, the goal should be to cultivate learners who can use AI to support inquiry, creativity, and problem solving while also maintaining critical judgment, ethical responsibility, and epistemic awareness. In this way, AI literacy becomes an essential component of future-oriented STEM education, enabling students to participate responsibly in academic, professional, and social worlds increasingly shaped by artificial intelligence.

The rapid emergence of GenAI has created new opportunities and challenges for STEM classrooms. On one hand, GenAI can support personalized learning, content generation, brainstorming, explanation of complex concepts, and formative feedback. On the other hand, its use raises concerns about accuracy, privacy, academic integrity, bias, overreliance, and the weakening of students' critical reasoning (Siregar et al., 2026). Chan and Hu (2023) found that students recognized the benefits of GenAI for learning support, writing, brainstorming, and research, but they also expressed concerns about accuracy, privacy, ethical issues, and broader implications for personal and social development. Similarly, Valeri et al. (2025) reported that students used ChatGPT across STEM subjects, particularly to understand concepts, but their AI knowledge remained limited despite some ability to manage prompting and potential inaccuracies. In science education, Cooper (2023) warned that ChatGPT may risk positioning itself as an "ultimate epistemic authority" when answers appear authoritative without adequate evidence, qualification, or transparency. These findings indicate that the integration of AI literacy into STEM education must address not only how AI can assist learning, but also how teachers help students verify AI-generated information, recognize uncertainty, and maintain epistemic responsibility.

The research problem addressed in this study is that although AI literacy is increasingly recognized as important in education, there remains limited understanding of how STEM teachers perceive and experience the ethical, pedagogical, and epistemic challenges of integrating AI literacy into classroom practice. Existing research has

emphasized the importance of AI literacy frameworks, teacher readiness, and responsible AI use, yet many studies remain broad, conceptual, or focused on students' perceptions rather than teachers' situated classroom experiences. Ayanwale et al. (2022) showed that teachers' confidence and perceived relevance of AI are important predictors of their readiness and intention to teach AI, while Du et al. (2024) found that teachers' AI literacy, ethical awareness, and self-efficacy are closely related to their intention to learn AI. Zhai (2025) further argued that teachers' roles are being transformed in the GenAI era, requiring them to move beyond basic acceptance of AI toward informed pedagogical integration, professional agency, and co-construction of knowledge with AI-supported systems. However, for STEM teachers, these challenges are more complex because they must align GenAI use with disciplinary accuracy, inquiry learning, problem-solving processes, assessment validity, and students' critical engagement with evidence.

The objective of this study is to explore how STEM teachers perceive and experience the ethical, pedagogical, and epistemic challenges of integrating AI literacy into STEM education. This study focuses on three STEM teachers who were purposively selected based on their teaching experience and familiarity with digital or AI-supported learning practices. Using an exploratory qualitative multiple-case study design, the study seeks to capture the depth and complexity of teachers' perspectives rather than produce statistical generalization. Data are collected through semi-structured interviews, classroom observations, and analysis of instructional documents and AI-related teaching artifacts. This design is appropriate because ethical, pedagogical, and epistemic challenges are context-dependent and often embedded in teachers' instructional decisions, classroom interactions, assessment practices, and professional judgments. By using thematic analysis, followed by within-case and cross-case analysis, the study aims to identify both recurring patterns and case-specific differences across the three teacher participants.

The significance of this study lies in its contribution to the emerging discussion on responsible AI literacy integration in STEM education. Ethical challenges such as academic integrity, privacy, bias, transparency, and student dependence require teachers to establish clear norms for responsible AI use. Pedagogical challenges require teachers to redesign STEM tasks so that GenAI supports inquiry, reasoning, and conceptual understanding rather than replacing student thinking. Epistemic challenges require teachers to help students evaluate AI-generated explanations, distinguish evidence from unsupported claims, and avoid overtrust in fluent but potentially inaccurate outputs. This is important because overreliance on AI dialogue systems has been associated with risks to students' decision-making, critical thinking, and analytical reasoning (Zhai et al., 2024). In addition, assessment practices must be reconsidered because GenAI has disrupted conventional assumptions about academic integrity, task design, and students' independent work (Moorhouse et al., 2023). Thus, this study may provide practical insights for STEM teachers, curriculum designers, school leaders, and

researchers who seek to develop AI literacy practices that are ethically responsible, pedagogically meaningful, and epistemically rigorous.

This study is guided by four research questions. First, how do STEM teachers perceive the meaning and importance of AI literacy in STEM education? Second, what ethical challenges do STEM teachers experience when integrating AI literacy into STEM teaching and learning? Third, what pedagogical challenges emerge when teachers design and implement AI-supported STEM learning activities? Fourth, what epistemic challenges do teachers encounter when guiding students to evaluate, question, and use AI-generated knowledge in STEM learning? Together, these questions are intended to clarify how teachers understand AI literacy, how they manage the risks and possibilities of GenAI, and how they support students in becoming critical, responsible, and reflective users of AI in STEM contexts

METHODE

This study employed an exploratory qualitative multiple-case study design to examine how STEM teachers perceive and experience the ethical, pedagogical, and epistemic challenges of integrating AI literacy into STEM education in the era of generative artificial intelligence. This design was selected because the study sought to generate an in-depth understanding of teachers' situated experiences rather than produce statistical generalizations. Each teacher was treated as an individual case, allowing the study to explore how AI literacy was understood, interpreted, and implemented across different STEM teaching contexts. The multiple-case approach also enabled comparison across cases to identify both shared and distinctive patterns in teachers' ethical concerns, pedagogical decision-making, and epistemic challenges related to the use of GenAI in STEM learning.

The participants consisted of three STEM teachers who were purposively selected based on their teaching experience and familiarity with digital or AI-supported learning practices. Purposive sampling was used to ensure that the participants had relevant knowledge and practical experience related to the research focus. The selection of three teachers was appropriate for the exploratory nature of the study, as it allowed for detailed investigation of each participant's perspectives, instructional practices, and classroom experiences. The study focused on how these teachers conceptualized AI literacy, how they responded to the emergence of GenAI in STEM education, and how they addressed issues such as academic integrity, student dependence on AI-generated answers, data privacy, bias, assessment practices, and students' ability to evaluate AI-generated information.

Data were collected through semi-structured interviews, classroom observations, and analysis of instructional documents and AI-related teaching artifacts. Semi-structured interviews were used to obtain rich descriptions of teachers' perceptions, experiences, and reflections on integrating AI literacy into STEM education. The interview questions focused on teachers' understanding of AI literacy, ethical concerns in using GenAI, pedagogical strategies for AI-supported STEM learning, and epistemic

issues related to students' trust in AI-generated outputs. Classroom observations were conducted to examine how teachers introduced, guided, or responded to AI-related learning practices in authentic instructional settings. In addition, instructional documents and teaching artifacts, such as lesson plans, learning materials, assessment tasks, AI-generated outputs, prompts, and teacher reflections, were analyzed to provide further evidence of how AI literacy was embedded in STEM teaching practices.

The data were analyzed using thematic analysis to identify patterns related to ethical, pedagogical, and epistemic challenges. The analysis began with repeated reading of interview transcripts, observation notes, and instructional artifacts to gain familiarity with the data. Initial codes were then generated to capture meaningful units related to teachers' concerns, strategies, and classroom experiences. These codes were grouped into broader themes that reflected the major findings of the study, including ethical concerns about academic integrity, student dependence, data privacy, and bias; pedagogical challenges in designing AI-supported STEM tasks, aligning GenAI use with learning objectives, and developing appropriate assessment strategies; and epistemic challenges involving students' overtrust in AI outputs, limited ability to verify scientific accuracy, and difficulty distinguishing explanation from evidence.

Following the thematic analysis, within-case and cross-case analyses were conducted. The within-case analysis examined each teacher's experiences individually to understand the specific context, challenges, and instructional responses within each case. The cross-case analysis then compared the three cases to identify recurring and divergent patterns across participants. This analytical process allowed the study to capture both the common challenges STEM teachers faced and the contextual differences in how they integrated AI literacy into their teaching. To enhance the trustworthiness of the findings, data from interviews, observations, and document analysis were triangulated. This helped ensure that the findings were not based only on teachers' self-reported perceptions, but also supported by classroom practices and instructional artifacts. Overall, the methodology was designed to provide a rich, contextualized understanding of how STEM teachers experience and respond to the ethical, pedagogical, and epistemic demands of AI literacy integration in the GenAI era.

RESULT AND DISCUSSION

The findings of this study show that STEM teachers perceived AI literacy as an increasingly necessary competence in the era of generative artificial intelligence, but they also experienced its integration as ethically, pedagogically, and epistemically complex. Across the three cases, teachers did not view AI literacy merely as the ability to operate GenAI tools; rather, they understood it as the capacity to use, question, evaluate, and regulate AI-generated information in meaningful STEM learning. This finding is consistent with Ng et al. (2021), who conceptualized AI literacy as involving the ability to know and understand AI, use and apply AI, evaluate and create with AI, and address ethical issues related to AI systems. In this study, one teacher explained, "Students should not only know how to ask AI for answers; they need to know when

the answer is wrong, biased, or incomplete” (T1). This statement reflects the central position of AI literacy as a critical competence rather than a technical skill. From an interpretivist worldview, teachers' meanings and classroom experiences are important because AI literacy is not implemented in a neutral space; it is shaped by teachers' beliefs, students' habits, institutional expectations, and the epistemic demands of STEM subjects.

The first major finding concerns ethical challenges, particularly academic integrity, student dependence on AI-generated answers, data privacy, and the reproduction of bias. Teachers expressed concern that students might use GenAI to complete STEM assignments without demonstrating their own reasoning process. One teacher stated, “When students submit a perfect answer, I sometimes cannot see whether they understand the concept or only copied what AI generated” (T2). This finding suggests that GenAI complicates conventional assumptions about authorship, originality, and student accountability. The ethical issue is not only plagiarism, but also the possibility that students may bypass the cognitive struggle required in STEM learning. This aligns with Moorhouse et al. (2023), who found that institutional guidelines on GenAI and assessment commonly emphasize academic integrity, assessment redesign, and clear communication with students. However, the present study extends previous research by showing that these concerns are experienced directly by STEM teachers at the classroom level, where they must make immediate pedagogical judgments about whether AI use supports or weakens student learning.

Teachers also raised ethical concerns about privacy and bias. Although GenAI can support personalized learning and provide rapid explanations, teachers were uncertain about what student data might be entered into AI platforms and how such data might be processed. One participant commented, “I worry when students put their personal information or classroom tasks into AI tools without understanding where the data goes” (T3). This concern reflects the broader ethical dimension of AI literacy, in which responsible use requires awareness of datafication, transparency, and potential algorithmic bias. Chan and Hu (2023) similarly reported that students recognized GenAI's benefits for learning support, brainstorming, and research assistance, but also expressed concerns about accuracy, privacy, ethical issues, and social implications. The present study indicates that teachers function as ethical mediators who must help students recognize that AI tools are not value-free systems. Within a human-centered educational worldview, AI literacy should therefore include explicit discussion of fairness, accountability, privacy, bias, and the limits of automation in learning.

The second major finding relates to pedagogical challenges in designing meaningful AI-supported STEM tasks, aligning GenAI use with learning objectives, and developing appropriate assessment strategies. Teachers acknowledged that GenAI could help students explore ideas, generate examples, compare explanations, and receive immediate feedback. However, they also emphasized that AI use must be carefully structured so that it does not replace inquiry, reasoning, experimentation, and problem solving. As one teacher explained, “If I only ask students to use AI to get the

answer, the task becomes too easy. I have to design questions that make them compare, test, and justify the AI answer" (T1). This finding shows that GenAI integration requires a shift from answer-oriented tasks to reasoning-oriented tasks. It supports Casal-Otero et al. (2023), who found that AI literacy in K–12 education involves both learning experiences and theoretical frameworks that guide how AI can be meaningfully integrated into educational practice. In this study, meaningful AI integration occurred when teachers positioned GenAI as a tool for inquiry and reflection rather than as a direct answer provider.

The pedagogical challenge was also linked to teachers' readiness and confidence. The three teachers demonstrated interest in integrating AI literacy, but they differed in how confidently they could design AI-supported STEM activities. One teacher reported, "I know AI can help students learn science, but I still need examples of how to connect it with learning objectives and assessment" (T2). This finding is consistent with Ayanwale et al. (2022), who found that teachers' confidence in teaching AI predicted their intention to teach AI, while perceived relevance strongly predicted AI readiness. Du et al. (2024) also emphasized the importance of AI literacy in teacher learning, particularly because many teachers still need support to understand and use AI effectively in educational contexts. The present study confirms that teacher readiness is not only a matter of technological access; it also involves pedagogical design capacity, assessment literacy, and professional judgment. Therefore, professional development for STEM teachers should not focus only on how to use GenAI tools, but also on how to design AI-supported tasks that preserve disciplinary rigor, student agency, and conceptual understanding.

The third major finding concerns epistemic challenges, especially students' overtrust in AI outputs, limited ability to verify scientific accuracy, and difficulty distinguishing explanation from evidence. Teachers observed that students often accepted AI-generated responses because they were fluent, confident, and well-structured. One participant stated, "Students think the AI answer is correct because it sounds scientific, but they do not always check whether the explanation is supported by evidence" (T3). This finding is particularly important in STEM education, where knowledge claims should be evaluated through evidence, logic, calculation, experimentation, and disciplinary standards. Cooper (2023) similarly warned that ChatGPT may produce convincing science-related explanations, but educators still need to critically examine its role in science pedagogy because fluent responses can obscure uncertainty, error, or lack of evidence. The present study suggests that epistemic vigilance should become a core component of AI literacy in STEM education. Students must learn not only how to ask GenAI questions, but also how to verify, challenge, and revise AI-generated knowledge.

This epistemic challenge also reveals a potential tension between efficiency and deep learning. GenAI can make STEM learning faster by providing immediate explanations, but speed may reduce students' engagement with productive confusion, trial-and-error reasoning, and conceptual struggle. One teacher noted, "AI helps

students when they are stuck, but if they use it too early, they stop thinking through the problem by themselves” (T2). This finding corresponds with Zhai et al. (2024), who reported that overreliance on AI dialogue systems may affect students’ decision-making, critical thinking, and analytical reasoning. The interpretation offered by this study is that the problem is not GenAI itself, but unregulated dependence on AI-generated outputs. From a constructivist perspective, learning occurs when students actively build, test, and revise understanding. Therefore, GenAI should be positioned as a dialogic learning partner that stimulates reasoning, not as an epistemic authority that replaces students’ own thinking.

Viewed across the three cases, the findings indicate that ethical, pedagogical, and epistemic challenges are interconnected rather than separate. For example, academic integrity is not only an ethical issue; it is also pedagogical because teachers must redesign assessment, and epistemic because students must demonstrate how they know something rather than merely present a correct answer. Similarly, student dependence on AI is not only a behavioral problem; it reflects deeper questions about agency, responsibility, and knowledge construction. Zhai (2025) argues that GenAI is transforming teachers’ roles and agency, requiring teachers to move beyond basic adoption toward more informed, collaborative, and innovative pedagogical practices. The findings of this study support that argument by showing that STEM teachers act as designers of learning environments, ethical gatekeepers, and epistemic guides. Their role is not diminished by GenAI; rather, it becomes more complex because they must help students use AI critically, responsibly, and reflectively.

Compared with previous research, this study contributes a more situated account of how STEM teachers experience AI literacy integration in classroom practice. Previous studies have established the conceptual importance of AI literacy (Černý, 2024; Chiu, 2025; Kong et al., 2023; Ng et al., 2021; Shiri, 2024; Yi, 2021), mapped AI literacy research in school contexts (Casal-Otero et al., 2023), identified teacher readiness as a key factor in AI education (Ayanwale et al., 2022), and examined students’ perceptions of GenAI benefits and risks (Chan & Hu, 2023). While these studies provide essential theoretical and empirical foundations, the present study adds a more contextualized perspective by focusing on how teachers interpret, negotiate, and respond to AI literacy demands within actual STEM teaching environments. This is important because the integration of AI literacy is not only a conceptual or policy-level issue, but also a practical classroom issue shaped by teachers’ instructional decisions, students’ learning behaviors, available digital infrastructure, school expectations, and the epistemic characteristics of STEM knowledge.

This study extends those findings by showing how three STEM teachers negotiated these issues through concrete instructional concerns, such as task design, assessment validity, student dependence, privacy, bias, and verification of scientific knowledge. The teachers’ experiences indicate that AI literacy integration requires more than introducing students to GenAI tools or encouraging them to use AI for learning support (Zhang et al., 2025). Instead, it requires teachers to carefully consider how AI

use can be aligned with STEM learning objectives, how students' independent reasoning can be maintained, and how AI-generated outputs can be evaluated against disciplinary standards. In STEM learning, the accuracy of explanations, the validity of evidence, and the logic of problem-solving procedures are central. Therefore, when students use GenAI to generate answers, explanations, summaries, or problem-solving steps, teachers must ensure that students do not treat AI outputs as final truths. Rather, students should be guided to compare, question, justify, and revise AI-generated information using scientific evidence, mathematical reasoning, or technological design principles.

The findings also demonstrate that teachers occupy a central role in transforming GenAI from a potentially disruptive technology into a meaningful pedagogical resource. Teacher readiness, as emphasized in previous research (Ayanwale et al., 2022), is not limited to teachers' willingness to adopt AI tools. It also involves teachers' ability to design learning activities that promote critical thinking, responsible AI use, and epistemic awareness. For example, a teacher may use GenAI to help students explore multiple explanations of a science concept, but the task becomes educationally meaningful only when students are required to evaluate which explanation is most accurate, identify possible misconceptions, and support their judgment with evidence. Similarly, in mathematics or engineering tasks, GenAI may be used to generate possible solution pathways, but students still need to examine whether the reasoning process is valid and whether the solution meets the requirements of the problem. In this sense, AI literacy becomes closely connected to STEM literacy because both require students to evaluate knowledge claims, apply logical reasoning, and make informed decisions.

The ethical dimension of AI literacy was also evident in teachers' concerns about academic integrity, privacy, bias, and student dependence. These concerns resonate with broader discussions about the benefits and risks of GenAI in education (Chan & Hu, 2023). However, this study shows that such ethical issues become more complex when they are embedded in everyday classroom practice. Teachers must decide whether students are allowed to use GenAI for assignments, how AI assistance should be disclosed, what types of AI use are considered acceptable, and how to prevent students from becoming overly dependent on AI-generated answers. Privacy also becomes a significant concern because students may enter personal information, classroom data, or school-related materials into AI platforms without fully understanding how such data may be stored, processed, or reused. Bias is another important issue because AI-generated explanations may reproduce social, cultural, linguistic, or scientific distortions that students may not easily recognize. Therefore, responsible AI literacy must include explicit classroom discussions about transparency, fairness, accountability, and the limitations of algorithmic systems.

The findings also suggest that AI literacy in STEM education should be framed through a responsible, human-centered, and epistemically rigorous worldview (Hsu & Lao, 2025). In this view, GenAI is neither rejected as a threat nor accepted uncritically as an innovation. Instead, it is treated as a socio-technical learning resource whose

educational value depends on teachers' ability to design ethical norms, pedagogical scaffolds, and epistemic practices that support critical STEM learning. A human-centered approach means that AI should support, rather than replace, human judgment, teacher expertise, student agency, and collaborative inquiry. Teachers remain essential because they help students interpret AI outputs, connect AI-generated information with disciplinary concepts, and reflect on the ethical implications of using AI in learning. An epistemically rigorous approach means that students must be taught to ask not only whether an AI answer is useful, but also whether it is accurate, evidence-based, logically sound, and appropriate for the task.

Consequently, this study contributes to the literature by shifting attention from general discussions of AI literacy toward the lived pedagogical realities of STEM teachers. It shows that AI literacy integration is a multidimensional process involving ethical regulation, instructional design, assessment reform, and knowledge validation. The study also highlights that GenAI should not be understood merely as a tool for efficiency or productivity. In STEM education, its deeper value lies in its potential to stimulate inquiry, comparison, critique, and reflection when teachers design learning environments that require students to engage actively with AI-generated content. Therefore, future AI literacy initiatives in STEM education should provide teachers with practical frameworks, classroom examples, assessment strategies, and ethical guidelines that help them integrate GenAI responsibly. By foregrounding teachers' situated experiences, this study offers a grounded contribution to the development of AI literacy practices that are not only technologically relevant, but also pedagogically meaningful, ethically responsible, and epistemically robust.

Overall, the findings suggest that integrating AI literacy into STEM education requires more than introducing GenAI tools into classrooms. It requires a deliberate instructional framework that helps students understand AI systems, use them responsibly, evaluate their outputs, and connect AI-supported learning with STEM reasoning. Ethical challenges require explicit classroom norms on privacy, bias, academic integrity, and responsible use. Pedagogical challenges require teachers to design tasks that use GenAI to support inquiry, explanation, comparison, and reflection rather than shortcut learning. Epistemic challenges require students to verify AI-generated claims, examine evidence, and maintain critical distance from fluent but potentially inaccurate responses. Therefore, this study highlights the need for STEM teacher professional development that integrates AI literacy, ethical awareness, pedagogical design, and epistemic vigilance. Such integration is essential for creating STEM learning environments that are not only technologically enhanced, but also critical, responsible, and intellectually rigorous.

CONCLUSION

This study concludes that the integration of AI literacy into STEM education is both necessary and complex in the era of generative artificial intelligence. Based on the experiences of three STEM teachers, the findings show that AI literacy cannot be

understood merely as the technical ability to use AI tools, but must also include ethical awareness, pedagogical judgment, and epistemic responsibility. The first major finding indicates that teachers were concerned about ethical issues such as academic integrity, students' dependence on AI-generated answers, data privacy, and the potential reproduction of bias. The second finding highlights pedagogical challenges, particularly in designing meaningful AI-supported STEM tasks, aligning GenAI use with learning objectives, and developing assessment strategies that can still capture students' own reasoning and conceptual understanding. The third finding reveals epistemic challenges, especially students' tendency to overtrust AI outputs, their limited ability to verify scientific accuracy, and their difficulty distinguishing AI-generated explanations from evidence-based knowledge. Together, these findings suggest that GenAI has the potential to support STEM learning, but only when its use is guided by critical, responsible, and reflective AI literacy practices.

The implications of this study are particularly relevant to contemporary educational issues, as schools and teachers are increasingly confronted with the rapid adoption of GenAI in learning environments. STEM teachers need to move beyond treating AI as a supplementary digital tool and begin positioning AI literacy as an essential part of STEM learning. This means that students should be guided not only to use GenAI for inquiry, problem solving, and content generation, but also to question its outputs, identify possible errors, evaluate evidence, and reflect on the ethical consequences of AI use. For teachers, the findings imply the need for professional development that focuses on responsible AI integration, AI-supported lesson design, assessment redesign, academic integrity, privacy protection, bias awareness, and epistemic vigilance. For curriculum developers and policymakers, the study suggests that AI literacy should be embedded into STEM education frameworks so that students are prepared to participate in future academic, professional, and social contexts shaped by artificial intelligence.

Further research is recommended to expand the scope of this study by involving a larger and more diverse group of STEM teachers across different school levels, disciplines, and institutional contexts. Since this study involved only three teachers, future studies may use broader qualitative, mixed-methods, or comparative designs to examine whether similar ethical, pedagogical, and epistemic challenges appear in other STEM learning environments. Future research could also include students' perspectives to understand how learners actually experience, interpret, and use GenAI in STEM tasks. In addition, experimental or design-based research could be conducted to develop and evaluate AI literacy modules, GenAI-supported STEM activities, or assessment models that promote critical thinking and responsible AI use. Longitudinal studies are also needed to examine how teachers' AI literacy, pedagogical strategies, and ethical decision-making evolve over time as GenAI becomes more deeply integrated into educational practice.

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