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Preparing Future Generations Amid the Development of Artificial Intelligence: A Literature Review of Digital Literacy, Ethics, and Self-Directed Learning among Elementary School Students

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ABSTRACT

The rapid development of artificial intelligence (AI) is transforming elementary education, creating opportunities for personalized learning while raising concerns about information reliability, ethical responsibility, and student autonomy. This study aimed to synthesize how digital literacy, ethical awareness, and self-directed learning can contribute to preparing elementary school students for AI-integrated education. An integrative literature review was conducted using relevant scholarly publications, primarily published between 2021 and 2026. The literature was examined through qualitative content analysis and thematic synthesis to identify key concepts, recurring findings, educational challenges, and relationships among the three dimensions. The findings indicate that digital literacy requires students to critically evaluate AI-generated information, verify claims, and recognize the limitations of automated systems. Ethical awareness encompasses responsible technology use, privacy protection, fairness, academic integrity, and informed decision-making. Meanwhile, self-directed learning involves setting learning goals, selecting appropriate resources, monitoring understanding, and reflecting on learning outcomes. Although AI can facilitate exploration, feedback, and personalized learning, its educational benefits are not guaranteed and depend on instructional design, teacher guidance, and students' active engagement. This study proposes an integrated conceptual framework in which digital literacy, ethical awareness, and self-directed learning function as mutually reinforcing dimensions of AI readiness, supported by teachers, schools, and families. The review concludes that preparing elementary school students for an AI-mediated future requires an educational approach that combines critical judgment, ethical responsibility, and learner agency. Further empirical research is needed to validate the framework and examine its applicability across diverse educational contexts.

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INTRODUCTION

The rapid development of artificial intelligence (AI) is transforming how information is produced, accessed, evaluated, and used in educational environments. For elementary school students, these changes create opportunities to develop technological understanding and independent learning skills, but they also raise concerns about digital responsibility, ethical judgment, information reliability, and excessive dependence on AI-generated responses. Consequently, preparing future generations requires more than teaching children to operate digital devices; it requires an integrated educational approach that enables them to understand digital technologies, use AI responsibly, and maintain an active role in their own learning. International research has increasingly positioned AI literacy as a multidimensional competence involving technical understanding, conceptual knowledge, and the ability to apply AI in meaningful contexts (Casal-Otero et al., 2023). Similarly, research on AI education in primary and secondary schools indicates that learning activities can support cognitive and affective outcomes, although assessment practices and contextual suitability remain important concerns (Rizvi et al., 2023). These developments demonstrate that elementary education needs to prepare students not only to participate in AI-supported environments but also to evaluate technological outputs critically and make informed decisions.

International studies have explored different approaches to introducing AI to school-age learners. AI education for young children, for example, needs to reflect developmental characteristics and curriculum objectives rather than treating technology as an isolated technical subject (Su & Yang, 2022). Project-based learning, games, constructivist approaches, and human–computer collaboration have also been identified as strategies for facilitating AI learning in K–12 education (Yim & Su, 2025). Other reviews have associated AI education with improvements in AI literacy, problem-solving, ethical reflection, motivation, and attitudes toward technology (Lee & Kwon, 2024). In elementary education, hands-on activities, collaborative learning, and project-based experiences are important, although teacher professional development and equitable access to technology remain substantial implementation challenges (Yeter et al., 2024). Digital storytelling provides another pedagogical opportunity because students can connect technological concepts with narrative construction and familiar experiences (Ng et al., 2022). Nevertheless, AI literacy in early childhood education requires careful attention to teacher readiness, appropriate learning materials, and children's developmental needs (Su et al., 2023). Taken together, these findings suggest that meaningful AI education should combine conceptual understanding, practical engagement, critical reflection, and age-appropriate guidance.

Alongside technological competence, ethical literacy has become a central concern in AI-supported education. Students need opportunities to understand the social and moral implications of using AI, including the responsibilities associated with technological development and future careers (Williams et al., 2023). Research reviewing AI ethics in K–12 education has identified ethical concerns that require more explicit consideration of children's needs and school contexts (Gouseti et al., 2025). Related work has also highlighted blind spots in educational ethics, emphasizing the need to consider governance and the consequences of technology alongside its instructional benefits (Mouta et al., 2024). A critical review of AI literacy further indicates that AI education intersects with digital literacy, data literacy, computational thinking, and ethics, suggesting the need for a more comprehensive framework for school-age learners (Yim, 2024). Empirical work on AI-literacy design among fifth-grade students has also explored the

development of AI knowledge, ethical understanding, attitudes, and problem-solving (Yue et al., 2025). However, teaching practices across K–12 settings continue to face methodological limitations, including short intervention periods, small samples, limited curriculum continuity, and insufficient long-term evaluation (Liu & Zhong, 2024). These concerns make it necessary to examine how digital competence, ethical responsibility, and self-directed learning can be addressed as interconnected educational priorities.

The Indonesian context presents related challenges and opportunities as schools continue to expand digital learning. Digital literacy has been associated with students' learning independence, particularly through the ability to access and use information to support learning activities (Wahyuni et al., 2022). However, digital literacy needs to extend beyond operational skills toward purposeful, critical, and responsible use of information and technology (Naimah et al., 2024). Introducing AI through digital literacy activities may help elementary students recognize the potential role of AI in learning (Rahmawati et al., 2025), while explicit guidance on digital ethics is necessary to encourage responsible communication and information use (Nuryanto et al., 2023). Learning arrangements such as flipped-classroom blended learning may also support independent preparation and more active participation in thematic learning (Padmawati et al., 2022). At the broader system level, digital transformation in Indonesian elementary education creates opportunities for innovation but requires attention to infrastructure, teacher competence, and sustainable implementation (Maharani et al., 2026). These issues indicate that the educational value of AI depends not simply on the availability of digital tools but on how they are integrated into learning objectives, teaching practices, and student development.

Regional and school-level studies further demonstrate the importance of learning environments and educational guidance. Digital literacy initiatives in local communities can help establish responsible technology-use practices beyond the classroom (Alwan et al., 2021). Digital literacy has also been linked to critical thinking because students need to interpret and evaluate online information rather than accept it uncritically (Asiah et al., 2025). Teachers' digital competence is therefore relevant to the quality of technology-supported learning and the guidance provided to students (Ibda, 2023). Practical training in digital applications can introduce technological skills at an early age when activities are appropriate to students' developmental needs (Furqon et al., 2025). Similarly, teachers have an important role in fostering digital literacy and digital citizenship so that students can engage with technology safely and responsibly (Damanik et al., 2025). Beyond basic digital applications, ChatGPT has been discussed as a potential learning medium for supporting creativity and self-directed learning, provided that students remain active in constructing knowledge and evaluating AI-generated responses (Thoibah Nasution et al., 2026). AI-based media literacy programs may also support digital safety, source verification, online ethics, and critical media evaluation (Transforming Clicks into Critical Thinking, 2026). Nevertheless, awareness of online interaction does not automatically translate into responsible digital behavior, underscoring the need to develop digital responsibility explicitly (Aka & Afandi, 2026).

Other emerging studies point to the value of integrating practical engagement with critical reflection. Action research in a suburban elementary school suggests that digital literacy development can be supported through repeated practice, student participation, and reflective learning (Subiyakto et al., 2026). A systematic review of coding and AI in elementary education identifies AI literacy and computational thinking as recurring learning outcomes while highlighting the importance of authentic problems and structured reflection (Yulfani & Putra, 2026). A meta-synthesis of elementary students' perspectives on AI further emphasizes the importance of

understanding children's experiences and interpretations of AI rather than relying exclusively on technical or curricular objectives (Polat & Sarıdaş, 2026). Integrating STEAM with connected learning has likewise been examined as an approach to developing digital-age competencies, including digital and media literacy (Exploring the Impact of STEAM and Connected Learning, 2026). In science education, inquiry-based learning supported by generative AI chatbots has been investigated for its potential to strengthen students' problem-posing abilities (Dai et al., 2026). These approaches should be guided by human-centered principles, including age appropriateness, privacy, safety, and ethical responsibility, so that AI supports rather than replaces human judgment and educational relationships (Miao & Holmes, 2023).

Despite this growing body of research, an important gap remains in how these educational dimensions are conceptualized together. Previous reviews have examined AI literacy, instructional strategies, ethical challenges, or digital competence, often as distinct areas of investigation (Casal-Otero et al., 2023; Gouseti et al., 2025; Yim, 2024). Other studies have investigated particular instructional interventions, including digital storytelling, AI-literacy design, and AI-supported inquiry (Ng et al., 2022; Yue et al., 2025; Dai et al., 2026). Although these contributions provide valuable insights, they do not, in the evidence reviewed here, establish a unified understanding of how digital literacy, ethical responsibility, and self-directed learning can be connected to prepare elementary school students for increasingly AI-mediated learning environments. In particular, the relationship between students' ability to evaluate digital information, their ethical judgment when using AI, and their capacity to regulate their own learning remains insufficiently synthesized. This limitation matters because students may possess operational digital skills without being able to assess information critically, recognize ethical risks, or determine when AI-generated answers require verification. Moreover, evidence concerning long-term outcomes, age-appropriate curriculum integration, and consistent evaluation remains limited in parts of the existing literature (Liu & Zhong, 2024; Rizvi et al., 2023). Addressing this gap is therefore important for developing a more coherent understanding of educational readiness in the AI era.

To address this limitation, the present study offers an integrative literature review of digital literacy, ethics, and self-directed learning among elementary school students in the context of AI development. Its novelty lies in synthesizing these three dimensions as interconnected components of educational preparedness rather than treating them as separate learning outcomes. Conceptually, the study considers digital literacy as the foundation for accessing and evaluating information, ethical understanding as a guide for responsible AI use, and self-directed learning as the capacity to participate actively in setting learning goals, selecting strategies, monitoring progress, and evaluating outcomes. This framing is consistent with research that positions AI literacy as multidimensional and emphasizes the importance of critical, ethical, and developmentally appropriate learning experiences (Casal-Otero et al., 2023; Su & Yang, 2022; Yim, 2024). The study does not claim to establish causal effects or a validated new theory; rather, it aims to clarify relationships across existing findings and identify priorities for future research and educational practice. Accordingly, it examines how digital literacy is conceptualized and developed among elementary school students in the AI era, what ethical challenges and educational strategies are associated with AI use, and how AI-integrated learning may foster self-directed learning while revealing unresolved gaps in the literature. Through this synthesis, the study seeks to contribute a more integrated perspective for researchers, teachers, and curriculum developers preparing elementary learners to engage with AI critically, responsibly, and independently.

METHODS

1. Research Design

This study employed an integrative literature review to examine how digital literacy, ethical responsibility, and self-directed learning were addressed in research on elementary school students in the era of artificial intelligence. This design was selected because the study aimed to synthesize conceptual perspectives, empirical findings, and educational implications across different types of publications rather than measure the effect of a single intervention. An integrative review enables researchers to critically compare and combine findings from diverse studies to identify patterns, conceptual relationships, and directions for future research (Snyder, 2019). Creswell and Creswell (2023) also emphasized that research design should be aligned with the study's objectives and research questions. Accordingly, this review was organized around three questions concerning the development of digital literacy, ethical challenges in AI use, and the contribution of AI-integrated learning to students' self-directed learning.

2. Sources and Selection Criteria

The literature consisted of peer-reviewed journal articles and relevant scholarly publications addressing AI literacy, digital literacy, AI ethics, and self-directed learning in elementary education. The sources identified for this study included international research and studies from Indonesia, allowing the review to consider both broader educational developments and national or regional contexts. The selection process was intended to prioritize publications from 2021 to 2026, consistent with the study's focus on recent developments, while retaining earlier methodological works where necessary to justify the review design. Zed (2018) explained that library research requires researchers to select, read, and record literature systematically in relation to the research problem. Similarly, Snyder (2019) highlighted the importance of establishing a clear review purpose and an appropriate approach to selecting and synthesizing literature.

The inclusion criteria were: (1) publications relevant to elementary or primary education; (2) studies addressing at least one of the three central dimensions—digital literacy, AI ethics, or self-directed learning; (3) publications discussing AI-supported learning, digital technology use, or related educational competencies; and (4) sources providing identifiable scholarly information. Publications were excluded when they were unrelated to the research questions, lacked sufficient information for interpretation, or duplicated another record. These criteria provided a consistent basis for assessing the relevance of the literature.

3. Search Strategy and Data Collection

The literature collection process was organized around combinations of keywords related to artificial intelligence education, AI literacy, digital literacy, AI ethics, elementary school students, and self-directed learning. Searches were intended to identify publications addressing these concepts individually and in combination. The selection process involved reviewing titles and abstracts before examining the relevance of the available full texts. Machi and McEvoy (2022) explained that a structured literature review requires a clearly defined research problem, purposeful literature searching, and systematic evaluation of relevant sources. In the Indonesian context, Hamzah (2020) similarly described library research as a process of identifying, examining, recording, and interpreting written sources to develop a coherent understanding of a research problem.

A literature extraction matrix was used to organize the selected sources. The recorded information included author and publication year, educational context, research objectives, methodological approach, principal findings, and relevance to the three research questions. This

procedure enabled the literature to be compared consistently and reduced the risk of interpreting individual studies without considering their contribution to the broader research objectives.

4. Data Analysis and Synthesis

The collected literature was analyzed using qualitative content analysis and thematic synthesis. First, the selected publications were read to identify statements and findings relevant to digital literacy, ethical responsibility, and self-directed learning. Second, the extracted information was coded according to these three dimensions, while additional categories were developed when recurring issues emerged from the literature. Third, findings were compared across international, Indonesian, and elementary-education contexts to identify similarities, differences, conceptual relationships, and unresolved issues. Saunders et al. (2023) emphasized the importance of aligning analytical procedures with research objectives and systematically interpreting evidence. Hardani et al. (2020) also described qualitative analysis as an organized process of selecting, categorizing, interpreting, and drawing conclusions from data.

The synthesis was then used to examine how the three dimensions could be understood as interconnected elements of educational preparedness in the AI era. Digital literacy was examined in relation to accessing, evaluating, and using digital information; ethical responsibility was considered in relation to safe, critical, and accountable AI use; and self-directed learning was examined in relation to students' active participation in planning, monitoring, and evaluating their learning. These categories provided an analytical structure rather than predetermined conclusions, allowing the review to identify both established findings and areas requiring further investigation.

5. Rigor and Trustworthiness

To strengthen the review's trustworthiness, the analysis maintained a clear connection between the research questions, extracted evidence, thematic categories, and synthesized conclusions. Findings were compared across sources rather than inferred from a single publication, and differences in educational context and research approach were considered when interpreting the evidence. Creswell and Creswell (2023) highlighted the importance of methodological coherence between research questions, procedures, and interpretation. Sidiq and Choiri (2019) likewise emphasized systematic interpretation and careful documentation in qualitative educational research. These principles informed the organization of the review and the presentation of its conclusions.

The study was limited by its reliance on published literature and the information reported in the selected sources. Differences in study design, participant age, educational setting, and outcome measures could limit direct comparisons. In addition, the available working dataset did not provide a complete database-search log, exact search dates, or numerical records of studies screened and excluded. These details therefore need to be documented before submission if the review is presented as a systematic review. The present design is more appropriately described as an integrative literature review unless a reproducible systematic search and screening procedure is subsequently established.

RESULTS

1. Digital Literacy among Elementary School Students in the Era of Artificial Intelligence

The development of artificial intelligence (AI) has expanded the meaning of digital literacy in elementary education beyond the ability to operate digital devices. Students increasingly need to understand how digital technologies function, evaluate information critically, recognize the limitations of AI-generated outputs, and use technological resources responsibly. In this context,

digital literacy constitutes an important foundation for preparing future generations to participate meaningfully in technology-mediated learning environments. The literature indicates that AI literacy should be developed alongside digital competencies, computational thinking, and critical engagement with information rather than treated merely as an additional technical skill (Casal-Otero et al., 2023; Su & Yang, 2022; Yim, 2024).

This section synthesizes the literature provided for the review, focusing on three interconnected dimensions: the conceptualization of digital and AI literacy, instructional strategies for developing students' digital competencies, and the challenges that affect implementation in elementary schools. As this study is a literature review, the findings presented below are a synthesis of the cited literature, not the results of newly collected field data. The synthesis distinguishes conceptual contributions from empirical findings where the supplied references allow such distinctions.

a. The Conceptualization of Digital and AI Literacy

The literature suggests that digital literacy in elementary education should be understood as a multidimensional competence encompassing operational skills, information evaluation, critical thinking, and responsible participation in digital environments. Although the ability to operate devices and applications remains a fundamental prerequisite, it does not necessarily indicate that students can interpret digital information accurately, recognize misleading content, or make appropriate decisions when using technology. Research on digital literacy implementation in elementary schools highlights the importance of developing students' competencies through educational activities that go beyond basic device operation (Naimah et al., 2024). Similarly, community-based initiatives to cultivate digital literacy among elementary school children illustrate the relevance of introducing digital competencies through learning activities that are accessible to children and connected to their immediate educational environments (Alwan et al., 2021).

Within this broader conceptual framework, AI literacy represents a related but more specialized area of digital competence. It concerns students' understanding of AI systems, their ability to interact with AI-supported tools, and their capacity to evaluate the outputs and implications of those systems. Casal-Otero et al. (2023), through a systematic literature review of AI literacy in K–12 education, provide a foundation for understanding AI literacy as an educational domain requiring structured learning objectives rather than incidental exposure to technological applications. Su and Yang (2022) likewise examine why, what, and how AI education should be incorporated into curriculum design and implementation for young children. These contributions support the view that elementary students should not merely learn to use AI applications but should also develop age-appropriate conceptual understanding of the technology.

A critical distinction therefore emerges between using technology and understanding technology. Operational competence enables students to navigate applications, enter information, and complete digital tasks. More advanced digital and AI literacy requires students to question the information presented, consider how outputs are produced, compare answers with other sources, and recognize that technological systems may generate incomplete or inaccurate information. Yim (2024) emphasizes the need to critically reconsider how AI literacy is taught and learned in primary education, while Ottenbreit-Leftwich et al. (2023) examine lessons from AI education involving elementary students and teachers. Taken together, these studies support an educational approach that combines practical interaction with conceptual understanding and critical reflection.

Digital literacy also intersects with information literacy, data literacy, and computational thinking. Information literacy concerns the ability to locate, evaluate, and use information

appropriately. Data literacy involves interpreting data and understanding how data inform decisions and technological processes. Computational thinking supports the formulation of problems, the identification of patterns, and the development of systematic solutions. AI literacy draws on these related competencies because students need to understand information, recognize patterns, and evaluate technology-mediated solutions. The relationship is complementary rather than interchangeable: operational digital skills provide access to technological resources, while information evaluation, data interpretation, and computational thinking help students use those resources more meaningfully (Casal-Otero et al., 2023; Lee & Kwon, 2024; Yim, 2024).

The literature further indicates that digital literacy has implications for students' critical thinking and educational independence. Asiah et al. (2025) specifically address the relationship between digital literacy and elementary students' critical-thinking abilities, while Wahyuni et al. (2022) examine the relationship between digital literacy and independent learning among elementary school students. These research topics establish a relevant connection between digital competencies and broader educational outcomes. However, the precise magnitude and direction of these relationships should not be generalized without examining the studies' methods and findings. For the present review, the defensible conclusion is that digital literacy should be considered part of a wider educational framework supporting critical engagement with information and increasingly independent participation in learning.

A further conceptual implication concerns the developmental appropriateness of AI education. Elementary school students require learning experiences that connect abstract technological concepts to concrete activities, familiar examples, and guided exploration. Su et al. (2023) discuss the challenges and opportunities associated with AI literacy in early childhood education, while Yeter et al. (2024) map international initiatives and challenges in integrating AI literacy into elementary education. These studies underscore the importance of considering educational context and learners' developmental needs when defining AI literacy objectives. Accordingly, digital and AI literacy should be developed progressively, beginning with safe and purposeful technology use and extending toward critical evaluation, conceptual understanding, and responsible decision-making.

The central finding of this conceptual synthesis is that digital literacy and AI literacy are interconnected but distinct educational priorities. Digital literacy establishes the broader capacity to navigate and evaluate digital environments, whereas AI literacy adds the need to understand AI-supported processes, assess generated outputs, and recognize the limitations and implications of intelligent technologies. An integrated approach is therefore more appropriate than a narrow model focused exclusively on technical proficiency.

b. Instructional Strategies for Developing Digital Literacy

The literature identifies instructional design as an important factor in developing digital literacy and AI literacy among elementary school students. Rather than relying exclusively on teacher demonstrations or routine computer exercises, digital literacy instruction can incorporate project-based learning, inquiry-based activities, digital storytelling, coding, educational games, and AI-supported learning experiences. These approaches provide opportunities for students to interact with technology while developing problem-solving skills, creativity, and critical engagement with information. Reviews of AI education in K–12 classrooms indicate that instructional approaches and learning outcomes are important dimensions in the development of AI-related educational practices (Lee & Kwon, 2024; Rizvi et al., 2023).

Project-based and inquiry-based learning are particularly relevant because they position students as active participants in constructing knowledge. Through structured projects, students can investigate problems, collect information, develop digital products, and communicate their findings. These activities can connect operational digital skills with information evaluation and reflective thinking. Dai et al. (2026), for example, investigate the impact of generative AI-based chatbots on primary school students' problem-posing abilities in science through inquiry-based STEM learning. This research provides a relevant direction for understanding how AI-supported inquiry may contribute to students' engagement in problem formulation. Nevertheless, the educational value of such tools depends on how they are incorporated into learning activities, including whether students are encouraged to formulate their own questions rather than simply accept AI-generated suggestions.

Digital storytelling represents another instructional strategy that connects technological engagement with creative production. Ng et al. (2022) examine digital story writing as a pedagogy for developing AI literacy among primary school students. This approach is significant because it positions children as creators of digital content rather than passive consumers of technological outputs. When students develop stories using digital tools, teachers can introduce questions about how technology supports content production, how information is represented, and how human decisions influence the final product. Digital storytelling can therefore provide an accessible entry point for connecting creative expression with foundational AI concepts.

Coding and hands-on activities also offer opportunities to introduce students to the logic underlying digital technologies. Coding activities encourage learners to organize instructions, identify errors, recognize patterns, and develop systematic solutions to problems. When integrated with AI-related concepts, these activities can help students distinguish between explicitly programmed operations and systems that use data to generate outputs. Yulfani and Putra (2026), through a systematic review and evidence map of coding and AI in elementary education, provide a relevant framework for examining the development of these instructional approaches. Similarly, Yeter et al. (2024) highlight the broader policy and implementation context surrounding AI literacy in elementary education. Together, these works support the importance of aligning practical technological activities with clearly defined learning objectives.

AI-based learning media may also expand opportunities for differentiated instruction and interactive learning. AI-supported applications can provide explanations, generate examples, and facilitate exploration of subject matter. However, their integration should be guided by pedagogical objectives rather than by technological novelty alone. Yim and Su (2025), in their scoping review of AI learning tools in K–12 education, offer a basis for examining the educational applications and challenges of such tools. The broader review by Polat and Sarıdaş (2026) also provides a synthesis of AI use in primary education. These sources suggest the importance of evaluating AI tools in relation to students' learning needs, the nature of classroom tasks, and the extent of teacher guidance.

Teachers remain central to the implementation of these instructional strategies. Their responsibilities include selecting appropriate digital resources, designing meaningful learning activities, helping students evaluate information, and ensuring that technology supports rather than replaces the learning process. Damanik et al. (2025) address teachers' roles in fostering digital literacy and citizenship among elementary school students, while Ibda (2023) examines digital competencies among elementary school teachers. These studies make teacher readiness a relevant consideration in the development of digital literacy programs. Teachers need more than

operational familiarity with digital applications; they also require pedagogical competence to integrate technology into learning and guide students toward critical and responsible use.

School and community participation can complement classroom instruction. Alwan et al. (2021) examine efforts to cultivate digital literacy among elementary school children through a community-based initiative in Kalijaga Village, East Lombok. Furqon et al. (2025) describe training in Microsoft Word for elementary school children, illustrating a practical approach to introducing digital skills. Subiyakto et al. (2026) investigate improvements in digital literacy at a suburban elementary school through action research conducted within a community service program. Collectively, these studies provide examples of digital literacy development extending beyond conventional classroom instruction. They also indicate the relevance of contextualized learning opportunities, particularly where students have unequal access to technological resources.

The synthesis of these instructional studies points to three complementary principles. First, digital literacy should be developed through active participation and meaningful tasks. Second, AI literacy should combine practical interaction with opportunities to understand and critically evaluate technology. Third, teachers, schools, and communities should work together to create learning environments in which students can practice digital competencies consistently. These principles provide a foundation for preparing elementary school students to use emerging technologies purposefully rather than merely consume their outputs.

c. Challenges in Digital Literacy Development

Despite the growing recognition of digital and AI literacy, their implementation in elementary education faces several challenges. The literature points to teacher preparedness, unequal access to technological infrastructure, the need for age-appropriate instruction, and limitations in assessing educational outcomes as important issues. These challenges suggest that the development of digital literacy cannot be addressed simply by introducing devices or AI applications into classrooms. Instead, it requires coordinated attention to instructional quality, institutional capacity, and the conditions under which students engage with technology (Maharani et al., 2026; Yeter et al., 2024).

One major challenge concerns teachers' digital competencies and readiness to teach AI-related concepts. Teachers may be familiar with basic digital applications without having sufficient knowledge to explain AI processes, evaluate AI-generated outputs, or design learning activities that integrate technology with critical thinking. Ibda (2023) examines digital competencies among elementary school teachers, while Ottenbreit-Leftwich et al. (2023) explore lessons learned from AI education involving elementary students and teachers. Liu and Zhong (2024) further review how educators teach AI in K–12 education. These sources establish teacher knowledge and instructional practice as significant areas of consideration in AI literacy development. Effective implementation therefore requires professional learning that addresses both technological understanding and the pedagogical strategies needed to translate that understanding into age-appropriate classroom activities.

A second challenge concerns infrastructure and unequal access to digital resources. Digital literacy instruction depends on students' opportunities to use appropriate devices, access reliable connectivity, and participate in guided digital learning activities. Differences in school resources and students' learning environments may affect the extent to which these opportunities are available. Maharani et al. (2026), in their systematic literature review of digital learning transformation in Indonesian elementary schools, examine developments, implementation

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challenges, and future opportunities. Community-oriented studies, including Alwan et al. (2021) and Subiyakto et al. (2026), also provide relevant contexts for considering how digital literacy initiatives operate in local educational environments. The broader implication is that technology-based learning initiatives should account for differences in institutional capacity and access rather than assume that all students begin with equivalent digital competencies.

The availability of technology also does not automatically guarantee meaningful learning. Students may learn to operate applications without developing the ability to evaluate information or understand the processes behind digital outputs. Consequently, instructional programs need to distinguish between participation in technology-based activities and demonstrable progress in digital and AI literacy. Casal-Otero et al. (2023) and Lee and Kwon (2024) provide systematic perspectives on AI literacy and AI education that can inform the formulation of educational objectives. Yim (2024) further contributes to the discussion by critically examining approaches to teaching AI literacy in primary education. These works support the need for learning objectives that encompass conceptual understanding and critical engagement, not merely the completion of digital tasks.

Assessment represents another challenge. Digital literacy is multidimensional, meaning that a single measure of operational performance may not adequately capture students' ability to evaluate information, understand AI limitations, or make responsible decisions. Assessment should therefore consider several dimensions, including practical skills, conceptual understanding, problem-solving, and critical evaluation. Classroom projects, student explanations, performance tasks, and guided reflections may provide complementary evidence of learning. However, the supplied references do not establish a single validated assessment framework that can be recommended for all elementary school contexts. Further research is needed to determine which assessment approaches most reliably capture the development of digital and AI literacy across different age groups and educational settings.

A related limitation concerns the evidence for long-term educational impacts. Research on AI education and digital learning provides important insights into instructional approaches and potential learning outcomes, but the existence of promising applications does not necessarily demonstrate sustained improvements in students' competencies. Reviews of AI education in K–12 settings, including Rizvi et al. (2023), Lee and Kwon (2024), and Yim and Su (2025), offer useful foundations for examining the scope of existing research. Nevertheless, conclusions about long-term retention, transfer of learning, and students' ability to apply digital competencies independently require evidence that extends beyond immediate classroom performance. The available reference information supplied for this review does not provide sufficient detail to quantify the extent of this evidence gap or establish a uniform pattern across studies.

The challenge of developmental appropriateness also remains important. Elementary school students need instructional support that reflects their cognitive development, prior knowledge, and ability to evaluate complex technological outputs. Introducing advanced applications without sufficient explanation may encourage superficial interaction rather than conceptual understanding. Su and Yang (2022) and Su et al. (2023) discuss curriculum design and the opportunities and challenges of AI literacy for younger learners. Their work reinforces the importance of designing learning experiences that connect technological concepts to familiar situations and provide structured opportunities for exploration. In this respect, teacher mediation is essential for helping students interpret digital information and recognize the limits of AI-supported responses.

Overall, the literature synthesis identifies digital literacy development as a process shaped by the interaction of student competencies, instructional design, teacher readiness, infrastructure, and assessment practices. The main implication is that elementary schools need an integrated approach that combines access to technology with meaningful learning experiences, teacher professional development, and systematic evaluation. Such an approach provides a stronger foundation for preparing future generations to engage critically and responsibly with AI. It also establishes the conceptual basis for the next sections of this review, which examine ethical challenges in AI use and the relationship between AI-integrated learning and students' self-directed learning.

2. Ethical Challenges and Educational Strategies for AI Use among Elementary School Students

The increasing integration of artificial intelligence (AI) into elementary education creates opportunities for interactive learning, personalized instruction, and information exploration, while also raising ethical concerns regarding children's privacy, information reliability, digital responsibility, and independent thinking. Preparing elementary school students for an AI-mediated learning environment therefore requires more than technical competence; it also requires the development of ethical judgment and responsible technological behavior. The literature on AI ethics in K–12 education emphasizes the importance of examining ethical issues alongside pedagogical practices and the institutional conditions governing AI use (Gouseti et al., 2025; Mouta et al., 2024).

For elementary school students, ethical AI education should be developmentally appropriate, integrated into everyday learning, and supported by teachers, schools, and families. Students need opportunities to understand that AI-generated information is not automatically accurate, that digital interactions may involve privacy risks, and that technological assistance should complement rather than replace their own reasoning. These concerns are particularly relevant because children may have limited experience evaluating the processes and consequences associated with emerging technologies. Accordingly, this section synthesizes the supplied literature into three dimensions: the ethical implications of AI use, instructional strategies for developing ethical awareness, and the roles of teachers and schools in establishing responsible AI practices.

a. Ethical Dimensions of AI Use in Elementary Education

The literature identifies ethical responsibility as a central dimension of preparing students to engage with AI in educational settings. Digital responsibility encompasses the ways learners interact with digital content, communicate with others, use technological resources, and consider the consequences of their online behavior. In elementary education, these responsibilities are closely connected to digital citizenship because students are still developing the judgment required to distinguish appropriate from inappropriate online conduct. Damanik et al. (2025) address the role of teachers in developing digital literacy and citizenship among elementary school students, while Nuryanto et al. (2023) examine digital ethics among elementary school learners. These studies provide a relevant foundation for understanding ethical digital behavior as an educational concern rather than merely a matter of enforcing technology-use rules.

The emergence of AI introduces additional considerations because students may interact with systems that generate text, images, explanations, and recommendations. Responsible use consequently involves understanding not only how to operate these systems but also when and how their outputs should be used. Aka and Afandi (2026) examine elementary students' digital responsibility profiles and awareness of online interactions in the AI era. Their focus is particularly

relevant to the need to connect students' everyday digital behavior with broader expectations of responsible participation in technology-mediated environments. From this perspective, ethical AI literacy should help students recognize that their digital actions have consequences and that the convenience of automated tools does not eliminate their responsibility for how generated content is interpreted or used.

Data privacy and information security constitute another important ethical dimension. AI-supported learning may involve students entering questions, sharing personal information, uploading materials, or interacting with digital platforms that process user-provided data. These activities raise questions about what information should be shared, who may access it, and how children can be protected from inappropriate data collection or disclosure. Miao and Holmes (2023), in UNESCO's guidance on generative AI in education and research, provide a policy-oriented foundation for considering the responsible integration of generative AI into educational environments. Gouseti et al. (2025), through a systematic literature review of AI ethics in K–12 education, also provide a framework for examining ethical concerns associated with the use of AI in school contexts.

For elementary school students, privacy education needs to be translated into understandable and practical rules. Students should learn to avoid sharing sensitive personal information with unfamiliar platforms, recognize the importance of secure accounts, and seek adult assistance when a digital application requests information they do not understand. Such guidance should be supported by institutional decisions about the suitability of educational applications and the handling of student data. The literature supplied for this review supports the relevance of privacy and responsible AI governance, although it does not provide sufficient detail to establish that one specific privacy-training model is consistently more effective than others across elementary school settings.

A further concern involves the reliability of AI-generated information. AI systems can produce plausible explanations or answers that contain errors, omissions, or misleading interpretations. Consequently, students should not treat generated outputs as automatically authoritative. Ethical AI use requires the ability to compare information with textbooks, teacher explanations, credible reference materials, and other appropriate sources. Mouta et al. (2024), in their systematic review of ethical issues in AI in education, provide a basis for examining ethical concerns that may be overlooked when AI implementation focuses primarily on technological functionality. Similarly, Gouseti et al. (2025) examine the ethical dimensions of AI use in K–12 education, making their review relevant to the development of responsible practices among school-aged learners.

Information verification is particularly important at the elementary level because students may interpret confident or fluent responses as evidence of correctness. Educational activities should therefore help them distinguish between an answer that sounds convincing and one supported by reliable evidence. Teachers can encourage students to ask where information originated, compare generated explanations with established learning resources, and identify statements that cannot be verified. These practices connect AI ethics with information literacy and critical thinking. They also establish a basis for responsible technology use by emphasizing that students retain an active role in evaluating the information they receive.

AI dependency presents a related educational and ethical concern. When students routinely rely on AI to provide immediate answers, they may have fewer opportunities to formulate questions independently, attempt solutions, explain their reasoning, or learn from mistakes.

However, the availability of AI assistance does not necessarily produce dependency; the outcome depends partly on how the technology is incorporated into learning activities. The systematic reviews by Gouseti et al. (2025) and Mouta et al. (2024) provide relevant perspectives for examining the ethical implications of AI integration, while UNESCO's guidance emphasizes the need for responsible approaches to generative AI in education (Miao & Holmes, 2023).

The educational issue is therefore not whether elementary students should encounter AI at all, but how their interactions with it should be structured. If students are encouraged to generate initial ideas, explain their reasoning, compare AI responses with other evidence, and revise their work independently, AI may serve as a resource for learning rather than a substitute for cognitive engagement. Conversely, activities that reward only the rapid production of answers may weaken the opportunities students have to practice independent reasoning. This distinction suggests that ethical AI education should explicitly address intellectual responsibility, including the importance of understanding and being able to explain work produced with technological assistance.

Overall, the literature synthesis identifies four interconnected ethical priorities: responsible digital behavior, privacy and child protection, verification of AI-generated information, and the preservation of students' independent reasoning. These concerns should not be treated as separate technical problems. They form a broader educational responsibility to ensure that children can use AI in ways that are safe, reflective, and consistent with the purposes of learning.

b. Educational Strategies for Promoting AI Ethics

The literature suggests that AI ethics should be integrated into educational activities rather than taught exclusively as a separate theoretical topic. Elementary school students can develop ethical awareness when questions about privacy, information reliability, fairness, and responsible technology use are connected to familiar learning situations. This approach allows students to understand ethical principles through concrete examples and practical decision-making. Gouseti et al. (2025) provide a systematic examination of ethical issues associated with AI use in K–12 education, while Mouta et al. (2024) investigate potential blind spots in educational ethics research on AI. Together, these reviews establish a relevant basis for incorporating ethical considerations into the design and implementation of AI-supported learning.

Integrating AI ethics across school subjects can make responsible technology use relevant to students' everyday experiences. In language learning, for example, students can compare an AI-generated paragraph with a textbook passage and identify differences in accuracy or meaning. In science, they can examine an AI-generated explanation and determine whether it is consistent with evidence presented in class. In social studies, students can discuss whether sharing another person's photograph or personal information online is appropriate. These examples are proposed instructional applications rather than documented findings from the cited studies. Their purpose is to translate the ethical concerns identified in the literature into age-appropriate learning activities.

Problem-based learning and case discussions offer additional opportunities for students to practice ethical reasoning. Rather than memorizing rules, students can examine realistic scenarios involving AI use and discuss possible consequences. For instance, a teacher might present a situation in which a student copies an AI-generated answer without understanding it, shares personal information with an unfamiliar application, or accepts inaccurate information because it appears convincing. Students can then identify the problem, consider who might be affected, evaluate possible responses, and justify their decisions. This approach connects ethical knowledge

with practical judgment and encourages students to recognize that responsible technology use involves more than compliance with classroom instructions.

The relevance of such approaches is supported by the broader focus of AI ethics research on the relationship between technological implementation and educational responsibility. Gouseti et al. (2025) synthesize literature concerning ethical issues in K–12 education, while Mouta et al. (2024) examine ethical concerns and gaps in AI-in-education research. Williams et al. (2023) also explore the integration of ethics and future careers with technical learning to promote AI literacy, although their study concerns middle school students rather than elementary school students. The latter study is therefore useful as related evidence for connecting ethical reflection with technical learning, but its findings should not be assumed to transfer directly to younger learners.

Teacher-guided information verification is another important strategy. Students should be encouraged to approach AI-generated responses as information that requires examination rather than as unquestionable answers. Teachers can model a verification process by asking students to identify the main claim in an AI response, locate supporting evidence in trusted learning materials, compare alternative explanations, and revise conclusions when discrepancies appear. These activities can help students develop habits of questioning and evidence-based reasoning. They also reinforce the principle that AI assistance does not remove the learner's responsibility to understand the material.

The use of AI in elementary education should additionally follow a student-centered and developmentally appropriate approach. Younger learners may require concrete demonstrations, guided practice, clear explanations, and opportunities to discuss ethical questions using familiar examples. Su and Yang (2022) examine the rationale, content, and implementation of AI education for young children, while Su et al. (2023) discuss the opportunities and challenges of AI literacy in early childhood education. Although early childhood and elementary education are not identical contexts, these studies are relevant to the broader principle that AI education should be designed in accordance with learners' developmental needs.

An effective instructional approach should also preserve students' active participation. Instead of asking students to rely immediately on an AI system, teachers can invite them to attempt a task independently, identify where they need assistance, consult AI when appropriate, and evaluate the resulting information. Students can then explain which parts of the AI response they accepted, modified, or rejected and why. This sequence offers opportunities to combine technological assistance with independent thinking and ethical reflection. It is a proposed pedagogical application consistent with the concerns raised in the literature, rather than a claim that one specific sequence has already been established as universally effective.

The synthesis indicates that ethical AI education is most meaningful when students have repeated opportunities to apply ethical principles in authentic learning situations. Curriculum integration provides continuity, case-based discussions support ethical reasoning, and teacher-guided verification encourages critical engagement with AI-generated content. These strategies can help transform ethical awareness from abstract knowledge into practical habits of responsible digital participation.

c. The Role of Teachers and Schools in Ethical AI Education

Teachers and schools play complementary roles in establishing the conditions for ethical AI use among elementary school students. Teachers guide students' everyday interactions with digital tools, while schools establish institutional expectations concerning technology selection, privacy, safety, and acceptable use. The literature on AI education emphasizes that successful

implementation involves pedagogical and ethical considerations alongside technical capability (Gouseti et al., 2025; Liu & Zhong, 2024). Ethical AI education should therefore be understood as a shared institutional responsibility rather than an individual teacher's isolated task.

Teachers first contribute through their own behavior and instructional decisions. When teachers demonstrate how to verify information, acknowledge uncertainty, protect personal information, and use digital resources appropriately, they provide concrete examples of responsible technology use. Their role extends beyond explaining rules because students also learn from how technology is incorporated into classroom activities. Damanik et al. (2025) examine the role of teachers in fostering digital literacy and citizenship among elementary school students, while Aka and Afandi (2026) address digital responsibility and awareness of online interaction in the AI era. These works are relevant to the view that responsible digital participation should be developed through both explicit instruction and guided practice.

Teacher professional development is equally important. The rapid development of AI applications creates a need for educators to understand the basic capabilities and limitations of these systems, recognize potential ethical risks, and select pedagogically appropriate tools. Liu and Zhong (2024) review how educators teach AI in K–12 education, and Ottenbreit-Leftwich et al. (2023) examine lessons learned from AI education involving elementary students and teachers. These contributions provide a basis for recognizing teacher preparation as a key consideration in AI literacy implementation.

Professional development should consequently address several interconnected areas: foundational AI concepts, evaluation of AI-generated information, data privacy and student protection, ethical classroom practices, and the design of learning activities that preserve students' independent reasoning. Training should also enable teachers to assess whether a particular application serves a clear educational purpose and whether its use is appropriate for the students' developmental level. However, the supplied reference information does not establish a single professional-development model as the most effective across all school contexts. The appropriate format and intensity of training require consideration of teachers' existing competencies, school resources, and curricular needs.

School policies provide the institutional framework within which these practices can be implemented consistently. Clear guidelines can specify which digital and AI tools may be used, what kinds of student information must not be shared, how generated content should be evaluated, and when adult supervision is required. Policies should also clarify expectations concerning academic honesty and the appropriate use of AI assistance in completing school assignments. UNESCO's guidance on generative AI in education and research provides a policy-oriented reference for considering responsible implementation (Miao & Holmes, 2023). Gouseti et al. (2025) further offer a systematic overview of ethical issues in K–12 education that can inform institutional discussions about responsible AI use.

Nevertheless, policies are unlikely to be sufficient if students do not understand their purpose. Rules concerning privacy, verification, and acceptable AI use should therefore be accompanied by age-appropriate explanations and opportunities for guided practice. Schools can reinforce these expectations through classroom discussions, digital citizenship activities, learning agreements, and teacher–student reflection. Such measures can help students understand that ethical guidelines exist to protect learners and support meaningful learning, rather than simply restrict access to technology.

School–family collaboration is another important dimension of ethical AI education. Students' digital experiences extend beyond the classroom, and the expectations they encounter at home may influence their habits of technology use. Communication between teachers and parents can support consistent guidance regarding screen use, personal information, online communication, and the role of AI in schoolwork. Families can also encourage children to explain what they have learned, identify when they have used AI assistance, and seek adult support when they encounter unfamiliar or concerning digital content. These practices are proposed implications of the literature's emphasis on digital responsibility and child protection; the supplied references do not establish the comparative effectiveness of specific school–family collaboration models.

Collaboration is particularly relevant when students have unequal access to technology or differing levels of adult support at home. Schools should avoid assuming that all families possess the same digital resources or technological knowledge. Instead, communication and educational support should be accessible to families with different circumstances. Community-based digital literacy initiatives, such as those examined by Alwan et al. (2021) and Subiyakto et al. (2026), provide relevant contexts for considering how digital learning support can extend beyond the classroom. Their work concerns digital literacy development more broadly, however, and should not be treated as direct evidence that a particular family-based AI ethics intervention is effective.

Taken together, the literature supports a multilevel framework for ethical AI education. Teachers provide modeling, guidance, and feedback; schools establish policies and professional support; and families reinforce safe and responsible habits outside school. These roles are interdependent. School policies require teachers who can translate them into practice, while classroom instruction becomes more consistent when students encounter compatible expectations across their learning environments.

The principal finding of this synthesis is that ethical AI education should be embedded within a coordinated educational framework that combines digital responsibility, privacy protection, critical verification, teacher preparation, and institutional governance. This framework positions elementary students not merely as users of AI tools but as developing learners who must understand the consequences of their technological choices. It also establishes an important connection with the next section of the review: the need to ensure that AI-supported learning strengthens students' agency and self-regulation rather than encouraging uncritical dependence on automated assistance.

3. AI-Integrated Learning and Self-Directed Learning among Elementary School Students

The integration of artificial intelligence (AI) into elementary education offers opportunities to support students' information exploration, subject-matter understanding, creativity, and independent learning. AI-supported tools can provide explanations, generate examples, respond to questions, and facilitate access to learning resources. However, their educational value depends on how these capabilities are incorporated into instructional activities and whether students remain actively involved in directing their own learning. The literature on AI learning tools in K–12 education and AI education in primary schools provides a foundation for examining both the potential benefits and the limitations of these technologies (Polat & Sarıdaş, 2026; Yim & Su, 2025).

Self-directed learning involves students taking an active role in identifying learning needs, determining goals, selecting strategies and resources, monitoring their understanding, and evaluating learning outcomes. In elementary education, these activities generally require structured

guidance because students are still developing the cognitive and metacognitive skills necessary to regulate their learning. The integration of AI therefore raises an important educational question: whether technological assistance strengthens students' capacity to learn independently or encourages them to rely excessively on immediate, automated responses. Research on digital literacy and independent learning provides relevant context for this issue (Wahyuni et al., 2022), while recent work examining ChatGPT as a learning medium directly addresses creativity and self-directed learning among elementary students (Thoibah Nasution et al., 2026).

This section synthesizes the supplied literature through three interconnected dimensions: AI's contribution to self-directed learning, students' agency and self-regulation in AI-supported environments, and the limitations and risks associated with AI-integrated independent learning. The discussion distinguishes the potential contributions of AI from claims about demonstrated educational outcomes, particularly where the available reference information does not provide sufficient empirical detail.

a. The Contribution of AI to Self-Directed Learning

The literature indicates that AI-supported learning tools can create opportunities for students to explore information and engage with subject matter beyond the immediate explanations provided by teachers. Through conversational interfaces and interactive applications, students can ask questions, request alternative explanations, and investigate concepts that they find difficult to understand. These functions may support independent exploration by allowing students to revisit information and seek additional explanations at their own pace. Yim and Su (2025), in their scoping review of AI learning tools in K–12 education, provide a relevant basis for examining the educational applications of these technologies. Polat and Sarıdaş (2026) likewise synthesize research on AI use in primary education, offering a broader perspective on the opportunities and challenges associated with integrating AI into learning environments.

For elementary school students, the value of AI-assisted information exploration lies not simply in the speed with which answers can be obtained but also in the opportunities it creates for sustained inquiry. For example, students learning about the natural environment may use an AI-supported tool to generate additional questions, clarify unfamiliar concepts, or explore examples related to a classroom topic. Such activities can encourage curiosity when students are prompted to investigate, compare, and explain information rather than accept the first response they receive. However, these examples illustrate possible instructional applications; they should not be interpreted as direct evidence that all AI tools improve students' independent learning.

AI may also support creativity and problem-solving by providing students with alternative ideas, examples, and prompts. Thoibah Nasution et al. (2026) specifically examine ChatGPT as an innovative learning medium for fostering creativity and self-directed learning among elementary school students. This research is directly relevant to the present review because it connects generative AI with two important dimensions of learner development. Nevertheless, the existence of a study examining these outcomes does not, by itself, establish that AI consistently improves creativity or self-directed learning across different school settings. Such conclusions depend on the study's design, measures, participants, and reported findings.

From a pedagogical perspective, AI-supported creativity is most educationally meaningful when students retain responsibility for developing and refining their ideas. An AI tool might suggest possible storylines, provide examples of mathematical problems, or offer alternative approaches to a science question. Students can then select, modify, and justify their choices. In this

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arrangement, AI serves as a resource for extending students' thinking rather than a substitute for their creative effort. This interpretation is consistent with the broader need to connect AI learning tools with clearly defined educational purposes, as discussed in research reviewing AI integration in primary and K–12 education (Polat & Sarıdaş, 2026; Yim & Su, 2025).

Another potential contribution concerns the personalization of learning. AI-supported tools may provide explanations at different levels of complexity, generate additional practice questions, or respond to particular questions raised by individual students. These functions could help learners revisit challenging material and explore topics according to their immediate learning needs. However, personalization should not be equated automatically with effective learning. A response tailored to a student's question may still be inaccurate, incomplete, or pedagogically unsuitable. Teacher oversight and the evaluation of learning progress therefore remain important when AI is used to adapt learning experiences.

The relationship between AI and self-directed learning also involves students' opportunities to make decisions about their learning goals, strategies, and resources. Self-direction does not mean that students must work without assistance; rather, it involves taking an active role in determining what they need to learn and how they will approach a task. AI may help students identify unfamiliar concepts, generate questions, or explore possible learning resources. Yet students' agency is maintained only when they participate meaningfully in selecting and evaluating these options. If the system determines the learning process entirely, the student may become a passive recipient of recommendations rather than an active learner.

Existing work on independent learning provides an additional perspective. Wahyuni et al. (2022) examine the relationship between digital literacy and independent learning among elementary school students, establishing a relevant connection between digital competence and learner autonomy. Although digital literacy and AI-supported self-directed learning are not identical constructs, the relationship is conceptually important: students need sufficient digital competence to navigate learning resources, evaluate information, and use technology purposefully. AI integration should therefore build on students' foundational digital skills rather than assume that access to an intelligent tool automatically enables independent learning.

The synthesis suggests that AI can potentially support self-directed learning through four related functions: facilitating information exploration, providing additional explanations and practice, supporting creative problem-solving, and expanding opportunities for students to make learning decisions. These functions should be understood as educational affordances rather than guaranteed outcomes. Their realization depends on the design of learning activities, students' digital competencies, the reliability of AI-generated information, and the extent to which teachers preserve students' active role in the learning process.

b. Students' Agency and Self-Regulation in AI-Supported Learning

Students' agency and self-regulation are central to understanding whether AI integration contributes meaningfully to self-directed learning. Learner agency refers to students' capacity to initiate activities, make decisions, and take responsibility for their learning, whereas self-regulation involves planning, monitoring, and evaluating their learning processes. In AI-supported environments, these capacities become particularly important because students can obtain immediate responses without necessarily engaging in the reasoning required to understand a problem. Consequently, the educational value of AI depends partly on whether students remain active participants in the learning process rather than becoming dependent on automated assistance.

The literature on digital literacy and independent learning provides a foundation for understanding this relationship. Wahyuni et al. (2022) examine the relationship between digital literacy and self-directed learning among elementary school students. Their research focus highlights the relevance of digital competence to students' capacity to engage with learning resources independently. However, digital literacy should not be treated as equivalent to self-regulation: students may be able to operate digital applications successfully while still requiring support to establish learning goals, manage their progress, and evaluate their understanding. AI-supported learning therefore needs to develop both technological competence and the learning strategies that enable students to use technology purposefully.

An important dimension of learner agency is the ability to initiate and direct learning activities. In conventional classroom settings, students may depend heavily on teachers to identify tasks, determine learning sequences, and provide explanations. AI-supported environments can create additional opportunities for students to ask questions, request clarification, and explore topics independently. Thoibah Nasution et al. (2026) examine ChatGPT as a learning medium in relation to creativity and self-directed learning among elementary school students. This work is particularly relevant because it places learner autonomy within the context of generative AI. Nevertheless, the educational significance of initiating questions or interacting with an AI system depends on whether these activities contribute to purposeful inquiry and deeper understanding.

Students' ability to monitor their understanding is equally important. Self-regulated learning involves recognizing what one understands, identifying areas of difficulty, and adjusting learning strategies when necessary. AI tools may help students identify unfamiliar concepts or obtain additional explanations, but they cannot be assumed to provide a complete or accurate assessment of a child's understanding. Students may feel confident after receiving a fluent explanation even when they cannot independently explain the concept or apply it to a new problem. Teachers can address this limitation by asking students to summarize concepts in their own words, solve related problems without assistance, and explain how they arrived at their answers.

Evaluating learning outcomes also requires students to distinguish between completing a task and understanding the knowledge involved. An AI-generated answer may help a student finish an assignment, but task completion alone does not demonstrate independent mastery. Assessment practices should therefore examine students' reasoning, explanations, and ability to transfer knowledge to unfamiliar situations. The literature reviewing AI learning tools in K–12 education provides a relevant context for considering the relationship between technological support and learning outcomes (Yim & Su, 2025). Similarly, Polat and Sarıdaş (2026) synthesize research on AI in primary education, providing a broader basis for evaluating the educational implications of AI-supported learning.

A further dimension of self-regulation is the ability to verify AI-generated answers. Students need opportunities to compare AI responses with textbooks, teacher explanations, credible educational resources, and evidence gathered through learning activities. This process encourages them to consider whether information is consistent, sufficiently supported, and appropriate to the question being investigated. It also reinforces the understanding that AI outputs are resources to be evaluated rather than unquestionable sources of knowledge. Miao and Holmes (2023) provide relevant guidance on the responsible use of generative AI in education, while Gouseti et al. (2025) examine ethical considerations associated with AI use in K–12 settings. These sources support the importance of responsible AI engagement, although they should not be interpreted as direct

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evidence that a particular verification technique produces specific learning gains among elementary students.

Teacher guidance remains essential for balancing technological assistance with independent effort. If students are expected to complete every task without assistance, they may lose opportunities to benefit from useful explanations and feedback. Conversely, if AI supplies answers before students have attempted to solve problems themselves, opportunities for independent reasoning may be reduced. A balanced approach can involve asking students to attempt a task first, use AI when they encounter a difficulty, verify the response, and then explain the solution independently. This sequence is a proposed pedagogical strategy informed by the literature's emphasis on responsible AI use and self-directed learning, not a universally validated instructional model.

Within this framework, teachers act as facilitators of metacognitive development. They can encourage students to establish achievable learning goals, select appropriate resources, monitor progress, and reflect on whether AI assistance has helped them understand a concept. These activities make self-regulation an explicit learning objective rather than an assumed consequence of technological access. They also enable teachers to identify when students are using AI constructively and when they may be relying on generated responses without sufficient understanding.

The synthesis identifies four essential elements of agency and self-regulation in AI-supported learning: initiating learning activities, monitoring understanding, evaluating learning outcomes, and verifying technological outputs. These elements are interdependent. Students who can formulate questions but cannot evaluate answers may remain vulnerable to inaccurate information, while students who can verify information but cannot establish learning goals may still depend heavily on external direction. Effective AI integration should therefore cultivate a combination of initiative, reflection, critical evaluation, and appropriate help-seeking.

c. Limitations and Risks of AI-Integrated Self-Directed Learning

Despite its potential contributions, AI-integrated self-directed learning presents several limitations that require careful consideration. These include the possibility of dependence on immediate answers, unequal access to technological resources, differences in students' developmental readiness, and insufficient evidence concerning long-term effects on learner autonomy. These issues indicate that AI-supported learning should not be assumed to produce independent learners simply because students can interact with intelligent systems. Its educational contribution must be evaluated in relation to students' actual learning processes and outcomes.

One significant risk is dependence on instant AI-generated answers. Generative AI can produce responses quickly, potentially reducing the effort required to search for information, formulate explanations, or solve problems independently. When students consistently accept generated answers without attempting tasks themselves, they may have fewer opportunities to practice reasoning, identify misconceptions, and develop persistence when facing difficult problems. This concern is especially relevant in elementary education, where foundational learning habits and independent problem-solving strategies are still developing.

However, frequent AI use should not automatically be interpreted as evidence of dependency. The educational consequences depend on the nature of the task, the guidance provided, and the extent to which students engage critically with the outputs. AI can provide useful assistance when it offers additional explanations or prompts students to consider alternative approaches. The risk emerges when assistance replaces the cognitive activities that students need to

practice. Research on AI ethics in K–12 education and AI learning tools provides relevant contexts for examining these issues (Gouseti et al., 2025; Yim & Su, 2025). The appropriate response is therefore not necessarily to prohibit AI assistance, but to structure its use so that students retain responsibility for thinking, explaining, and evaluating.

A second limitation concerns unequal access to technological resources and differences in digital competencies. AI-integrated learning may depend on access to appropriate devices, reliable internet connectivity, and applications that are suitable for educational use. Students who have greater access to these resources may have more opportunities to experiment with AI-supported learning, while others may experience restricted participation. Differences in digital literacy can also influence how effectively students use the same technology. Research on digital literacy development in elementary schools highlights the relevance of educational context and access to learning opportunities (Alwan et al., 2021; Maharani et al., 2026; Subiyakto et al., 2026).

These inequalities have implications for learner autonomy. Self-directed learning requires opportunities to access resources, make learning decisions, and practice independent problem-solving. When access to AI-supported tools is uneven, students may encounter different conditions for developing these capacities. Schools should therefore consider whether their technology initiatives provide equitable opportunities for participation and whether students receive adequate support in developing foundational digital skills. AI should complement accessible learning resources rather than become a prerequisite that disadvantages students who cannot use particular platforms.

Developmental appropriateness presents a third challenge. Elementary school students differ in their reading comprehension, prior knowledge, ability to evaluate information, and capacity to monitor their own learning. Some students may be able to compare AI responses with established sources, while others may need explicit teacher support to recognize contradictions or inaccuracies. Su and Yang (2022) discuss curriculum design and implementation for AI education among young children, while Su et al. (2023) examine the challenges and opportunities associated with AI literacy in early childhood education. These works provide a relevant foundation for emphasizing age-appropriate instructional design, although their findings should be applied with attention to differences between early childhood and elementary school populations.

Developmentally appropriate support involves more than simplifying instructions. It also requires deciding which tasks students can undertake independently, when adult guidance is necessary, and which technological features are appropriate for their learning needs. For younger learners, teachers may need to provide structured prompts, model information verification, and establish clear boundaries for AI use. As students develop greater competence, instructional support can gradually encourage more independent decision-making. This progression represents a pedagogical implication of the literature rather than a claim that a particular sequence has been empirically established as optimal for every age group.

A further limitation concerns the reliability of AI-generated information. Students who rely on AI to explain unfamiliar concepts may encounter outputs that are incomplete, misleading, or inconsistent with established learning materials. If students lack the knowledge or skills required to recognize these limitations, AI assistance may reinforce misconceptions rather than resolve them. This problem is closely connected to the ethical concerns discussed in the previous section and reinforces the need for information verification and teacher guidance. Miao and Holmes (2023)

provide relevant policy guidance on generative AI in education, while Gouseti et al. (2025) examine the ethical dimensions of AI use in K–12 settings.

The long-term effects of AI-integrated learning on student autonomy also require further investigation. Although recent research addresses AI learning tools, AI use in primary education, and the relationship between ChatGPT and self-directed learning, the existence of these studies does not establish that AI produces sustained improvements in students' capacity to learn independently. Polat and Sarıdaş (2026), Yim and Su (2025), and Thoibah Nasution et al. (2026) provide relevant reference points for examining this emerging area. Nevertheless, conclusions about long-term effects require attention to research design, duration, assessment methods, and the characteristics of the participating students.

Future research should therefore distinguish immediate performance from sustained learner development. For example, students may complete an assignment more efficiently with AI assistance without demonstrating better retention, greater independence, or stronger problem-solving skills when the tool is unavailable. Longitudinal studies could examine whether students continue to set goals, monitor their understanding, verify information, and solve problems independently over time. Comparative studies could also investigate how different forms of teacher guidance influence the relationship between AI use and learner autonomy. These are research priorities arising from the synthesis, rather than claims that the supplied studies have already demonstrated particular long-term outcomes.

Overall, the literature suggests that the educational contribution of AI-integrated self-directed learning depends on the interaction between technological affordances, students' digital competencies, developmental readiness, and instructional guidance. AI can potentially expand opportunities for exploration, creativity, and personalized assistance, but these opportunities must be balanced against the risks of dependency, unequal access, and insufficient evaluation of information. The central implication is that AI should function as a supportive learning resource within a pedagogical framework that preserves students' agency, critical thinking, and responsibility for their own learning.

DISCUSSION

1. Results Analysis

This review examined how digital literacy, ethical awareness, and self-directed learning can be integrated to prepare elementary school students for the growing presence of artificial intelligence (AI) in education. The synthesis identifies three interrelated dimensions of AI readiness: the ability to critically evaluate AI-generated information, the capacity to make ethically responsible decisions, and the development of autonomy in managing learning. The central finding is that preparing elementary school students for an AI-mediated learning environment requires more than technological competence; it requires the integration of critical judgment, ethical responsibility, and learner agency. These dimensions provide a conceptual basis for understanding how AI can support educational development without replacing students' reasoning, decision-making, or responsibility for learning.

The first dimension, digital literacy, acquires a more demanding meaning in an environment where AI can generate information that appears convincing but may be inaccurate, incomplete, or biased. Students therefore need to develop the ability to question generated responses, verify claims against credible sources, recognize uncertainty, and distinguish plausible explanations from reliable knowledge. The educational significance of this finding lies in the difference between using technology and exercising informed judgment through technology. Operational proficiency may

enable students to interact with AI applications, but critical literacy determines whether they can assess the quality and relevance of the information they receive. Because elementary school students are still developing their reasoning and evaluative capacities, these competencies require explicit instruction, age-appropriate activities, and sustained teacher guidance rather than an assumption that digital familiarity naturally produces critical understanding.

The second dimension, ethical awareness, concerns the principles that govern how students engage with AI and interpret its consequences. Issues such as privacy, fairness, misinformation, authorship, accountability, and excessive dependence on automated assistance demonstrate that AI use is not merely a technical activity. It involves decisions about what information to share, which outputs to trust, how to acknowledge assistance, and when independent effort is necessary. The findings suggest that ethical competence is most meaningfully developed when students encounter these issues within concrete learning situations. For example, students can be guided to examine whether an AI-generated answer is fair, determine whether personal information should be disclosed, or explain why submitting an unverified response may undermine learning integrity. Such practices position ethics as an active process of reasoning and decision-making rather than a set of abstract rules imposed on technology use.

The third dimension, self-directed learning, concerns students' capacity to take an active role in determining learning goals, selecting resources, monitoring understanding, and evaluating progress. AI may support these processes by providing explanations, alternative examples, feedback, and opportunities for exploration. However, the availability of immediate assistance creates a pedagogical tension: the same tool that facilitates learning may also encourage passivity when students accept generated answers without examining them. Accordingly, the educational value of AI cannot be inferred solely from the speed of task completion or the availability of personalized responses. It also depends on whether students remain intellectually engaged throughout the learning process. At the elementary level, self-directed learning should therefore be developed progressively through structured choices, guiding questions, reflective tasks, and feedback. Teacher support remains essential because meaningful autonomy at this stage involves learning to make increasingly informed decisions, not being left to learn independently without supervision.

These interpretations directly address the research objective by explaining how the three dimensions contribute to preparing students for AI-integrated education and why they should be considered together. Digital literacy enables students to examine the information generated by AI; ethical awareness provides principles for deciding how that information should be used; and self-directed learning translates critical and ethical capacities into purposeful learning practices. Their relationship is reciprocal rather than strictly sequential. Critical evaluation can inform ethical decisions, ethical awareness can influence the choice of learning strategies, and self-directed learning provides opportunities to practice and refine both competencies. This relationship is particularly important in elementary education because students' engagement with AI occurs within developmental, social, and instructional conditions that shape how they interpret information and exercise judgment.

Theoretically, this synthesis conceptualizes AI readiness as an integrated educational competence rather than an isolated technical skill. AI literacy involves the capacity to understand, use, evaluate, and engage with AI responsibly (Ng et al., 2022), while AI-supported learning requires pedagogical arrangements that preserve meaningful student participation rather than

equating access to technological assistance with learning itself (Su & Yang, 2022). Within this perspective, students are not merely recipients of AI-generated information but active participants who must interpret, question, and evaluate the resources available to them. Teachers, schools, and families consequently serve as enabling structures that support age-appropriate AI use, model responsible practices, and provide opportunities for guided reflection.

The analytical synthesis of these findings yields a three-dimensional framework for developing AI readiness in elementary education, supported by an enabling educational environment. The framework consists of critical digital literacy, ethical awareness, and self-directed learning, with teacher guidance, school policies, and family involvement operating across all three dimensions. Critical digital literacy enables students to evaluate AI-generated content; ethical awareness guides their decisions regarding appropriate and responsible use; and self-directed learning supports the purposeful application of these competencies in learning activities. These dimensions can reinforce one another through repeated cycles of questioning, verification, decision-making, and reflection. The proposed framework therefore presents AI readiness as a developmental process in which technological interaction becomes educationally meaningful when accompanied by critical judgment, ethical reasoning, and learner agency. Its contribution is a conceptual explanation of how these competencies may be integrated into elementary education, rather than a claim that their effectiveness or causal relationships have already been empirically established. The framework can inform curriculum design, teacher preparation, and future empirical studies examining how students develop these competencies across different educational contexts.

2. Comparison with Previous Studies

The findings of this review are consistent with previous studies that conceptualize artificial intelligence (AI) literacy as a multidimensional educational competence rather than merely the ability to operate technological applications. Casal-Otero et al. (2023) emphasized the importance of establishing structured learning objectives for AI literacy in K–12 education, while Ng et al. (2022) examined digital storytelling as an approach to developing AI literacy among primary school students. These studies provide a foundation for understanding AI literacy as a competency that can be deliberately cultivated through educational activities. The present review extends this perspective by positioning critical digital literacy alongside ethical awareness and self-directed learning. This synthesis suggests that students' ability to understand and interact with AI should be accompanied by the capacity to evaluate its outputs, make responsible decisions, and maintain an active role in constructing knowledge.

Regarding instructional approaches, the findings correspond with Rizvi et al. (2023), whose review identified the educational potential of AI-related teaching and learning while indicating limitations associated with research contexts and assessment. Similarly, Yim and Su (2025) highlighted the relevance of project-based learning, games, constructivist approaches, and human–computer collaboration in AI education. Lee and Kwon (2024) also identified learning outcomes associated with AI education, including literacy, problem-solving, ethical reflection, motivation, and attitudes. Collectively, these studies support the view that meaningful AI education requires pedagogical approaches that engage students actively rather than treating technology as an isolated instructional tool. However, the present synthesis adds a critical qualification: engaging activities and favorable learning outcomes do not necessarily demonstrate that students can independently evaluate AI-generated information or transfer responsible practices to unfamiliar situations. Consequently, the quality of AI education should be considered in relation to both immediate

learning outcomes and the development of competencies that enable students to use AI judiciously over time.

The present findings also reinforce Su and Yang's (2022) argument that AI education for young learners requires attention to developmental appropriateness and curriculum design. This consideration is particularly relevant to elementary education, where students are still developing the reasoning, self-regulation, and evaluative capacities necessary for responsible engagement with AI. Yeter et al. (2024) similarly emphasized the importance of hands-on, collaborative, and project-based learning while identifying teacher development and access to educational resources as continuing challenges. Su et al. (2023) also highlighted difficulties associated with teacher readiness, learning materials, and developmental suitability in early AI literacy education. These findings indicate that effective implementation cannot depend exclusively on students' access to AI applications. It also requires teachers who can design age-appropriate learning experiences, scaffold critical thinking, and help students recognize the limitations of AI-generated responses. The present review brings these concerns together by identifying teacher guidance and institutional support as enabling conditions for developing digital literacy, ethical awareness, and self-directed learning simultaneously.

With respect to digital literacy, the synthesis is consistent with Naimah et al. (2024), who emphasized that digital literacy activities should extend beyond operating devices, and Asiah et al. (2025), who connected digital literacy with critical thinking. Wahyuni et al. (2022) also examined the relationship between digital literacy and independent learning. These perspectives support the importance of integrating information evaluation and learner autonomy into elementary education. Nevertheless, generative AI introduces a distinctive challenge because students may receive fluent, seemingly authoritative answers without identifying the sources, assumptions, or limitations underlying them. The present review therefore places particular emphasis on verification, questioning, and reflective evaluation as competencies connecting digital literacy with independent learning. Rather than treating critical thinking and autonomy as automatic consequences of digital technology use, this synthesis conceptualizes them as educational outcomes that require explicit instructional support and purposeful practice.

The ethical dimension of the findings is particularly relevant to the concerns raised by Gouseti et al. (2025), who highlighted the need for stronger attention to AI ethics in school and K–12 contexts. Mouta et al. (2024) likewise emphasized the need to consider educational benefits alongside governance and ethical concerns. The present review supports this position while extending its implications to students' everyday learning decisions. Ethical AI education should address not only general principles or institutional rules but also practical situations involving privacy, fairness, misinformation, authorship, and dependence on automated assistance. This distinction matters because students may understand that AI should be used responsibly without knowing how to apply that principle when completing assignments or evaluating generated answers. Integrating ethical reflection into ordinary classroom activities can help bridge the gap between awareness of responsible use and the ability to make reasoned decisions.

A further point of convergence concerns the potential of AI to support personalized learning and problem-solving. Research such as Dai et al. (2026), which examined generative-AI chatbots in science problem posing, illustrates the relevance of investigating how AI can facilitate students' engagement with learning tasks. However, the educational value of such applications must be interpreted in relation to the extent to which students remain intellectually involved. The

present synthesis distinguishes between receiving assistance and developing self-directed learning: AI may provide explanations, prompts, or alternative perspectives, but students must still formulate questions, assess information, monitor understanding, and reflect on their progress. This interpretation complements previous work on AI-supported learning by emphasizing learner agency as a necessary consideration when evaluating the educational implications of AI integration.

Taken together, the reviewed studies establish important foundations for AI literacy, developmentally appropriate instruction, digital competence, ethical education, and AI-supported learning. The distinctive contribution of the present review is to synthesize these strands into an integrated framework connecting critical digital literacy, ethical awareness, and self-directed learning. Whereas the cited studies address particular competencies, instructional approaches, learning outcomes, or implementation challenges, the present synthesis explains how these dimensions may function together in preparing elementary school students for AI-mediated learning. It also cautions against assuming that technical proficiency, engaging instruction, or personalized assistance automatically produces critical judgment and responsible learner autonomy. The proposed framework should therefore be understood as a conceptual contribution derived from the literature, not as an empirically validated causal model. Future empirical studies could examine how the three dimensions interact in classroom practice and whether their integration contributes to students' sustained capacity for critical, ethical, and independent engagement with AI.

3. Implications of Findings

The findings have both theoretical and practical implications for AI-integrated elementary education. Theoretically, this review contributes to the literature by conceptualizing AI readiness as an interconnected competence comprising critical digital literacy, ethical awareness, and self-directed learning. This perspective extends the understanding of AI literacy beyond technical proficiency by emphasizing the relationship between critical judgment, responsible decision-making, and learner agency. Practically, the findings suggest that elementary school curricula should integrate AI literacy with ethical reflection, information verification, and guided independent learning. Teachers should design age-appropriate activities that encourage students to question AI-generated responses, protect personal information, acknowledge AI assistance, and reflect on their learning processes. Schools should also establish clear guidelines for responsible AI use and provide professional development to strengthen teachers' pedagogical and ethical competencies. These implications emphasize that AI should function as a supportive educational resource rather than a substitute for students' reasoning or teachers' instructional responsibilities.

4. Research Limitations

This review has several limitations. First, the synthesis depends on the scope, quality, and availability of the selected literature; consequently, relevant studies may have been overlooked, particularly research published in less accessible journals or languages. Second, differences in research designs, educational settings, student age groups, and definitions of AI literacy limit direct comparisons across studies. Third, because the study employed an integrative literature review rather than primary empirical research, the proposed relationship among digital literacy, ethical awareness, and self-directed learning remains conceptual and has not been empirically validated as a causal model. In addition, the absence of fully documented database-specific search records and numerical screening procedures limits the reproducibility of the review. Future research should employ transparent and replicable review protocols and conduct empirical studies across diverse

elementary school contexts to examine the framework's applicability, developmental relevance, and educational outcomes.

CONCLUSION

This review examined how digital literacy, ethical awareness, and self-directed learning can contribute to preparing elementary school students for the growing integration of artificial intelligence (AI) in education. The findings indicate that these three dimensions constitute interrelated foundations for meaningful AI readiness. Digital literacy enables students to critically evaluate AI-generated information, ethical awareness guides responsible and informed technology use, and self-directed learning supports students in establishing goals, monitoring progress, and reflecting on learning outcomes. The central insight is that effective preparation for an AI-mediated educational environment requires more than technical proficiency; it requires the integration of critical judgment, ethical responsibility, and learner agency. Accordingly, AI should be positioned as a supportive learning resource that enhances exploration and understanding without replacing students' independent reasoning or teachers' pedagogical responsibilities.

This review contributes a conceptual framework that integrates the three dimensions within an educational environment supported by teacher guidance, school policies, and family involvement. Nevertheless, because the study relied on an integrative literature review, the proposed framework has not yet been empirically validated, and variations in the reviewed studies limit the generalizability of its implications. Furthermore, the absence of fully documented database-specific search records and numerical screening procedures constrains reproducibility. Future research should employ transparent review protocols and conduct empirical investigations across diverse elementary school contexts to examine how the three dimensions develop, interact, and influence students' learning outcomes. Longitudinal and classroom-based studies would be particularly valuable for determining whether guided AI use strengthens critical evaluation, ethical decision-making, and self-directed learning over time. Such evidence could inform age-appropriate curricula, teacher professional development, and institutional guidelines for responsible AI integration in elementary education.

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