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Constructing AI Literacy: A Hands-On Approach for School Children

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Abstract. This narrative literature review examines constructionist approaches to AI literacy education for school-aged children, synthesizing research from 2009–2024 to develop a pedagogical framework grounded in hands-on learning principles. Through systematic analysis of studies retrieved from Web of Science, Scopus, IEEE Xplore, and ACM Digital Library, five interconnected themes emerged: active hands-on learning, project-based inquiry, ethics integration, age-appropriate scaffolding, and teacher support with accessible tools. The findings demonstrate that constructionist methodologies – emphasizing learning through creating AI-powered artifacts – effectively foster conceptual understanding, ethical reasoning, and critical agency among young learners. The review reveals that AI literacy develops most effectively when students actively manipulate and experiment with AI systems rather than passively consuming theoretical content. Age-differentiated strategies are essential, with primary students benefiting from embodied analogies and narrative contexts, while secondary students engage with collaborative design projects addressing real-world challenges. Teacher preparation and accessible tools emerge as critical implementation factors. This framework provides educators and policymakers with evidence-based guidance for integrating meaningful AI literacy experiences into K-12 curricula through constructionist pedagogies.

Keywords: artificial intelligence literacy, constructionism, hands-on learning, K-12 education, ethics in AI, project-based learning, computational thinking 2.0.

1. Introduction

The increasing ubiquity of AI underscores the need to develop AI literacy among school children. AI literacy encompasses skills that enable a deep understanding of AI through three key dimensions: understanding AI concepts, grasping how AI works, and preparing for life with AI (Casal-Otero *et al.*, 2023). These dimensions align closely with UNESCO's AI Competency Framework for Students (Miao *et al.*, 2024), which emphasizes understanding AI fundamentals, using AI tools effectively, and developing ethical reasoning about AI's societal impact. While such initiatives often focus on ter-

tiary education students, they tend to neglect school-age children in mandatory education (Yue Yim, 2024). While many AI education initiatives focus on abstract, high-level concepts, this proposal advocates instead for a constructionist approach that fosters learning through hands-on creation and exploration rather than passive instruction. Engaging children in hands-on experiences integrates Computational Thinking 2.0, which extends traditional computational thinking by incorporating machine learning, data-driven problem-solving, and ethical considerations (Tedre *et al.*, 2021). This approach ensures that AI literacy education goes beyond coding to include AI's broader societal and technical aspects.

2. Theoretical Framework

This study is grounded in the learning theory of constructionism, articulated by Papert (1980) and later expanded by Harel and Papert (1991). Constructionism builds on Piagetian constructivism by emphasising the creation of personally meaningful artefacts as a vehicle for learning. Rather than absorbing knowledge passively, learners construct understanding through active engagement in designing, building, and sharing projects that reflect their evolving mental models. Central to this approach is the notion that learning occurs most effectively when individuals are engaged in constructing a public entity, whether tangible or digital, that is meaningful to them. AI education is often regarded as abstract, technical, and opaque; constructionism, however, offers a powerful pedagogical lens. By enabling students to manipulate, train, and experiment with AI models, constructionist environments demystify complex concepts such as machine learning, classification, and algorithmic logic. This hands-on, iterative engagement allows learners to internalise key ideas through the process of 'learning-by-making', as they create AI-powered artefacts and reflect on how these systems operate. Tools like Scratch, App Inventor, and other block-based platforms align well with constructionist principles, offering accessible, low-floor entry points that promote exploration, creativity, and computational thinking (Resnick *et al.*, 2009; Tedre *et al.*, 2021).

This constructionist approach directly supports UNESCO's vision of developing "AI-ready citizens" who can think critically about AI's role in society while actively participating in shaping AI development (Miao *et al.*, 2024). The framework's emphasis on human-centered AI design aligns with constructionist principles of learner agency and meaningful creation, positioning students as active participants in knowledge construction and ethical inquiry.

A growing body of empirical work supports the value of constructionist methods in fostering conceptual understanding and 21st-century skills such as problem-solving, creativity, and critical thinking (Brennan and Resnick, 2012; Kafai and Burke, 2015; Morales-Navarro *et al.*, 2023). When learners engage in building AI systems – particularly those that are socially or personally meaningful – they develop not only technical fluency but also a sense of ownership and agency. These experiences position students

as active participants in knowledge construction and ethical inquiry, laying the foundation for a responsible and critically informed engagement with artificial intelligence in both their academic and everyday lives.

This review therefore adopts constructionism as the guiding lens through which recent literature is interpreted, with the goal of constructing a pedagogical framework for AI literacy that is grounded in hands-on, ethical, and developmentally appropriate learning experiences for primary and secondary education.

3. Methodology

This study adopts a Narrative Literature Review (NLR) approach, a qualitative method appropriate for synthesising research from a wide range of disciplinary domains. The narrative review was chosen in view of the theoretical diversity and evolving pedagogical practices surrounding artificial intelligence (AI) literacy in school contexts. As Baumeister and Leary (1997) argue, narrative reviews allow for theory development and the interpretation of findings that may not lend themselves to quantitative aggregation due to methodological heterogeneity. In this sense, the NLR is well positioned to uncover conceptual trends, pedagogical innovations, and practical challenges across studies that differ in scope, method, and context. The current review applies this approach to examine the intersection of AI literacy, constructionist learning, and formal schooling, particularly focusing on project-based and hands-on pedagogical strategies.

Following the best-evidence synthesis model proposed by Green *et al.* (2006), the review was structured around four iterative stages: the initial definition of the scope of inquiry, the identification of relevant literature, the critical evaluation and synthesis of findings, and the thematic organisation of evidence into coherent categories. This approach ensures that although the review is narrative in form, it maintains a high level of rigour, transparency, and conceptual clarity.

3.1. *Defining the Scope*

The overarching aim of this review was to examine how constructionist pedagogical principles have been applied within AI literacy initiatives designed for school-aged children. Three guiding research questions shaped the scope of the inquiry. First, the review sought to identify examples of best practice in promoting AI literacy through learning-by-making. Second, it aimed to surface the pedagogical, technological, and ethical challenges that arise when applying such approaches in school settings. Finally, the review sought to highlight gaps in the literature, particularly with regard to how children conceptualise AI when exposed to constructionist tools and frameworks. The focus remained firmly on primary and secondary education, as these are areas where AI education remains comparatively underdeveloped.

3.2. *Literature Search Strategy*

The literature search was conducted using four leading academic databases: Web of Science, Scopus, IEEE Xplore, and the ACM Digital Library. These databases were selected to ensure comprehensive coverage across educational research, computing education, and technology-enhanced learning. A consistent Boolean search strategy was applied across all databases, structured to retrieve literature situated at the intersection of AI literacy, school-level education, constructionist pedagogy, and educational frameworks or ethical considerations.

The search terms were grouped thematically under four conceptual areas, as presented in Table 1. Within each category, search terms were combined using the `OR` operator, and the four categories were connected using the `AND` operator to refine the search to studies that addressed all four dimensions simultaneously.

The search was limited to peer-reviewed articles published in English between 2009 and 2024. Titles and abstracts were screened manually to assess relevance against the inclusion criteria, and the reference lists of selected papers were examined to identify additional studies through backward snowballing. This strategy ensured that the review captured both foundational and emerging contributions to the field.

To complement the database searches and support broader discovery, the AI-supported tool *Elicit* was used in a supplementary capacity. Elicit employs large language models to assist researchers in identifying potentially relevant peer-reviewed literature based on natural language queries. In this study, it was not used as a primary search engine but rather to verify coverage and identify additional studies that may not have been captured through conventional indexing. Any sources surfaced via Elicit were subject to the same manual screening and inclusion criteria as those retrieved through standard databases, ensuring consistency and academic rigour.

3.3. *Inclusion and Exclusion Criteria*

In line with established protocols for narrative reviews (Green *et al.*, 2006), clear inclusion and exclusion criteria were defined to focus the analysis while retaining conceptual breadth. Studies were included if they examined AI literacy or computational thinking

Table 1
Thematic search terms used across all databases

Conceptual Area	Search Terms Used
AI Literacy	“AI literacy”, “artificial intelligence education”, “AI curriculum”, “teaching AI”
Age Group	“school children”, “primary education”, “elementary education”, “K–12”
Pedagogical Approach	“constructionism”, “constructionist learning”, “learning by making”, “hands-on learning”, “project-based learning”
Educational Framing	“educational technology”, “pedagogy”, “framework”, “ethics”, “curriculum”

in primary or secondary school contexts, featured a constructionist, project-based, or hands-on learning approach, and were published in peer-reviewed academic journals or conference proceedings in English. Both empirical studies and theoretically grounded conceptual papers were considered, provided they contributed to the pedagogical discourse on teaching AI to school-aged children.

Studies were excluded if they focused exclusively on tertiary education or adult learners, addressed AI without an educational or pedagogical lens, or were not peer-reviewed. Grey literature, including reports, blog posts, opinion pieces, and conference abstracts, was also excluded from the final review set to maintain academic rigour and traceability.

3.4. *Data Analysis and Synthesis*

In accordance with narrative review conventions outlined by Baumeister and Leary (1997), the synthesis process was inductive, interpretive, and thematically organised. Each included article was read in full and subjected to qualitative coding to identify recurring concepts and thematic patterns. Particular attention was given to how the studies defined and operationalised AI literacy, the learning environments and tools employed, the cognitive and ethical learning outcomes reported, and the contextual factors that facilitated or constrained implementation. Methodological diversity across studies was embraced rather than controlled for, with the understanding that variations in design offer important insights into how pedagogical strategies function in real-world settings.

The review paid specific attention to the integration of constructionist theory into educational practice. Drawing on Papert's conception of learning-by-making (Papert, 1980), the analysis sought to examine the extent to which reviewed studies encouraged learners to create artefacts, interact with AI systems, and reflect critically on AI's role in society. Several studies included activities such as training image classifiers, developing chatbot narratives, or building rule-based systems using block-based programming languages. These activities were interpreted not only as technical exercises, but also as opportunities for young learners to grapple with the ethical, societal, and cognitive implications of intelligent systems. Where possible, the review compared outcomes across age groups, toolsets, and pedagogical scaffolds, thereby producing a layered understanding of how AI literacy can be meaningfully integrated into school curricula.

4. Themes

In reviewing the literature, five interrelated themes emerged that collectively characterise the constructionist and hands-on approaches to teaching AI literacy in school contexts. These themes – active hands-on learning, project-based and inquiry-driven engagement, integration of ethics, age-appropriate scaffolding, and teacher support with

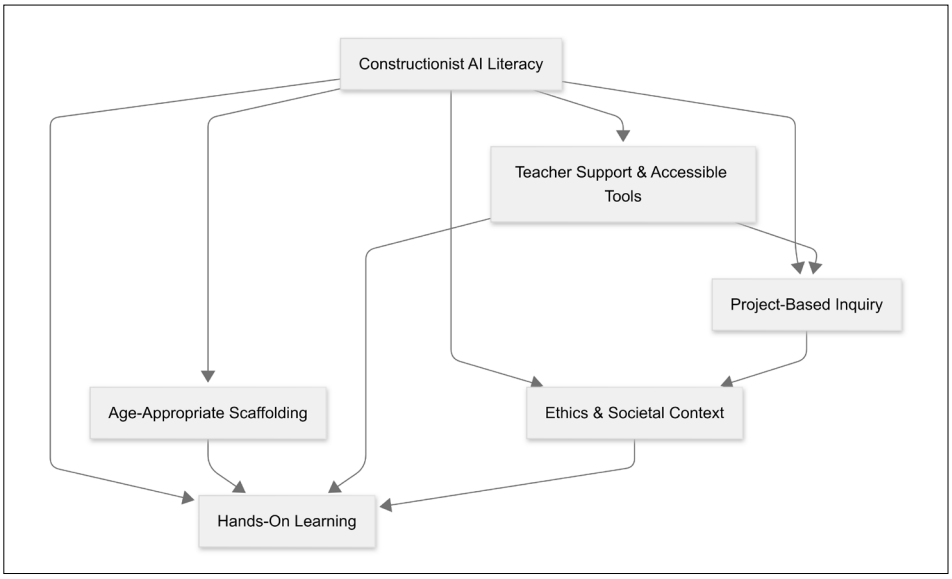

Fig. 1. Conceptual model showing interrelationships among five pedagogical themes in constructionist AI literacy education.

accessible tools – form the conceptual scaffolding of this review. Rather than existing as isolated categories, they represent a network of pedagogical principles that are often implemented in overlapping and mutually reinforcing ways.

Fig. 1 visualises this synthesis. Central to the network is a constructionist understanding of AI literacy, where learning occurs through the creation of meaningful artefacts in personally and socially relevant contexts. The diagram illustrates how teacher preparedness and the availability of accessible tools underpin the effective use of hands-on and project-based methods. These, in turn, provide fertile ground for ethical reasoning to emerge through practice. Scaffolding strategies operate across all levels, ensuring that learners of varying developmental stages can engage productively and equitably with complex AI concepts.

This thematic model offers a high-level synthesis of current pedagogical patterns, serving as a conceptual orientation to the more detailed thematic findings that follow.

5. Findings

Building upon the conceptual framework outlined in the previous section, the following thematic analysis delves into how the reviewed studies address the pedagogical, cognitive, and ethical dimensions of AI literacy in school settings. Each theme is discussed in detail, drawing from diverse empirical and theoretical contributions to illustrate current practices, emerging challenges, and opportunities for future development within constructionist and hands-on approaches.

5.1. *Active, Hands-On Learning as a Catalyst for Conceptual Understanding*

A consistent finding across the reviewed literature is that hands-on learning provides an effective means for students to engage with artificial intelligence not as abstract theory but as a tangible, manipulable domain of inquiry. This aligns with constructionist principles that posit knowledge is best internalised through the design and creation of shareable artefacts. Whether through robotics kits, visual programming environments such as Scratch or App Inventor, or interaction with AI agents, physical and digital construction activities consistently allowed students to develop a conceptual grasp of complex AI processes including classification, decision-making, and data-driven prediction (Estevez *et al.*, 2019; Breazeal *et al.*, 2023; Van Brummelen *et al.*, 2021).

Several studies specifically highlight the pedagogical value of anchoring AI concepts in physical or embodied experiences. Dai (2024a) demonstrated that embodied analogies and constructionist play among upper primary student facilitated the formation of more stable mental models of supervised learning processes such as training and inference. Other studies have shown that when students engage in physical simulations of AI processes – such as role-playing classification tasks or creating rule-based decision artefacts – they are more likely to articulate their understanding in intuitive and personalised ways, making sense of abstract mechanisms through analogy and iterative construction.

Zhang *et al.* (2024) further observed that designing and manipulating AI-powered artefacts – such as chatbots or learning classifiers – empowered students to reason about system behaviour in their own terms, even in the absence of advanced technical vocabulary. Learners moved from passive interaction with AI to actively shaping its logic, which led to more detailed understandings of how data, features, and algorithmic rules co-produce outcomes. In one classroom case, students trained a visual classifier and, through a process of experimentation, discovered how insufficient training data led to erratic model outputs. This realisation prompted reflective discussion and iterative refinement of the training set, deepening both conceptual understanding and metacognitive awareness.

Further examples of constructionist interaction include the use of conversational AI platforms, where learners developed chatbot systems using block-based tools such as App Inventor (Van Brummelen *et al.*, 2021). Similarly, in informal settings, embodied approaches such as the Robot Theatre Platform have been used to engage children in building narrative performances around AI ethics through puppetry and physical artefact manipulation (Mitchell *et al.*, 2024). While these activities serve varied purposes – from language development to moral reasoning – they reaffirm that construction remains central to forming intuitive models of AI behaviour.

Such findings reaffirm that hands-on activities are not peripheral motivational tools but central mechanisms through which learners form and revise mental models of AI. They serve as conceptual bridges – particularly in younger learners – allowing abstract systems thinking to be grounded in personal, embodied, and social contexts. When students build, test, and share their own AI artefacts, they begin to internalise the logic,

limitations, and implications of intelligent systems. Hands-on, constructionist learning thus emerges not only as an instructional strategy, but as a foundational condition for cultivating meaningful AI literacy in school settings.

5.2. *Project-and Inquiry-Based Learning to Deepen Engagement and Support Skill Transfer*

Project-based and inquiry-driven pedagogies emerged across the literature as central to cultivating meaningful and transferable forms of AI literacy. Rooted in the constructionist emphasis on learner agency and purposeful creation, these approaches enable students to engage with AI as co-designers rather than mere users or observers. In such contexts, learners are encouraged to pose questions, explore solutions iteratively, and reflect critically on both the technical and societal dimensions of their work.

Van Brummelen *et al.* (2021) reported that when students designed conversational agents, they not only applied foundational programming and data structuring concepts but also navigated complex design cycles involving ideation, testing, and revision. This process mirrored authentic AI development workflows and positioned students as active participants in knowledge construction. Similarly, project-based modules in middle school classrooms described by Lee *et al.* (2021) integrated ethical inquiry into technical design challenges. Students collaboratively developed AI applications such as voice assistants or simple recommendation systems, reflecting on privacy, fairness, and inclusivity as part of the development process. These cycles of questioning, experimentation, and refinement supported both technical fluency and deeper ethical reasoning.

The literature also highlights the motivational and cognitive benefits of grounding AI learning in real-world contexts. Projects framed around socially relevant issues – such as environmental monitoring, accessibility, or health applications – were found to increase student engagement and perceived relevance. When learners saw their AI solutions as tools to address meaningful problems, they were more likely to invest sustained effort, iterate on their designs, and connect abstract technical concepts to personal and societal values (Li *et al.*, 2025; Yue *et al.*, 2025).

Design-based approaches in particular appeared to facilitate what Vartiainen *et al.* (2020) describe as "computational empowerment" – a state in which students feel confident not only using AI tools but also understanding, modifying, and questioning them. This empowerment was amplified when students worked in collaborative settings, engaging in peer feedback, joint problem-solving, and collective sense-making. In these environments, learning became dialogic and distributed, with students contributing diverse ideas, negotiating design decisions, and collectively refining their understanding of AI systems.

In addition to creation and collaboration, assessment and reflection emerged as vital components of inquiry-based AI education. Masla *et al.* (2025) emphasised the value of integrated formative assessments that allow learners to document their evolving understanding and revise their projects based on feedback. These assessment strategies reinforced the process-oriented nature of constructionist learning and helped teachers scaffold students' progression more effectively.

Taken together, these studies suggest that project-based and inquiry-driven learning strategies offer more than motivational value – they provide essential scaffolds for integrating technical, ethical, and reflective dimensions of AI literacy. By anchoring AI education in personally meaningful problems and open-ended creation, these approaches cultivate habits of experimentation, critical thinking, and collaborative engagement that extend well beyond the scope of a single curriculum unit.

5.3. *Embedding Ethics and Societal Context at the Core of AI Literacy*

A recurring insight across the reviewed literature is that ethical reflection is not a peripheral component of AI literacy but a foundational pillar. As AI systems increasingly mediate social decisions – from hiring to surveillance – educational initiatives have begun to embed ethical inquiry into core learning experiences. These approaches shift the focus from merely understanding how AI works to interrogating what it does, whom it affects, and under what conditions it should be deployed. In doing so, they cultivate what has been described as a critically aware, socially responsible form of AI literacy.

Several studies found that students were more likely to develop thoughtful ethical reasoning when issues were presented not through abstract lectures, but as embedded design constraints or real-world dilemmas. This ethics-first approach reflects UNESCO's competency framework, which positions ethical reasoning as foundational rather than supplementary to AI literacy (Miao *et al.*, 2024). The framework's emphasis on understanding AI's societal implications supports the constructionist strategy of embedding ethical reflection within technical activities.

Williams *et al.* (2022) implemented a middle school curriculum in which students investigated current AI controversies – such as algorithmic bias in hiring or surveillance systems – and responded by prototyping more equitable alternatives. These activities led students to critically examine the assumptions embedded in training data and to articulate the consequences of design choices in terms of fairness, transparency, and accountability.

Zhang *et al.* (2022) extended this approach by integrating future-oriented thinking into AI ethics education. In their study, students explored how the AI systems they created might shape or disrupt future professions, social interactions, and civic participation. This framing encouraged learners to reflect on their roles not just as users of AI, but as future contributors to its design and governance. By inviting students to imagine themselves as ethical agents within evolving sociotechnical systems, the programme deepened engagement and fostered a greater sense of responsibility.

The importance of contextualisation was further supported in studies where students trained or modified AI models using datasets relevant to their own communities. In these settings, the experience of witnessing a model fail or behave inequitably – such as misclassifying based on gender, age, or race – led to critical conversations about the sources of bias and the limits of algorithmic reasoning (Dai, 2024b; Lin and Dai, 2025). These embodied encounters with ethical complexity often yielded deeper understanding than would be possible through theoretical exposition alone.

Ethics was also successfully integrated through interdisciplinary and informal learning environments. For instance, Mitchell *et al.* (2024) describe how the Robot Theatre Platform was used with young children to stimulate ethical reasoning through embodied storytelling and AI-driven role play. Students explored fairness and accountability through physical enactments of AI decisions, helping bridge cognitive gaps through experiential learning.

The literature increasingly points to the emergence of a "critical constructionist" stance in AI education (Arastoopour Irgens *et al.*, 2022; Yim and Su, 2024). In this view, learners do not merely construct technological artefacts; they also construct and reconstruct ethical frameworks through engagement with real-world problems. Design decisions become opportunities for ethical deliberation, and debugging becomes an occasion for social critique. This orientation is especially powerful when students are tasked with creating AI systems intended to be used by others, as it foregrounds questions of inclusion, unintended consequences, and human values.

In sum, the integration of ethical inquiry into hands-on AI education is not only feasible but essential. It equips students to navigate a world where AI systems will shape the contours of everyday life, and it provides them with tools to critically assess and ethically intervene in that world. When ethics is treated not as an add-on but as a constitutive element of design, students emerge better prepared to engage with AI as thoughtful, informed, and responsible citizens.

5.4. *Age-Appropriate Scaffolding to Enable Accessible and Meaningful AI Learning*

Ensuring that AI literacy is developmentally appropriate remains a central concern in the design and implementation of educational programmes, particularly in primary and lower-secondary contexts. The reviewed literature consistently highlights the importance of differentiated scaffolding strategies to accommodate learners' cognitive, linguistic, and technical readiness. Without such scaffolding, students may struggle to move beyond surface-level engagement, especially when confronted with abstract or jargon-laden aspects of artificial intelligence.

For younger learners, unplugged activities and narrative-based approaches have proven especially effective in lowering the barrier to entry. Studies incorporating physical games, role-playing, and story-based simulations allow students to interact with core AI principles – such as classification, training, and rule-based inference – without needing to confront programming syntax or complex interfaces (Breazeal *et al.*, 2023; Davy Tsz Kit *et al.*, 2022; Dai, 2024b). For instance, digital storytelling exercises supported by structured templates and embedded inquiry prompts have enabled children to understand AI logic while simultaneously developing language and emotional literacy. These hybrid tasks support dual engagement: with computational ideas and with personally meaningful expression.

Dai's research into constructionist learning with primary students similarly emphasised the value of analogical scaffolds, wherein physical materials and relatable meta-

phors were used to represent data flows or classification logic (Dai, 2024a). These approaches fostered conceptual stability and helped learners transfer insights across tasks. Yue *et al.* (2025) extended this work by designing a scaffolded design-thinking framework that guided younger learners through stages of AI project development. The authors showed how iterative prototyping and structured peer feedback enabled students to take ownership of increasingly complex ideas while maintaining age-appropriate support.

Research demonstrates that successful AI education initiatives carefully structured learning progressions to match students' developmental levels (Yue Yim, 2024; Dai, 2024b). Gupta *et al.* (2024) likewise emphasised the utility of "Use–Modify–Create" sequences to scaffold learners' progression from passive exploration to active authorship.

Finally, broader reviews confirm that effective AI education requires age-appropriate pedagogical mediation. Yue *et al.* (2022) identify scaffolding as a recurring feature of successful interventions across contexts and age groups, underscoring its centrality not just for accessibility but also for equity in AI literacy initiatives.

Ultimately, age-appropriate scaffolding does more than simplify content – it enables learners to meaningfully participate in the epistemic practices of AI. By tailoring tasks, supports, and tools to learners' developmental stages, educators can cultivate both foundational understanding and a sense of agency. In this way, scaffolding functions as a vital mediating structure through which abstract AI principles are rendered concrete, comprehensible, and personally relevant.

5.5. *Scaling AI Literacy Through Teacher Support and Accessible Tools*

The sustainability and scalability of AI literacy education are inextricably linked to the readiness and confidence of teachers, as well as the availability of accessible, cost-effective tools. Despite growing interest in AI education at the policy and curriculum levels, numerous studies highlight that many educators feel underprepared to teach AI-related topics, often citing limited professional development opportunities, fast-evolving content, and a lack of clear pedagogical frameworks (Arastoopour Irgens *et al.*, 2022).

When teachers are supported through targeted training, co-designed lesson materials, and access to practitioner communities, they are better equipped to integrate AI into their existing teaching practice. Arastoopour Irgens *et al.* (2022) reported that teachers who participated in collaborative curriculum development processes gained not only content knowledge but also a stronger sense of pedagogical ownership. This empowerment was especially important in contexts where AI was introduced across disciplines, requiring educators to balance technical instruction with social, ethical, and critical dimensions. Similarly, Li *et al.* (2025) highlight how co-designing a project-based AI literacy toolkit with teachers enabled classroom implementation that reflected both local constraints and pedagogical priorities.

The availability of low-cost, intuitive AI tools also plays a significant role in democratising access to AI education, particularly in under-resourced settings. Okolo (2024) documented the successful use of tools such as Teachable Machine, LearningML, and other block-based platforms that require minimal infrastructure and are

adaptable to varied classroom contexts. These tools offer graphical interfaces and immediate feedback, enabling both teachers and students to experiment with training and deploying simple AI models without advanced coding knowledge. Importantly, they also support rapid prototyping and iterative learning, features that align well with constructionist pedagogies.

Additional studies confirm that when teachers are given the time and space to adapt resources, they are more likely to experiment and innovate. Masla *et al.* (2025) found that assessment tools co-developed with teachers improved confidence in evaluating student progress in AI concepts, reinforcing the value of teacher input in shaping effective practice. Yue *et al.* (2025) also observed that when teachers facilitated student-driven AI projects, they often reinterpreted their own roles, adopting more exploratory and supportive postures.

In classroom-based interventions where teachers received toolkits and implementation guides, even educators without prior computing backgrounds were able to facilitate meaningful AI learning experiences. For example, workshops designed around open-source resources allowed teachers to incorporate AI projects into existing STEM curricula without requiring substantial curricular overhaul. This approach not only increased feasibility but also helped normalise AI literacy as part of everyday schooling, rather than a specialised or extracurricular pursuit. Trifonova *et al.* (2024) note that when teachers are trained to approach AI literacy through a humanistic lens, they become more confident in addressing ethical and societal issues, even with limited technical knowledge.

Kong *et al.* (2024) emphasise the importance of institutional alignment and policy support to ensure AI literacy is not dependent solely on individual teacher initiative. They advocate for systematic professional development pathways and curricular integration strategies that embed AI across age groups and subject areas. Without such structural support, even the most enthusiastic teachers may struggle to maintain momentum, and promising pedagogical innovations risk remaining isolated or short-lived.

In sum, the literature affirms that effective AI literacy education is not only a matter of curriculum design but also of systemic enablement. Teachers must be recognised as co-learners and co-designers in this evolving field, and they must be supported through accessible tools, time for experimentation, and collaborative infrastructure. Ensuring equity of access – both to knowledge and to the means of creation – will be key to realising the full promise of constructionist AI education at scale.

6. Framework for Age-Differentiated AI Literacy Pedagogy

This review finds strong justification for presenting a developmentally sensitive framework that distinguishes between strategies used in primary and lower-secondary settings, aligning with UNESCO's recognition that AI competencies must be scaffolded according to cognitive readiness (Miao *et al.*, 2024). While the underlying constructionist principles remain consistent, their pedagogical enactment varies significantly across age groups, with primary students focusing on foundational concepts through

embodied learning and secondary students engaging with more complex ethical and technical dimensions.

The following section synthesizes observed approaches into two strands, beginning with strategies designed for early and upper primary education.

6.1. *Primary Education*

Constructionist AI literacy interventions in primary settings typically centre on the use of concrete, embodied, and narrative-based activities that minimise cognitive overload and foster intuitive engagement with core AI concepts. Across the literature, a consistent pattern emerges: effective learning experiences for younger children combine multiple pedagogical modalities that foreground tangibility, imagination, and age-appropriate scaffolding.

Unplugged and embodied learning activities serve as a foundational strategy. Dai (2024b), for instance, successfully employed embodied analogies to represent supervised learning processes, enabling students to grasp training and inference through physical simulation. Similarly, Badillo-Perez *et al.* (2023) documented how constructionist tasks inspired by Montessori principles allowed children aged 6 to 9 to develop intuitive understandings of pattern recognition and categorisation by manipulating physical materials.

Narrative-driven approaches likewise feature prominently. Ng *et al.* (2022) found that digital storytelling and structured story-writing exercises provided students with meaningful contexts in which to explore AI logic. These tasks encouraged learners to personify AI systems, articulate processes in everyday language, and reflect on AI behaviour through familiar narrative forms.

Hands-on, project-based activities remain integral to constructionist pedagogy at the primary level, albeit with simplification. Arastoopour Irgens *et al.* (2022) reported on successful interventions with learners aged 9 to 13, in which students constructed rudimentary AI artefacts using visual programming platforms. These activities prioritised experience over technical fluency and promoted engagement through iterative creation and playful experimentation.

Developmental considerations are repeatedly emphasised across the reviewed studies. Dai *et al.* (2023) and Yue *et al.* (2022) caution against prematurely introducing abstract terminology or complex workflows, recommending instead the use of visual metaphors, physical analogies, and task structures that align with students' existing cognitive schemas. Yim and Su (2024) argue that effective scaffolding is essential, particularly in facilitating the transition from conceptual play to reflective understanding.

Taken together, the literature indicates that primary-level AI literacy is best supported through:

- Physically embodied or visually grounded representations of AI processes.
- Contextualised, child-relevant narratives that embed algorithmic logic.
- Low-floor, high-ceiling tools that invite manipulation without technical barriers.
- Sequenced scaffolds that support exploration, modification, and reflection.

These strategies collectively enable younger students to engage with artificial intelligence not as passive consumers but as active builders and sense-makers, in line with constructionist commitments to agency, creativity, and personally meaningful learning.

6.2. *Secondary Education*

In contrast to the strategies employed at the primary level, AI literacy initiatives in lower-secondary education tend to foreground technical fluency, critical engagement with ethical implications, and authentic project-based learning. While the constructionist foundation remains central – emphasising learning through making and reflection – the pedagogical emphasis in this age group shifts toward complex problem-solving, collaborative design, and the integration of real-world applications.

Several studies highlight the value of hardware and software-based learning environments as effective vehicles for constructionist engagement. Van Brummelen *et al.* (2021) documented positive outcomes from activities involving programmable robotics and visual machine learning tools with learners in Grades 6–12. Similarly, Xia *et al.* (2022) demonstrated that Grade 9 students responded well to technical tasks involving data labelling, model training, and interface design. Williams *et al.* (2022) combined such digital engagements with unplugged activities to reinforce conceptual understanding while maintaining accessibility.

Collaborative, project-based learning emerged as a recurring pedagogical strategy. Kong *et al.* (2024) and Lee *et al.* (2021) both implemented extended design challenges in which students worked in teams to prototype AI applications with social relevance, such as health monitoring tools or recommendation systems. These projects promoted not only technical knowledge acquisition but also socio-ethical reflection, particularly when learners were encouraged to consider the consequences of their design decisions on users and communities. Zhang *et al.* (2022) extended this paradigm by embedding discussions of future careers and civic participation into collaborative projects, enabling students to reflect on their potential roles in shaping AI development.

A defining characteristic of secondary-level constructionist AI education is the deliberate and sustained integration of ethics and real-world context. Ali *et al.* (2021a) developed units that focused on manipulation and misinformation in AI-generated media, prompting students to critique the authenticity and intent of algorithmic outputs. Kaspersen *et al.* (2022) advocated for an "ethics-first" approach in which learners encountered ethical dilemmas prior to technical instruction, thereby framing AI as a socio-technical system from the outset. Zhang *et al.* (2022) "Ethics in AI Education" programme offered a scaffolded sequence for teaching fairness, accountability, and transparency, often through iterative experimentation with biased or incomplete datasets.

Secondary-level curricula also accommodate the exploration of advanced AI concepts. Across multiple studies, learners were introduced to the fundamentals of machine learning, decision trees, neural networks, and generative models (Ali *et al.*, 2021b; Ng *et al.*, 2024). These topics, when mediated through accessible platforms and guided design tasks, enabled students to grasp the statistical and probabilistic underpinnings of intelligent systems without requiring high-level mathematical formalism.

Several success factors are consistently reported across the literature. Effective programmes:

- Integrate ethics directly into technical tasks rather than treating them as supplemental.
- Emphasise real-world applications to support relevance and sustained engagement.
- Provide access to sophisticated tools while maintaining a low floor for entry.
- Encourage critical reflection and ethical reasoning as core learning outcomes.

As Yim and Su (2024) observe, approaches at the secondary level are typically more technically demanding and require learners to engage with abstract systems thinking and interdisciplinary inquiry. Nevertheless, when supported through constructionist pedagogy, these engagements empower students to move from understanding how AI works to interrogating its role in society and envisioning its future development.

7. Conclusion

This narrative literature review synthesized research on constructionist approaches to AI literacy education for school-aged children, revealing five interconnected pedagogical themes that collectively form a robust framework for implementation. The analysis demonstrates that hands-on, making-centered approaches are not merely effective alternatives to traditional instruction – they are essential for developing the conceptual understanding, ethical reasoning, and critical agency that constitute meaningful AI literacy.

7.1. *Key Findings and Implications*

The evidence strongly supports three fundamental principles for AI literacy education. First, learning occurs most effectively when students actively construct AI-powered artifacts rather than passively consuming information about AI systems. This constructionist approach enables learners to internalize complex concepts through direct manipulation and experimentation, transforming abstract algorithmic processes into tangible, comprehensible experiences. Second, ethical reasoning emerges naturally through hands-on engagement when students encounter real consequences of their design decisions, bias in their training data, or unexpected model behaviors. Third, age-appropriate scaffolding must be carefully calibrated – younger learners benefit from embodied analogies and narrative contexts, while secondary students can engage with more sophisticated technical concepts and societal implications. However, the review also reveals significant implementation challenges that must be addressed for widespread adoption. Teacher preparation emerges as the critical bottleneck, with many educators feeling underprepared to facilitate AI literacy experiences despite their enthusiasm. The evidence suggests that effective professional development must combine technical familiarity with pedagogical confidence, supported by accessible tools and collaborative learning communities.

7.2. *Actionable Recommendations*

For educators, this framework provides a clear progression: begin with unplugged activities that make AI concepts tangible, advance to block-based programming tools that enable direct manipulation of AI systems, and integrate ethical reflection throughout technical activities rather than treating it as supplementary content. Primary teachers should prioritize embodied learning experiences and narrative contexts, while secondary educators should emphasize collaborative design projects with real-world applications. For administrators and policymakers, the findings underscore the need for systematic investment in teacher professional development, accessible technology infrastructure, and curriculum integration strategies. AI literacy cannot be relegated to computer science classes – it requires interdisciplinary integration and institutional commitment to constructionist pedagogies. Schools must also address equity concerns by ensuring all students have access to hands-on AI learning experiences, regardless of socioeconomic background. For researchers, several critical gaps require immediate attention. Long-term studies are needed to assess whether constructionist AI literacy experiences produce sustained learning outcomes and transfer to novel contexts. Cross-cultural research must examine how different educational systems and cultural values shape AI literacy development. Additionally, more sophisticated assessment frameworks are needed to evaluate the complex interplay of technical, ethical, and critical thinking competencies that constitute AI literacy.

7.3. *Limitations and Future Directions*

This review's narrative approach, while appropriate for synthesizing diverse methodological approaches, limits the strength of causal claims about pedagogical effectiveness. Many reviewed studies involved small samples and short intervention periods, raising questions about scalability and sustainability. Geographic bias toward North American and European contexts also limits generalizability to other educational systems and cultural contexts. Future research should prioritize longitudinal studies that track AI literacy development over multiple years, comparative studies that isolate the effects of specific constructionist elements, and implementation research that addresses real-world constraints and challenges. Particular attention should be paid to developing culturally responsive approaches and supporting teachers in under-resourced contexts.

7.4. *A Call for Systemic Change*

The increasing ubiquity of AI systems in society makes AI literacy education not merely beneficial but essential for democratic participation and social justice. However, achieving this vision requires moving beyond pilot programs and isolated initiatives toward systemic educational transformation. This means reconceptualizing AI literacy not as a technical skill set but as a fundamental dimension of citizenship in an AI-driven world. The constructionist framework presented here offers a pathway forward that honors chil-

dren's capacity for sophisticated thinking while providing concrete guidance for implementation. By grounding AI literacy in hands-on creation, ethical reflection, and collaborative inquiry, we can prepare young learners not merely to use AI systems but to shape their development in ways that reflect human values and social justice principles. The question is not whether schools should integrate AI literacy education, but how quickly and equitably they can do so. As UNESCO's framework emphasizes, preparing students for an AI-integrated future requires more than technical skills – it demands cultivating critical thinking, ethical reasoning, and creative problem-solving capabilities that constructionist approaches uniquely provide (Miao *et al.*, 2024). The evidence reviewed here suggests that constructionist approaches provide the most promising foundation for this critical educational imperative. The time for incremental change has passed – what is needed now is bold commitment to transforming how we prepare young people for an AI-integrated future.

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