

Artificial Intelligence Use and Learner Autonomy Among Secondary Students: The Roles of AI Literacy and Metacognitive Self-Regulation

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Publication history:

Received: December 20, 2025

Accepted: October 2, 2026

Revised: April 13, 2026

Published: October 3, 2026

International Journal of Sustainable and Integrated Studies, Vol. 1, No. 2, pp. 74–81, September 2026.

Abstract

The increasing use of artificial intelligence (AI) in secondary education has created new opportunities for personalized support, immediate feedback, problem-solving, and self-directed learning, while also raising concerns about students' reliance on AI-generated information. This narrative literature review examined AI use and learner autonomy among secondary students, with particular attention to the roles of AI literacy and metacognitive self-regulation. Recent literature published primarily from 2021 to 2026 was identified, screened, and synthesized through narrative and reflexive thematic analysis. Across the reviewed studies, AI supported learner autonomy most clearly when students used it for exploration, feedback, problem-solving, and self-regulated learning rather than as a substitute for independent thinking. AI literacy helped students understand AI, evaluate generated information, recognize its limitations, and make responsible decisions about its use. Metacognitive self-regulation, in turn, supported students in planning, monitoring, and evaluating their learning while working with AI. The literature also pointed to challenges, including excessive reliance on AI, limited AI knowledge, inconsistent learner engagement, and differences in self-regulatory abilities. Overall, learner autonomy in AI-supported settings depends on how students use the technology and on the development of AI literacy and metacognitive self-regulation with appropriate teacher guidance. The study contributes primarily to Sustainable Development Goal 4 (Quality Education) by supporting responsible and learner-centered integration of AI in secondary education. From a sustainability perspective, strengthening students' critical and self-regulatory competencies may promote more responsible, adaptable, and sustainable use of emerging digital technologies in education.

Keywords: AI Literacy; Artificial Intelligence; Learner Autonomy; Metacognitive Regulation; Secondary Education; Self-Regulation; Sustainability

1. Introduction

Artificial intelligence (AI) has become increasingly common in education, especially with the availability of tools that can generate text, explain lessons, answer questions, provide feedback, and assist students with different academic tasks. Generative AI has made learning support more accessible, allowing students to obtain information and assistance even outside the classroom. However, its growing use has also raised concerns about how students learn when AI becomes part of their everyday academic activities. UNESCO emphasized that generative AI should be used through a human-centered approach in which technology supports learning without replacing human thinking and decision-making (Miao & Holmes, 2023). Similarly, the Organization for Economic Co-operation and Development discussed the potential of digital technologies and AI to support personalized learning while recognizing the importance of students' motivation, effort, and ability to regulate their learning (OECD, 2023).

Because of these developments, it is important to look beyond how often students use AI and consider how its use may influence their ability to learn independently. Learner autonomy is important in this discussion because AI gives students greater opportunities to manage certain aspects of their learning without depending entirely on their teachers. Students can use AI to ask questions, clarify difficult concepts, generate ideas, and receive immediate feedback. These functions may encourage students to take a more active role in deciding what and how they learn. However, simply having access to AI does not automatically make students independent learners. Studies suggest that the way students use AI and the guidance they receive can influence whether the technology supports or limits independent learning (Almohesh, 2024; Alsuwaylim et al., 2026). Research involving senior high school students also indicates that students differ in how independently and reflectively they use ChatGPT, suggesting that access to AI alone may not be enough to develop learner autonomy (Keumala et al., 2026).

One factor that may help explain these differences is AI literacy. AI literacy involves more than knowing how to use an AI application or enter prompts. It also includes understanding how AI works, evaluating the information it produces, applying it appropriately, and recognizing ethical issues related to its use. Ng et al. (2021) described AI literacy through competencies involving understanding AI, using and applying AI, evaluating and creating with AI, and considering its ethical implications. UNESCO also identified a human-centered mindset, ethics of AI, AI techniques and applications, and AI system design as important areas of student AI competency (Miao et al., 2024). These skills are particularly important for secondary students because AI-generated information should not always be accepted without question. Students need to determine whether information is accurate and appropriate and whether using AI for a particular task actually contributes to their learning. Recent studies further show why AI literacy deserves attention among secondary students. Zhong and Liu (2025) developed an AI literacy framework for secondary students that considers areas such as AI knowledge, attitudes, and thinking. In the Philippines, Co et al. (2026) examined AI literacy among senior high school students and reported widespread use of AI tools, including ChatGPT, while also showing that students often learned about AI through informal sources and interactions with their peers. This suggests that frequent exposure to AI does not necessarily mean that students have received enough structured preparation to use it critically and responsibly. As AI becomes more common in schoolwork, understanding students' AI literacy becomes increasingly relevant when examining their ability to learn independently.

Metacognitive self-regulation is central to independent learning because students must plan how to approach a task, monitor their understanding, adjust strategies when difficulties arise, and evaluate their progress. These processes may become especially important when AI can produce answers and explanations almost immediately. Simply copying or accepting AI-generated responses can reduce opportunities for students to develop their own understanding. By contrast, questioning, verifying, comparing, and reflecting on AI-generated information can allow students to use AI as a learning resource while remaining actively involved in the learning process. Research on AI and self-regulated learning has shown increasing interest in this relationship, although important gaps remain in understanding how AI affects students' self-regulatory learning processes across different educational settings (Banihashem et al., 2025). In this context, AI literacy and metacognitive self-regulation address different but related aspects of learner autonomy: the former supports informed and critical use of AI, while the latter keeps students actively engaged in managing their own learning. Students with these abilities may be better prepared to judge when AI assistance is useful, evaluate the responses they receive, and continue thinking independently. Heavy reliance on AI without evaluating its outputs, however, may shift responsibility for academic tasks away from the learner. Hamamra et al. (2026) found that AI literacy influenced how university students engaged with ChatGPT-supported writing and showed that learner autonomy in AI-supported environments involves an active process rather than simply using the technology. Although findings involving university students cannot automatically be applied to secondary students, they provide an important basis for examining similar relationships among younger learners.

The growing role of AI in education is also receiving attention at both international and national levels. UNESCO has emphasized the need for students to develop the knowledge, skills, values, and attitudes necessary to use AI responsibly while maintaining human judgment and agency (Miao et al., 2024). The OECD has similarly emphasized that successful digital transformation in education requires more than simply providing technological tools; students and educational institutions also need the competencies and practices necessary to use these technologies meaningfully (OECD, 2023). These perspectives show that the educational value of AI depends not only on what the technology can do but also on how students understand and use it. In the Philippines, AI is also becoming an important part of discussions about the future of basic education. The Department of Education established the Education Center for AI Research to support research and innovation involving AI in teaching, learning, and educational administration (Department of Education, 2025). The Basic Education Artificial Intelligence Framework further provides guidance for the responsible adoption of AI in Philippine basic education and emphasizes areas such as AI literacy, ethical awareness, human agency, inclusion, and appropriate educational use (Department of Education, 2026). These developments show that AI is becoming increasingly relevant to Philippine schools and highlight the importance of preparing students to use these technologies without losing their ability to think and learn independently.

Despite the increasing number of studies on AI in education, there are still areas that require further examination. Much of the available research has focused on university students, ChatGPT perceptions, academic performance, language learning, or the general advantages and disadvantages of generative AI. Research specifically examining secondary students remains developing, particularly studies that consider AI use, AI literacy, metacognitive self-regulation, and learner autonomy together. Frequent use of AI should also not automatically be interpreted as effective or independent learning. Understanding these relationships is important in determining how AI can serve as a learning support while allowing students to remain active and responsible participants in their education. Therefore, this review examines artificial intelligence use and learner autonomy among secondary students, with particular attention to the roles of AI literacy and metacognitive self-regulation. It brings together existing literature to understand how students' ability to use and evaluate AI, together with their capacity to plan, monitor, and reflect on their learning, may influence independent learning in AI-supported environments. Rather than assuming that AI is either beneficial or harmful to education, the review considers how students' knowledge, behaviors, and learning skills may influence the way AI affects their autonomy.

This study is primarily connected to Sustainable Development Goal 4 (SDG 4), which promotes inclusive and equitable quality education and lifelong learning opportunities. Developing AI literacy, learner autonomy, and self-regulation may help students become more responsible and capable learners in increasingly digital educational environments. The study also relates to Sustainable Development Goal 9 (SDG 9) because it considers the responsible use of technological innovation in education. From a broader sustainability perspective, the topic contributes to educational and digital sustainability by examining how schools can benefit from emerging technologies while maintaining critical thinking, responsible technology use, and human involvement in learning. Sustainable use of AI in education should therefore involve not only access to new technologies but also the development of students who can use these tools critically, responsibly, and independently.

2. Material and methods

2.1 Research Design

The study used a narrative literature review supported by reflexive thematic analysis. Narrative reviews provide a flexible approach for bringing together literature from different research designs and perspectives while allowing researchers to interpret patterns, relationships, and gaps within an existing body of knowledge (Sukhera, 2022). This design was appropriate because research concerning AI use, learner autonomy, AI literacy, and metacognitive self-regulation include quantitative, qualitative, mixed-methods, intervention, and review studies conducted across different educational settings. Rather than statistically combining findings, the study synthesized the literature to identify common patterns and differences across the available evidence. Reflexive thematic analysis was used to support the identification and interpretation of recurring patterns within the selected literature. This approach allows themes to be developed through an interpretive process of familiarization, coding, theme development, review, and refinement (Byrne, 2022). Braun and Clarke (2021) emphasize that reflexive thematic analysis involves active researcher engagement in interpreting patterns of meaning rather than treating themes as findings that simply emerge from the data. In this review, the analysis focused on how students use AI for learning, how AI literacy influences their understanding and evaluation of AI-generated information, and how metacognitive and self-regulatory processes may contribute to learner autonomy.

2.2 Locale of the Study

The review was not limited to a single geographical location. It considered research conducted in different secondary education settings to provide a broader understanding of AI-supported learning. The reviewed literature included evidence from Asian and other international educational contexts, with Philippine literature included where directly relevant. Studies from different geographical settings were considered because the use of AI among secondary students is an emerging educational issue that extends across educational systems. Literature from higher education was considered only when it provided relevant theoretical or supporting evidence concerning learner autonomy, AI literacy, or self-regulated learning that could help explain concepts that remain underexplored among secondary students.

2.3 Respondents of the Study

As a narrative literature review, this study did not directly recruit human respondents. Instead, published empirical studies and relevant scholarly reviews served as the units of analysis. Priority was given to studies involving secondary and senior high school students. The identified literature included studies involving secondary learners engaged in AI-supported learning, AI literacy education, generative AI use, self-regulated learning, and learner autonomy. Literature involving other educational populations was used selectively when it provided important conceptual evidence concerning AI literacy, learner autonomy, metacognition, or self-regulated learning.

2.4 Sample and Sampling Procedure

Purposive literature selection was used to identify publications relevant to the objectives of the review. Narrative reviews require clearly defined boundaries and transparent justification for the literature included in the synthesis (Sukhera, 2022). The primary search period therefore covered studies published from 2021 to 2026, with emphasis on recent empirical research addressing the growing use of generative AI in education. Earlier publications were considered when necessary to provide essential theoretical or conceptual foundations. Studies were considered for inclusion when they addressed educational AI and at least one of the central concepts of the review, including AI literacy, learner autonomy, metacognitive self-regulation, or self-regulated learning. Empirical research involving secondary or senior high school students received priority. Relevant review studies were also considered to establish broader patterns and research gaps. Publications were excluded when they did not concern educational applications of AI, lacked meaningful relevance to learner autonomy or self-regulatory processes, or focused primarily on technological development without relevant learner or educational outcomes. Studies involving university students were considered selectively for conceptual support and were not treated as direct evidence concerning secondary students.

2.5 Research Instrument

Predetermined literature-selection criteria and a thematic coding framework served as the primary means of organizing and evaluating the documentary evidence. The selection criteria considered publication period, educational population, relevance to AI-supported learning, and contribution to the major concepts of the review. During analysis, relevant findings and recurring concepts were identified and organized according to AI use, learner autonomy, AI literacy, metacognitive self-regulation, self-regulated learning, AI reliance, ethical AI use, and educational implications. Consistent with reflexive thematic analysis, coding was treated as an interpretive process used to identify meaningful patterns across the selected literature (Braun & Clarke, 2021; Byrne, 2022).

2.6 Data Gathering Procedure

Relevant literature was identified through searches of scholarly databases, publisher platforms, and academic search resources, including Google Scholar, ERIC, ScienceDirect, SpringerLink, and Wiley Online Library. Searches used combinations of terms such as “artificial intelligence in education,” “generative AI,” “ChatGPT,” “secondary students,” “high school students,” “AI literacy,” “learner autonomy,” “self-directed learning,” “metacognitive self-regulation,” and “self-regulated learning.” Clear reporting of search boundaries, information sources, and selection decisions contributes to the transparency of narrative literature reviews (Sukhera, 2022). Titles and abstracts were initially examined for relevance to the study objectives. Publications addressing secondary education, AI literacy, AI-supported independent learning, learner autonomy, metacognition, or self-regulated learning were examined more closely. Recent secondary-level empirical research was prioritized, while relevant review literature was used to provide broader context and identify research gaps. Selected publications were subsequently reread and organized according to the major concepts addressed in the review.

2.7 Data Analysis Techniques

The selected literature was analyzed through narrative synthesis and reflexive thematic analysis. Following the general process described by Byrne (2022), analysis involved familiarization with the literature through repeated reading, generation of relevant codes, development of potential themes, review and refinement of themes, and interpretation of the resulting patterns. The process was iterative rather than strictly linear, allowing themes to be reconsidered as relationships among findings became clearer. Coding focused on recurring concepts related to students’ purposes for using AI, AI literacy and critical evaluation of AI-generated information, reliance on generative AI, learner autonomy, metacognitive self-regulation, and self-regulated learning. Related codes were grouped into broader themes representing meaningful patterns across the literature. Reflexivity was maintained by recognizing that theme development involved researcher interpretation rather than assuming that themes existed independently within the reviewed studies (Braun & Clarke, 2021). Findings were compared across educational settings and research designs rather than treated as directly equivalent. Evidence from secondary-school populations was given greater emphasis when interpreting implications for secondary students. The synthesis considered both the potential benefits and limitations of AI-supported learning and was used to explain how AI literacy and metacognitive self-regulation may influence whether AI supports independent learning or contributes to greater reliance on technological assistance.

3. Results and Discussion

3.1 Artificial Intelligence Use and Learner Autonomy Among Secondary Students

3.1.1 Patterns and Purposes of Artificial Intelligence Use

Recent evidence shows that secondary students use generative AI for different learning purposes. Ma et al. (2026) examined 278 students from 22 secondary schools and found that students used ChatGPT for self-directed second-language learning through functions such as conversational practice, personalized feedback, input enhancement, and task generation. Students used AI as an additional source of learning support, although patterns of use varied across the participants. In practical terms, this use can give secondary students more flexibility in obtaining

learning assistance outside direct classroom instruction. They can seek explanations, generate practice activities, obtain feedback, and explore learning materials according to their individual needs. Access to these functions, however, does not by itself establish learner autonomy. What matters is whether students continue making decisions about their learning rather than transferring those decisions entirely to the technology (Ma et al., 2026).

3.1.2 Artificial Intelligence as a Support for Independent Learning

Evidence from secondary education indicates that appropriately designed AI tools can support some aspects of self-regulated and independent learning. Ng et al. (2024) conducted a three-week science-learning study involving 74 Secondary 4 students in Hong Kong. Students using a generative AI-based self-regulated learning chatbot demonstrated improvements in science knowledge, behavioral engagement, and motivation. The number of interactions with the chatbot was also associated with variation in self-regulated learning. The findings suggest that generative AI can function as a learning scaffold when it is deliberately integrated into educational activities. Rather than simply providing answers, AI can be designed to encourage students to maintain learning routines, engage with academic content, and regulate aspects of their learning. Nevertheless, the results should not be interpreted as evidence that any use of generative AI will improve learner autonomy. The structured learning environment, guidance provided to students, and design of the AI-supported activity remain important considerations (Ng et al., 2024).

3.1.3 Risks of Artificial Intelligence Reliance and Reduced Learner Independence

The reviewed literature also identifies the risk of students becoming reliant on generative AI. Cruz et al. (2026) investigated 595 secondary-level students in the Philippines and found a mean AI literacy score of 8.71 out of 20, which the authors interpreted as limited understanding of generative AI. Their regression analysis showed that AI literacy was a significant negative predictor of AI reliance. In other words, students with greater AI knowledge tended to report lower reliance on generative AI. AI literacy and ethical practices together explained 6.02% of the variance in AI reliance. These findings provide particularly relevant evidence that frequent or convenient access to AI should not be equated with effective independent learning. Students who lack sufficient understanding of AI may be less prepared to recognize its limitations and determine when its assistance should or should not be used. At the same time, the relatively small proportion of variance explained by AI literacy and ethical practices indicates that AI reliance is likely influenced by additional factors. Learner autonomy should therefore be understood as involving not only access to AI but also students' capacity to make informed decisions about when, why, and how the technology is used (Cruz et al., 2026).

3.2 Challenges Affecting Learner Autonomy in AI-Supported Learning

Several challenges may affect the development of learner autonomy in AI-supported environments. These include differences in AI literacy, the possibility of excessive reliance on generated responses, difficulties in critically evaluating AI output, and variations in students' ability to regulate their own learning. Cruz et al. (2026) demonstrated that secondary students may use generative AI despite having limited knowledge about the technology, while Fütterer et al. (2026) showed that providing structured generative AI support does not necessarily produce improvements across all dimensions of self-regulated learning. The randomized controlled trial conducted by Fütterer et al. (2026) involved 371 students in Grades 7–9 who participated in six learning sessions. Students received either generative AI support targeting utility value, AI support targeting cognitive learning strategies, or standard ChatGPT access. The utility-value intervention showed more favorable development in perceived utility value compared with the cognitive-strategy condition. However, neither intervention demonstrated significant advantages over standard ChatGPT for effort, domain-specific knowledge, or elaboration-based strategy use. Exploratory findings suggested that students who engaged more meaningfully with the AI showed more sustained interest. These results demonstrate that simply adding prompts or AI-based support to learning activities may not be sufficient to improve students' self-regulation. The quality of student engagement appears important. AI can provide opportunities for personalized support, but students must still process information, evaluate responses, select appropriate strategies, and remain cognitively involved in the learning activity. Consequently, the challenge for secondary education is not merely providing access to AI but designing learning experiences that maintain student agency and active participation (Fütterer et al., 2026).

3.3 Roles of AI Literacy and Metacognitive Self-Regulation

3.3.1 AI Literacy and Critical Use of Artificial Intelligence

AI literacy was consistently relevant to how students engaged with artificial intelligence. Zhong and Liu (2025) developed and validated an AI literacy framework specifically for secondary students. Based on 1,392 valid responses, the framework identified three major dimensions: AI Knowledge, AI Affectivity, and AI Thinking. The framework emphasizes that AI literacy among secondary students extends beyond technical knowledge and includes attitudes toward AI and higher-order thinking about the technology. Evidence also shows that these competencies can be developed through structured educational experiences. Kong et al. (2024) evaluated a 14-hour project-based AI literacy course involving 128 senior secondary students. After completing the course, students demonstrated improvement in their ability to apply AI concepts to real-life problem-solving. Self-report findings also indicated significant improvement in metacognitive strategies for problem-solving and greater

understanding of ethical principles and boundaries related to AI. Across these studies, AI literacy involves more than learning how to operate AI tools. Students also need opportunities to understand how AI works, critically consider its output, recognize ethical concerns, and determine when AI assistance is appropriate. The negative relationship between AI literacy and reliance reported by Cruz et al. (2026) further supports the importance of developing students' understanding of AI. Strengthening AI literacy may help students become more deliberate users of technology rather than passive recipients of AI-generated information (Cruz et al., 2026; Kong et al., 2024; Zhong & Liu, 2025).

3.3.2 Metacognitive Self-Regulation in AI-Supported Learning

Metacognitive self-regulation also appeared repeatedly across the reviewed studies. Effective self-regulated learning requires students to take an active role in their learning processes by selecting strategies, monitoring progress, evaluating understanding, and modifying their approach when necessary. Ng et al. (2024) demonstrated that a generative AI-based chatbot designed specifically around self-regulated learning could improve behavioral engagement, motivation, and science knowledge among secondary students. Kong et al. (2024) also reported significant improvement in students' metacognitive strategies following participation in an AI literacy course. Considered together, these findings show that learning about AI and reflecting on one's own learning processes can develop within the same educational experience. Carefully structured AI education can require students to consider how they solve problems, evaluate technological assistance, and judge the appropriateness of AI-generated solutions. Fütterer et al. (2026), however, provide an important qualification. Their randomized controlled trial did not find consistent benefits of generative AI interventions across strategy use, effort, and domain-specific knowledge. AI-supported prompts alone, therefore, cannot be assumed to strengthen self-regulation. Students still need to engage meaningfully with the activity and apply appropriate learning strategies. AI may provide scaffolding, but responsibility for monitoring and regulating learning remains with the student.

3.3.3 Interaction of AI Literacy, Self-Regulation, and Learner Autonomy

Across the reviewed studies, learner autonomy appears closely connected to two capacities: understanding AI well enough to evaluate its output and regulating one's own learning while using it. Zhong and Liu (2025) showed that secondary-student AI literacy incorporates knowledge, affective dimensions, and higher-order thinking. Kong et al. (2024) further demonstrated that structured AI literacy education can develop alongside metacognitive problem-solving strategies. Studies of students' actual interactions with generative AI provide additional context. Ng et al. (2024) demonstrated that AI designed around self-regulatory processes could support engagement and learning, while Ma et al. (2026) showed that secondary students can use ChatGPT as a companion for self-directed learning. Conversely, Cruz et al. (2026) found that stronger AI literacy was associated with lower AI reliance. Taken as a whole, this evidence indicates that learner autonomy involves more than having independent access to AI. Students must still evaluate AI responses, regulate their learning behavior, and retain responsibility for academic decisions. These relationships should not be interpreted as a proven causal pathway in which AI literacy automatically produces metacognitive self-regulation and learner autonomy. The reviewed studies differ in research design, population, learning context, and outcomes. The literature instead points to these concepts as interconnected factors that may shape how effectively secondary students use AI for independent learning.

3.4 Implications for Secondary Education

The findings have practical implications for secondary education. Rather than treating generative AI only as something to permit or restrict, schools can also consider how students are being prepared to use it. Evidence from Fütterer et al. (2026) and Ng et al. (2024) shows that outcomes vary with students' engagement, self-regulatory abilities, and the design of AI-supported instruction. Structured AI literacy education is therefore relevant to this preparation. Zhong and Liu (2025) emphasize AI knowledge, affectivity, and higher-order thinking, while Kong et al. (2024) provide empirical evidence that project-based AI literacy instruction can improve problem-solving competence, metacognitive strategies, and ethical understanding. In the Philippine context, Cruz et al. (2026) further demonstrate the importance of AI literacy by showing that greater AI literacy was associated with lower AI reliance among secondary-level students. Teacher involvement also remains important in the development of learner autonomy. Ma et al. (2026) emphasize the continuing importance of teacher guidance and scaffolding in AI-assisted self-directed learning. Teachers can help students formulate effective prompts, verify AI-generated information, compare sources, recognize inappropriate reliance, and reflect on whether the use of AI contributes to genuine understanding. Across the literature, AI is most useful for learner autonomy when students remain active participants in the learning process. AI literacy supports critical evaluation of the technology, while metacognitive self-regulation helps students maintain control over how they learn. With these competencies in place, AI can serve as a resource for feedback, exploration, problem-solving, and self-directed learning. Without them, increased use of AI may not translate into stronger independent learning skills.

4. Conclusion & Recommendations

This narrative review shows that artificial intelligence has the potential to support learner autonomy among secondary students by providing accessible learning assistance, feedback, opportunities for problem-solving, and support for self-directed and self-regulated learning. However, the findings indicate that the benefits of AI are not automatic and depend largely on how students understand, evaluate, and regulate their use of the technology. AI literacy enables students to use AI more critically and responsibly, while metacognitive self-regulation helps them plan, monitor, and evaluate their learning. The reviewed evidence also highlights the risk of excessive AI reliance when students use generated information without sufficient critical evaluation or active engagement. Overall, AI appears most beneficial when it functions as a learning support rather than a substitute for students' own thinking, decision-making, and responsibility for learning.

Secondary schools are encouraged to integrate AI literacy and metacognitive self-regulation into teaching and learning rather than focusing only on allowing or restricting the use of generative AI. Students should be taught how to critically evaluate AI-generated information, verify responses using reliable sources, recognize the limitations and ethical concerns associated with AI, and reflect on how AI affects their own learning processes. Teachers should continue to provide guidance and structured opportunities for students to use AI for exploration, feedback, problem-solving, and independent learning while maintaining active student participation. Future research should further examine how AI literacy and metacognitive self-regulation relate to learner autonomy among secondary students, particularly through longitudinal, experimental, and context-specific studies, including research within Philippine secondary education.

This study is limited by its narrative review design and therefore does not provide the exhaustive search, formal quality appraisal, or statistical synthesis expected in a systematic review or meta-analysis. Although priority was given to recent literature involving secondary and senior high school students, research directly examining the combined relationships among AI use, AI literacy, metacognitive self-regulation, and learner autonomy at the secondary level remains developing. The reviewed studies also differed in educational setting, research design, AI application, sample characteristics, and measured outcomes, which limits direct comparison and generalization across contexts. In addition, the rapid development of generative AI means that new technologies and evidence may emerge after the review period. The conclusions should therefore be interpreted as a synthesis of the available literature rather than as evidence of a definitive causal relationship among the major concepts examined.

5. Compliance with ethical standards

The authors affirm that no conflicts of interest exist in relation to this study. As a narrative literature review, the study did not directly recruit human participants or collect primary data; instead, it analyzed information from published scholarly literature. The review was conducted by accurately representing the findings of the included sources and appropriately acknowledging the original authors through citation.

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