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Artificial intelligence literacy education in primary schools: a review

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Abstract

Artificial intelligence (AI) has become an important part of 21st-century life and this requires that students understand how to adapt to this change. Despite calls to extend AI literacy education from university to young students, there remains a lack of evidence-based research informing educators and researchers on the content of AI literacy education at the primary school level. This study aims to offer a comprehensive overview of what constitutes AI literacy education in primary schools, including its theoretical frameworks, pedagogical strategies, learning tools, assessment methods, educational outcomes, and challenges. The study presents a systematic review mapping process using Scopus and the Web of Science. Twenty-five empirical studies focusing on the primary school context were selected. The review revealed that (1) AI literacy encompasses a fluid conceptual understanding of digital literacy in terms of interacting and collaborating with AI, computational thinking, critical data literacy, and AI ethics; (2) constructionism, the constructivist theoretical framework, and the ARCS (Attention, Relevance, Confidence, and Satisfaction) model of instructional design were the dominant means of constructing the research design of the selected studies; (3) constructivist methodologies, project-based learning, programming, and human-agent interaction were commonly used by the selected studies, and AI learning tools, particularly intelligent agents, were often adopted in AI literacy teaching and learning research; (4) mixed-research methods were the most common, with surveys, interviews, and artifacts being employed to evaluate students' learning outcomes; and (5) there were positive academic, affective, and behavioral educational outcomes, as well as course satisfaction. To our knowledge, this is the first systematic review to offer a detailed perspective on AI literacy at the primary school level, providing valuable insights for researchers, policymakers, and educators designing future educational frameworks, curricula, and assessment. Future research directions are also discussed.

Keywords Artificial intelligence literacy primary education · AI literacy teaching and learning · AI ethics · Conceptual and theoretical framework · Young students · Systematic reviews

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Introduction

Artificial intelligence (AI) is ubiquitous, significantly impacting our lives, work, and education. Despite its prevalence, AI literacy education for young students is still in its infancy and lacks a clear definition for effective implementation. Although there have been calls to extend AI literacy education from university students to young students (Vartiainen et al., 2020), specific content and pedagogies for teaching remain largely under-explored (Su et al., 2023, 2024a). This gap presents several challenges in primary school education, including determining age-appropriate AI concepts suitable for students without a technical background (Mertala et al., 2022), and the development of strategies and learning tools to help young students understand the conceptual underpinnings of AI (Carvalho et al., 2022; Dai et al., 2023).

Since AI was introduced in 1956 as “the science and engineering of making intelligent machines, especially intelligent computer programs” (McCarthy, 2007, p.2), AI has become an omnipresent force influencing various aspects of human life and most industries, including healthcare, finance, education, transportation and consumer service (Crawford, 2021). In light of this impact, the important of AI literacy extends beyond the domain of computer scientists (Ng et al., 2021) and includes individuals of all ages, including young students (Su et al., 2023a). While advocates argue for universal AI literacy, stating that everyone should be equipped with conceptual knowledge of AI (Seldon & Abidoye, 2018; Long & Margeko, 2020), others believe that children are too young to comprehend the complexities of AI (Laupichler et al., 2022; Su et al., 2022).

Despite young students growing up in an environment saturated with AI technologies, such as SIRI and Alexa (Su & Yang, 2022; Van Brummelen et al., 2021), there is a disconcerting gap in their understanding of the underlying assumptions and algorithms of AI (Ali et al., 2019). A lack of awareness about the accuracy of AI data (Mertala et al., 2022) and the phenomenon of deepfakes (CBS, 2023) have fueled discussions on ethical considerations (Crawford, 2021) and the privacy and security implications of AI (Floridi, 2018). Addressing this deficit is crucial in AI literacy education for young students to build a conceptual understanding of AI (Mertala et al., 2022; Rodríguez-Garciá et al., 2021).

Internationally, many countries (Miao & Shiohira, 2022) have promoted the inclusion of AI literacy for young students in formal educational settings, and various educational frameworks (Chiu et al., 2021; Sentence & Waite, 2022) have been developed to guide curriculum design in recent years. However, it is often assumed that educators already possess the necessary pedagogical strategies, learning tools, and assessment methods to design appropriate AI learning activities for young students (Rizvi et al., 2023; Yue et al., 2022). Casal-Otero et al. (2023) further elaborate that AI literacy education is a cognitive and pedagogical challenge for educators that requires ongoing professional development for teachers and well-designed curricula. Despite the growing need for AI literacy education for young students (Miao & Shiohira, 2022), the implementation of AI literacy in primary school settings has been overlooked and underreported (Chai et al., 2020a, 2020b; Druga et al., 2019).

To bridge these gaps, there is an urgent need to offer educators a systematic review of the theoretical frameworks, pedagogical strategies, learning tools, assessment methods, learning outcomes, challenges, and recommendations associated with AI literacy education, synthesizing empirical studies to develop a widely accepted approach to AI literacy learning and education for primary school students.

Literature review

AI literacy and conceptual framework

Kandlhofer et al. (2016) introduced the term "AI literacy" to refer to a set of technological skills essential for understanding the fundamental concepts and theories underpinning AI-driven technologies, which include automata, intelligent agents, graphs and data structures, and other technologies that engage in sorting and problem solving by searching, classic planning, and machine learning. They asserted that AI literacy would soon be as crucial as traditional literacy in reading and writing. Long and Magerko (2020) identified 17 competencies, and 13 design considerations related to AI literacy, aiming to reveal emerging themes about the definition of AI literacy and common perceptions and misconceptions related to AI. Based on Bloom's taxonomy framework (Bloom, 1956), Ng et al. (2021), instead of focusing solely on learning and pedagogical methods, expanded the definition of AI literacy to include "know and understand AI", "use and apply AI", and "evaluate and create AI",. Despite these efforts, however, there remains a lack of public consensus on students' perceptions of AI (Kreinsen & Schulz, 2021) and a clear conceptual definition of AI literacy (Yim, 2021, 2024a) to guide effective AI literacy education implementation.

Recent initiatives 2024., 2021, such as UNESCO's AI literacy frameworks and national guidelines, aim to address this gap, providing comprehensive guidelines for the development of AI resources for young students (Miao & Shiohira, 2024; Miao et al., 2021). Examples include the Five Big Ideas of AI Curriculum, the Six Big Ideas of AI literacy (Yim, 2024b), the Machine Learning Education framework (Lao, 2020), the SEAME (Social and Ethical, Application, Models, and Engines) framework (Sentence & Waite, 2022) and the AKIEE (i.e., Awareness, Knowledge, Interaction, Empowerment, and Ethics) framework (Chiu et al., 2021). The European Commission has also integrated AI into its Digital Competence Framework for Citizens (Vuorikari et al., 2022). However, studies incorporating age-appropriate content and a comprehensive conceptual understanding of AI literacy are lacking, especially in the context of primary school education (Kim et al., 2021). Considering the pressing need to offer AI literacy education to young students, it is crucial to develop a clear, age-appropriate conceptual definition of AI literacy. This will help enable educators to implement effective teaching strategies in primary school settings.

AI literacy in primary education

AI literacy education for primary school students is relatively new, with the subject having conventionally been taught in computer science programs at universities and, since the late 2010s, in secondary schools (Maio et al., 2021), with the belief that it requires advanced programming skills young students have yet to develop (Chiu et al., 2021). Educators face challenges in teaching AI literacy to primary school students due to their level of cognitive development and teachers' need to use age-appropriate learning tools and pedagogies to build a conceptual understanding of AI concepts (Dai et al., 2023; Mertala et al., 2022). Gong et al. (2020) explain that lagging technological advancements and insufficiently effective AI teaching tools in the teaching space for AI technologies hinder the effective teaching of AI literacy education. Melsion et al. (2021) further elaborate that teaching concepts such as bias is difficult due to their complexity and abstract nature. Age-appropriate AI learning tools such as block-based programming and software (Li & Song, 2020;

Toivonen et al., 2020), intelligent agents (Shamir & Levin, 2021), and unplugged activities (Ho et al., 2019; Ali et al., 2019) reduce the complexity of AI literacy teaching and learning (Toivonen et al., 2020; William et al., 2019). However, there is insufficient discussion about the effectiveness of these tools for improving the learning outcomes of students (Yim & Su, 2024). More importantly, due to the lack of standardization of AI primary education curricula (Gong et al., 2020), there is little consensus on how to teach young students (Kim et al., 2021; Su et al., 2022) and the appropriateness of related assessment methods (Mertala et al., 2022; Ng et al., 2021).

Previous AI literacy reviews

Although the inception of AI literacy learning activities for young students dates back to 1970 (Yim, 2024a), AI literacy education for primary school students has been underexplored by researchers. Twelve recent reviews have highlighted the increasing popularity of AI literacy education, as evidenced in Table 1. Long and Magerko (2020) and Ng et al. (2021) comprehensively defined AI literacy across educational levels. Casal-Otero et al. (2023) investigate current AI literacy approaches for K-12 students, identifying two predominant categories: learning experience and theoretical perspective. Yue et al. (2022), on the other hand, review 22 articles from 2010 to 2022, highlighting the positive impact of pedagogical design and AI teaching activities on K-12 students' engagement, motivations, and attitudes. With the advancement of K-12 learning tools, Crompton et al. (2022) review 169 relevant articles and focused on the affordances and challenges posed by AI learning tools, whereas Rizvi et al. (2023) explore the learning outcomes of AI literacy education. Marques et al. (2020) examine the educational content of machine learning, while Gresse von Wangenheim et al. (2021) investigate its visual learning methods, with both papers discussing the lack of collaborative learning and performance-based assessment regarding machine learning, a subset of AI literacy learning.

In these reviews mapping pedagogical strategies, AI learning tools, and student outcomes in AI education, there has been a specific focus on teaching AI literacy in the kindergarten (Su et al., 2024a), secondary school (Ng et al., 2023), and higher education (Laupichler et al., 2022) contexts. While the reviews contribute to the field of AI literacy education research, they lack a detailed exploration of the theoretical underpinnings of learning activities, as well as the pedagogies, assessment methods, and outcomes related to AI literacy education in the primary school context.

There is currently a limited number of reviews summarizing AI literacy education in primary schools. To inform educators about the effective implementation of AI literacy education for young students, this review offers evidence-based research to conceptualize the term "AI literacy" and to present an overview of current approaches to understanding its content and how it is taught and assessed in primary school contexts. This study could also serve as a valuable reference for informing academics and educators to establish the groundwork for designing future educational frameworks, curricula, and assessment.

This review formulated seven research questions:

RQ1 How has AI literacy been defined in relation to primary schools?

RQ2 What theoretical frameworks have underpinned research on AI literacy in primary schools?

Table 1 Previous AI literacy review

Review	Year	Range	# of studies	Education level	Focus
Casal-Otero et al. (2023)	2023	2021–2023	179	K-12	Educational approach
Crompton et al.(2022)	2022	2011–2021	169	K-12	Affordance and challenges of using AI Learning tools in supporting teaching
Gresse von Wangenheim et al. (2021)	2011	2011–2021	24	K-12	Visual tools for teaching machine learning
Laupichler et al. (2022)	2022	2016–2022	30	Higher and adult education	Thematic foci, definition, pedagogical structure, and target audience
Long and Magerko (2020)	2022	Up to 2019	150	All levels includes citizens	Definition
Marques et al. (2020)	2020	Up to 2020	30	K-12	Learning content of machine learning
Ng et al. (2021a)	2021	2014–2020	18	All levels includes citizens	Definition, pedagogies, and evaluations
Ng et al. (2023)	2023	2016–2022	50	Secondary Schools	Learning tools, pedagogy, learning outcomes
Rizi et al. (2023)	2023	2019–2022	28	K-12	Leaning context and learning outcomes
Su et al. (2022)	2022	2018–2022	14	K-12 in Asia Pacific	Research design and future directions
Su et al. (2024a	2023	2016–2022	16	Early childhood education	Challenges and opportunities
Su et al. (2024a)	2024	2019–2022	21	K-12	Learning goals, content, teaching methods, assessment, and learning effects
Yue et al. (2022)	2022	2010–2022	32	K-12	Pedagogical design, teaching and learning activities

RQ3 What pedagogical strategies have been adopted to teach AI literacy in primary school?
RQ4 What learning tools have been employed to teach AI literacy in primary schools?
RQ5 What assessment methods have been used to teach AI literacy in primary schools?
RQ6 What outcomes have been identified in relation to AI literacy in primary schools?
RQ7 What challenges, limitations, and recommendations have been identified in relation to AI literacy in primary schools?

Methods

This review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement approach as outlined by Page et al. (2021) and involved three main steps: (1) article selection, (2) article screening, and (3) data coding, extraction, and analysis.

Article selection

To identify relevant literature, the following search terms were used, consistent with previous studies (Su et al., 2022): ("Artificial Intelligence literacy" OR "AI literacy") AND ("learning" OR "teaching" OR "pedagogy" OR "curriculum") AND ("primary" OR "students" OR "primary school*" OR "children" OR "primary students*" OR "elementary schools" OR "K-12 schools"). This search was also conducted for articles whose terms appeared in the keywords and were published before the end of March 2024. Relevant studies were identified from two electronic databases, Scopus and the Web of Science, in March 2024. A total of 44 studies were retrieved.

Eligibility criteria

To select articles for the primary analysis, a screening and inclusion process was employed. In the subsequent stage, a literature scan was conducted to eliminate irrelevant papers. The exclusion criteria were as follows: (1) studies that were not pertinent to the research topic (n = 3); (2) duplicate studies (n = 3); (3) studies that did not focus on primary school settings (n = 7); (4) studies that did not contain research data (n = 4); and (5) studies that did not contain empirical research (n = 2). Ultimately, 25 studies were subjected to a comprehensive review, as shown in Fig. 1.

Coding theme

The two authors independently reviewed the titles and abstracts of the articles to identify empirical studies related to AI literacy in primary schools. To achieve interrater reliability higher than 80%, disagreements were settled by discussion between the two researchers. The coding themes for the selected studies on AI literacy included author/year, country, definition of AI literacy, theoretical frameworks, pedagogical strategies, learning tools, assessment methods, educational outcomes, challenges, limitations, and recommendations (Table 2).

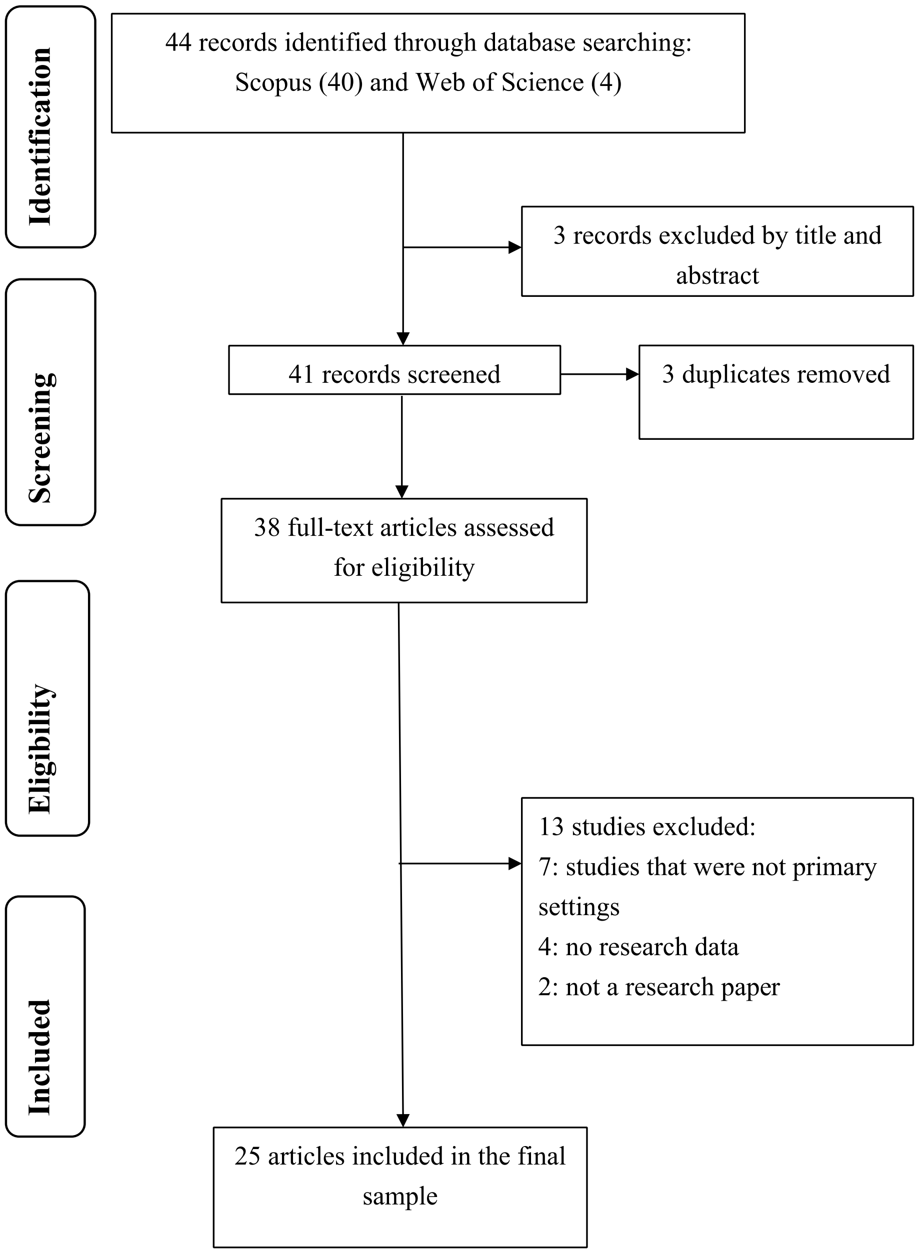


Fig. 1 PRISMA diagram of studies selected for review

Overview of the selected studies

Twenty-five studies were identified. The majority were conducted in China (n = 8), the USA (n = 6), Finland (n = 3), and Israel (n = 2) (Table 3). Most of the studies adopted a

Table 2 Coding scheme

RQs	e.g. Theme	Explanations/reference
RQ1. Definition	AI Ethics	AI ethics guidelines allow citizens to become sufficiently aware of AI relevant to the social, ethical, and environmental issues to all creatures including human and human and natural life when making informed choices in guiding the development, deployment, and use of AI systems (Jobin et al., 2019; Laugksch, 2000)
	Computational thinking skills	Computation thinking skills involve a thought process of formulating problems so that the answers can be expressed as computational steps and algorithms (Wing, 2006)
	Critical data literacy	The Critical Data Literacy Framework allows students to use and critically produce data (Tygel et al., 2016)
	Digital literacy in terms of use and interact with AI	Based on Digital literacy framework, it includes visual representation literacy, reproduction literacy, information literacy, branching literacy and socio-emotional literacy (Eshet, 2004)
RQ2. Theoretical frameworks	ARCS Model of instructional design	The ARCS Model of instructional design is composed of four conceptual categories, namely, attention, relevance, confidence and satisfaction to assess the motivation of students (Li & Keller, 2018)
	Constructionism /Constructivism	Constructionism is a learning theory developed by Seymour Papert. that suggest that students learn best through constructing an artefacts or participating in a project that relevant to them (Papert & Harel, 1991)
	AI4K12: The Five Big Ideas of AI framework	An AI4K12 initiative (http:// ai4k12.org/) released a national guideline of Five Big Ideas Framework in AI, namely, perception, representation and reasoning, learning, natural interaction and societal impact, for K12 population if students

Table 2 (continued)

RQs	e.g. Theme	Explanations/reference
RQ3: Pedagogical Strategies	Project-based learning	Project-based learning involves learning through hands-on real-life problems or projects, making the learning experience more relevant to students' lives (Ali et al., 2019; Rodríguez-Garciá et al., 2021)
	Programming	Programming refers to as coding, a process of designing and building executable computer programs to accomplish a specific task or solve a particular problem (Dai et al., 2023; Shamir & Levin, 2022)
	Human-agent interaction	Human-agent interaction involves learning through experience with artificial agents, how humans and artificial agents can communicate, collaborate, and work together effectively (Druga et al., 2019; Relmasira et al., 2023)
RQ4: Learning Tools	Intelligent agent	An intelligent agent is a smart computer system or device that can make decisions and take actions based on its environment or inputs (Druga & Ko, 2021; Vartiainen et al., 2020)
	Software	Software refers to a set of instructions or programs to operate a computer how to perform specific tasks (Shamir & Levin, 2021 & 2022)
	Unplugged activities	Unplugged activities involve learning about AI without technological and computer device (Ali et al., 2019; Ng et al., 2022)
RQ5: Assessment Methods	Quantitative methods	Quantitative methods include methods such as surveys and questionnaires (Chai et al., 2020a; Du et al., 2022)
	Qualitative methods	Qualitative methods include methods such as interviews and artifact-based assessment (Melsion et al., 2021; Ng et al., 2022)
RQ6. Learning outcomes	Academic Outcomes	As Academic outcomes include outcomes such as knowledge and skills (Shamir & Levin, 2021; Rodríguez-Garciá et al., 2021)
	Affective and Behavioral Outcomes	Affective and behavioral outcomes include outcomes such as students' motivation and engagement (Shamir & Levin, 2021; Voulgari et al., 2021)
	Course Satisfaction	Course satisfaction refers to students' level of satisfaction with their experience (Shamir & Levin, 2022)

Table 2 (continued)

RQs	e.g. Theme	Explanations/reference
RQ7. Challenges, limitations, and recommendations	Challenges	Such as lack of systematic AI curriculum and measurements (Gong et al., 2020), Student perceptions, readiness, and gender differences in AI learning (Chai et al., 2020a); and Insufficient teaching experience and required professional training (Henry et al. (2021)
	Limitations	Such as small sample size (Vartiainen et al. (2020), potential bias in answers (Dai et al., 2020), selection bias (Mertala et al., 2022), data collection method (Ng et al., 2022)
	Recommendations	Such as curriculum design (Chai et al., 2021), professional training (Lee et al., 2021), interdisciplinary learning (Dai et al., 2024)

Table 3 Overview of selected studies

Countries	N
Belgium	1
China	8
Finland	3
Greece	1
Hong Kong	1
Indonesia	1
Israel	2
Spain	1
Sweden	1
USA	6
Research Methods	N
Mixed Methods	10
Qualitative	8
Quantitative	7
Year	N
2019	2
2020	6
2021	9
2022	3
2023	4
2024	1

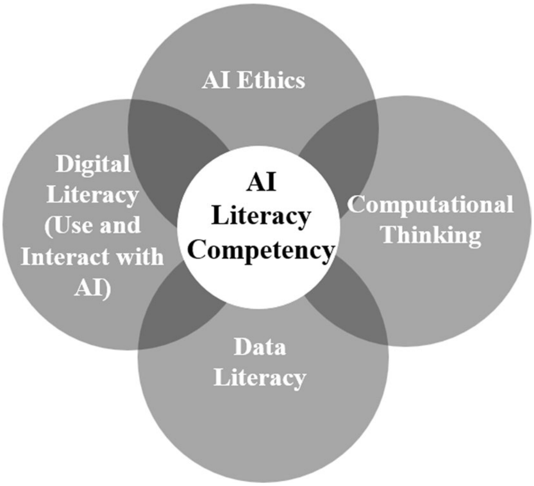
mixed method (n = 10), or qualitative (n = 8) and quantitative (n = 7), approach. No studies were conducted before 2019. There was a dramatic increase in the number of studies from 2019 (n = 2) to 2020 (n = 6) and 2023 (n = 4), with the peak occurring in 2021, when nine articles were published. The sample sizes of these studies ranged from six to 682 participants. Most were conducted in formal school settings, with four conducted online (Melsion et al., 2021; Rodríguez-Garciá et al., 2021; Shamir & Levin, 2021, 2022), two in mixed locations and educational settings (Druga & Ko, 2021; Druga et al., 2019), and one in a non-school setting (Vartiainen et al., 2020). All the studies reflected the diversity of school students, as evidenced by participants' backgrounds and nationalities.

Findings

RQ1. How has AI literacy been defined in relation to primary schools?

This section outlines the conceptual framework for defining AI literacy competencies in the primary school context (Fig. 2), incorporating four literacy components: (1) digital literacy in terms of interacting and collaborating with AI (n = 19); (2) computational thinking (n = 10); (3) AI ethics (n = 10); and (4) data literacy (n = 5), as shown in Table 4. These four components are integral to the definition of AI literacy, since, as outlined below, they provide the basic knowledge students need.

Fig. 2 The conceptual framework of AI literacy competency in primary school settings



Interacting and collaborating with AI In general, all the selected studies defined AI literacy as a component of digital literacy, aiming to enable individuals to interact and collaborate with AI. This definition overlaps with Eshet's (2004) definition of AI literacy as involving visual representation literacy, reproduction literacy, information literacy, branching literacy, and socioemotional literacy.

Visual representation literacy refers to the ability to understand concepts presented in visual representation and media texts in digital interfaces. It sees AI as constituting both an actor and artifact, and argues that AI literacy cannot be fully differentiated from media literacy, as online media increasingly employs AI-generated content (Henry et al., 2021; Mertala et al., 2022). Visual representation literacy suggests, therefore, that students should learn to identify examples of AI in their daily life (Ali et al., 2019) and interact with or explain AI-enabled digital technologies (Vartiainen et al., 2020).

Reproduction literacy is a process of creating and using external representations for modeling and reasoning practices (Ali et al., 2019; Shamir & Levin, 2022). This approach can be interpreted as reproducing knowledge from existing information for higher-order thinking processes, such as neural network construction (Shamir & Levin, 2021) and codesign of a machine learning application (Toivonen et al., 2020).

Branching literacy is nonlinear digital competency related to associative-branching thinking and allows students not only to know, use, and apply but also evaluate and create AI effectively and ethically for learning, living, and working in daily life (Ng et al., 2022). Voulgari et al. (2021) regards AI literacy as a digital literacy skill for students to navigate the digital world freely through playing games, which allows them to acquire multidimensional thinking skills and gain an understanding of supervised and reinforcement learning through AI.

Information literacy is the ability to understand AI, analyze its representations and approach it critically (Henry et al., 2021). According to Mertala et al. (2022), AI literacy requires distinguishing narrow AI, which performs specific tasks, from general and super AI, which are found in science fiction but not yet in reality.

Socioemotional digital literacy refers to the ability to communicate and engage in information sharing through social practice, collaborative learning, and knowledge construction in AI-infused digital spaces (Lee et al., 2021). AI literacy learning occurs when knowledge

Table 4 Typology of AI literacy

Types	Sub-types	N	Studies
Digital Literacy in terms of use, interact and collaborate with AI	Visual representation literacy / Media literacy	N = 19	Ali et al. (2019); Chai et al. (2020a); Chai et al. (2020b); Chai et al. (2021); Dai et al. (2020); Gong et al. (2020); Henry et al. (2021); Lee et al. (2021); Lin et al. (2021); Melsion et al. (2021); Mertala et al (2022); Ng et al (2022); Ottenbreit-Leftwich et al. (2023); Rodríguez-Garciá et al. (2021); Shamir and Levin (2021); Shamir and Levin (2022); Toivonen et al., (2020; Vartiainen et al. (2020); Voulgari et al. (2021)
	Reproduction literacy	N = 6	Ali et al. (2019); Chai et al. (2021); Ng et al. (2022); Shamir and Levin (2021); Shamir and Levin (2022); Toivonen et al. (2020)
	Information literacy (output level)	N = 10	Ali et al. (2019); Chai et al. (2020a); Chai et al. (2021); Henry et al. (2021); Melsion et al. (2021); Ng et al (2022); Rodríguez-Garciá et al. (2021); Shamir and Levin (2022); Vartiainen et al. (2020); Voulgari et al. (2021)
	Branching literacy	N = 4	Chai et al. (2020a); Ng et al (2022); Relmasira et al. (2023); Voulgari et al. (2021)
	Socio-emotional literacy	N = 5	Lee et al. (2021); Relmasira et al. (2023); Rodríguez-Garciá et al. (2021); Vartiainen et al. (2020); Voulgari et al. (2021)
Computational Thinking / Skills	Computational skills / programming	N = 10	Dai et al., (2023); Dai et al., (2024); Druga and Ko (2021); Druga et al. (2019); Du et al., (2022); Gong et al. (2020); Lin et al. (2021); Shamir and Levin (2021); Shamir and Levin (2022); Vartiainen et al. (2020)
Data literacy	Data bias, data justice (input level)	N = 5	Ali et al. (2019); Melsion et al. (2021); Shamir and Levin (2022); Vartiainen et al. (2020); Voulgari et al. (2021)
AI Ethics	Make informed decisions with societal and ethical considerations	N = 10	Ali et al. (2019); Chai et al. (2020a); Chai et al. (2021); Dai et al., (2023); Dai et al., (2024); Henry et al. (2021); Ottenbreit-Leftwich et al. (2023); Relmasira et al. (2023); Rodríguez-Garciá et al. (2021); Toivonen et al. (2020)

is shared and communicated among students and through AI in “teaching a computer” activities where no writing, syntax, or programming experience is required (Vartiainen et al., 2020). Such AI activities support children in gaining AI literacy to reason about the relationship between their bodily expressions and the output of AI applications.

Computational thinking: In addition to defining AI literacy as digital literacy, 10 articles alluded to AI literacy as including computational thinking literacy for developing programming skills (Dai et al., 2023; Du et al., 2022). This is the cognitive thinking process by which students find algorithms to solve problems (Lin et al., 2021). Shamir and Levin (2022) stresse the importance of integrating construction and ontological principles in AI literacy learning, such as decomposition, pattern recognition, abstraction, and algorithm design, for automating the discovery of a computational thinking solution to a problem. Gong et al. (2020) interpret AI literacy as promoting the ability to think computationally, reason systematically, and work collaboratively. Others believe that students access AI literacy through tinkering and playful engagement with intelligent agents (Druga et al., 2019; Drug & Ko, 2021). They view these intelligent agents as “playthings that do things,” providing students with tangible objects for cognitive exploration (Druga et al., 2019) and comprehending the emergent behavior of machines (Drug & Ko, 2021).

AI ethics: Ten articles addressed elements of AI ethics, which is beyond the core components typically included in existing AI literacy curricula. It is argued that AI is of ethical and societal importance due to the fact that functions in a wide variety of social contexts (Ali et al., 2019). Students who are AI literate play various roles in line with the extent of their involvement in society, such as their roles as consumers (Henry et al., 2021) and responsible citizens (Chai et al., 2020a). In these roles, they must understand what constitutes AI, how to apply AI to different problems, and how to ethically apply AI for the social good (Chai et al., 2021). Rodríguez-Garciá et al. (2021) advocate “five big ideas” about the societal impact of AI and argue that this impact requires students’ ability to predict and understand the probable consequences of their actions using AI. Relmasira et al. (2023) employ three learning activities to increase students’ ethical awareness regarding AI: “Observing AI Products”, “Instagram AI Filters,” and “Evil Genius”.

Critical data literacy: Five articles show slight variation in their conceptual understanding of AI literacy, supplementing it with the notion of critical data literacy (Melsion et al., 2021). They argue that data literacy is the ability to critically analyze and interpret data while being aware of how and where personal data are produced and understanding related algorithmic principles and processes (Vartiainen et al., 2020). AI literacy involves understanding the importance of training data in machine learning algorithms and how a biased dataset (such as one containing gender bias) can affect the data we receive (Melsion et al., 2021). Voulgari et al. (2021), meanwhile, describe AI literacy as the ability to identify new cultural and social biases that are ingrained in computer system design and to understand their ethical and political ramifications.

RQ2. What theoretical frameworks have underpinned research on AI literacy in primary schools?

Overall, 16 of the selected studies explicitly state the theoretical and conceptual frameworks that underpin their studies. As shown in Table 5, a number of theories and models have been identified in the empirical research on AI literacy in primary education. These include constructionism and constructivism (n=8), the ARCS model of instructional design (n = 6), and the Technology Readiness Index Model (n = 3). Researchers

Table 5 Summary of theoretical frameworks and models used in selected studies

Theoretical frameworks and models	Studies	N
(ARCS) (Keller, 2010)	Chai et al. (2020a); Chai et al.(2020b); Dai et al. (2020); Lin et al. (2021); Shamir and Levin, (2021); Shamir and Levin, (2022)	N = 6
Constructionism/Constructivism (Papert, 1980)	Ali et al. (2019); Druga and Ko (2021); Druga et al. (2019); Du et al., (2022); Ng et al. (2022); Relmasira et al. (2023); Shamir and Levin, (2021); Shamir and Levin, (2022); Voulgari et al. (2021)	N = 8
Technology readiness index model (Parasuraman, 2000)	Chai et al.(2020b); Chai et al. (2021); Dai et al. (2020)	N = 3
AI4K12 the five big ideas of AI framework (Touretzky et al., 2019)	Mertala et al. (2022); Rodríguez-Garciá et al. (2021)	N = 2
Game-based learning theory	Lee et al. (2021); Voulgari et al. (2021)	N = 2
Self-Determination Theory of motivation (Ryan and Deci, 2000)	Chai et al.(2020b); Lin et al. (2021)	N = 2
Technology Acceptance Model (Park et al., 2012)	Chai et al.(2020a); Chai et al. (2021)	N = 2
Theory of planned behavior, Theory of reasoned action (Fishbein and Azjen, 1975)	Chai et al. (2021); Dai et al. (2020)	N = 2
Bloom Taxonomy (Forehand, 2010)	Ng et al. (2022)	N = 1
Computational Thinking framework (Brennan and Resnick, 2012)	Shamir and Levin, (2022)	N = 1
Kohlberg's Theory of Moral Development (Duska and Whelan, 1975)	Ali et al. (2019)	N = 1
Sense making theory	Druga and Ko (2021)	N = 1
Sociocultural Learning Theory, Activity Theory, Theory of Guided Participation (Rogoff, 1990)	Vartiainen et al. (2020)	N = 1
Stages of AI (Kaplan and Haenlein, 2019)	Mertala et al. (2022)	N = 1
Structural mapping theory (Gentner, 1983)	Dai et al. (2023)	N = 1
Theoretical Model of Critical Citizenship Education in AI (Saariketo, 2014)	Henry et al. (2021)	N = 1
Transformative learning theory	Relmasira et al. (2023)	N = 1
Vygotskian-based idea of everyday concepts (Edwards et al., 2018; Mertala, 2019)	Mertala et al. (2022)	N = 1
Zone of proximal development theory (Vygotsky, 1978) and scaffolding (Emig etl., 2014)	Dai et al. (2023); Dai et al. (2024)	N = 2

often use theories to frame and inform their empirical studies to conceptualize their research design (Ali et al., 2019; Henry et al., 2021; Vartiainen et al., 2020), inform data collection and analysis (Chai et al., 2020a; Dai et al., 2020), and discuss research outcomes (Ng et al., 2022; Shamir & Levin, 2022).

First, constructionism and constructivism suggest that students learn best by doing and applying their knowledge while engaging in projects that are personally relevant to them (Papert & Harel, 1991). Constructivism focuses on how learners construct knowledge through active interaction with the world, while constructionism emphasizes learning by making. These theories are used in the selected articles to conceptualize the research and establish their purpose (Ali et al., 2019; Druga et al., 2019; Ng et al., 2022; Voulgari et al., 2021), propose research questions (Shamir & Levin, 2021), and validate research outcomes (Shamir & Levin, 2022). For example, Shamir and Levin (2021) asked students to construct a neural network of machine learning algorithms, and their research sought to identify which scaffolds were required for primary school students to learn to construct such a network. In line with the design principle of an AI curriculum emphasizing constructivism (Ali et al., 2019), Voulgari et al. (2021) designed learning activities to inform students regarding the concept of supervised and reinforcement learning through a game-based artbot educational device. In a different approach, Shamir and Levin (2022) applied constructionist theories to assess whether students could build machine learning systems using robotics. They asked students to self-assess their abilities by responding to questionnaire statements such as "*I can make a machine learning system*". Meanwhile, Relmasira et al. (2023) analyzed student experiences with various educational interventions to determine how well such interventions aligned with cognitive, constructionist, and social constructivist learning theories.

Second, the ARCS model has been adopted to inform data collection and analysis, with the use of questionnaires (Chai et al., 2020a, b; Dai et al., 2020; Lin et al., 2021) to assess the motivation of students (Shamir & Levin, 2021, 2022). The ARCS model is an instructional design that seeks to assess attention, relevance, confidence, and satisfaction. For instance, Chai et al. (2020a) designed a questionnaire for students to report their perception of their AI literacy, their confidence in AI, their use of AI for the social good, and their behavioral intention in engaging in AI learning. The confidence items in the questionnaire (e.g., "*I feel confident that I will do well in this class*") were used to identify students' beliefs regarding whether they would succeed in the AI literacy section of the primary school curriculum. Shamir and Levin (2021), on the other hand, used the ARCS model to assess the motivation of students in terms of attention (e.g., attention should be sustained during the learning process), relevance (e.g., the learning material is important to students), confidence (e.g., persistence and accomplishment in terms of artifact analysis), and satisfaction (e.g., AI activity makes students feel good about their accomplishments).

Third, the technology readiness index model has been used to inform data collection and analysis in the form of questionnaires to understand the readiness of students when introducing an AI primary curriculum (Chai et al., 2020b, 2021). Dai et al. (2020) discuss relevance, AI anxiety, AI literacy, and AI confidence as key factors to consider when constructing their technology readiness index model. Chai et al., (2020a, b), meanwhile, identify emotional and psychological factors, such as AI relevance and AI anxiety, in measuring student readiness for AI curricula. AI relevance refers to how students perceive the importance and applicability of AI with regard to their education, while AI anxiety reflects the fear or discomfort students may experience when thinking about or interacting with AI, potentially affecting their engagement with it.

RQ3: What pedagogical strategies have been adopted to teach AI literacy in primary school?

As shown in Table 6, the three primary pedagogical strategies employed in AI literacy studies are project-based learning (n = 7), programming (n = 5), and human-agent interaction and collaborative learning (n = 4). Initially, many educators drew inspiration from a constructionist pedagogy characterized by hands-on and project-based approaches that afford students the freedom to explore AI literacy in their learning (Ali et al., 2019; Rodríguez-Garciá et al., 2021). Ali et al. (2019) exemplified this by implementing three projects aimed at engaging primary school students with an emphasis on constructionism. One project involved a social robot peer, catalyzing and helping students to think by modeling innovative behavior. Rodríguez-Garciá et al. (2021) further contributed to this pedagogical approach by introducing the LearningML platform, which supports students in the creation of hands-on programming projects, particularly rooted in machine learning techniques.

A second avenue of significance in AI literacy learning is programming, which facilitates the acquisition of computational thinking skills via MIT Scratch (Dai et al., 2023), MIT App Inventor (Du et al., 2022), and the Cognimates AI platform (Druga & Ko, 2021). Shamir and Levin (2022) highlight that most computing education continues to focus on traditional rule-based programming, with little emphasis on machine learning. They propose a new area of educational research aimed at introducing young students to machine learning, encouraging a shift from rule-based thinking to data-driven approaches via machine learning courses on learning-by-design and learning-by-teaching, both grounded in constructionism. However, these courses require students to possess prior coding and programming experience in order to understand the logic behind programming languages (e.g., Scratch).

Third, human–computer interaction serves as a crucial component for students to comprehend human-centric computing (Druga et al., 2019; Relmasira et al., 2023). Druga and Ko (2021) incorporated activities such as the rock paper scissors (an image training learning activity) and the smart home (a text and speech training learning activity). Through interaction and training via these activities, students formulated hypotheses about machine learning, enriching their understanding of AI.

Table 6 Pedagogical strategies in teaching AI literacy in primary school context

Pedagogical strategies	Sample Studies	N
Project-based learning	Ali et al. (2019); Gong et al. (2020); Rodríguez-Garciá et al. (2021)	N = 6
Programming	Shamir and Levin (2021); Shamir and Levin (2022); Du et al. (2022)	N = 5
Human–computer interactions, collaborative learning	Druga and Ko (2021); Druga et al. (2019); Relmasira et al. (2023)	N = 4
Game-based learning	Henry et al. (2021); Lee et al. (2021); Voulgari et al. (2021)	N = 3
Analogy-based learning	Dai et al. (2023); Dai et al. (2024)	N = 2
Participatory learning	Vartiainen et al. (2020)	N = 1
Digital story writing / Inquiry-based learning	Ng et al (2022)	N = 1

RQ4: What learning tools have been employed to teach AI literacy in primary schools?

Three main learning tools were identified in AI literacy education for primary school students (Table 7): intelligent agents (n = 15), software (n = 8), and unplugged activities (n = 3). Intelligent agents are often adopted to support a dynamic and interactive AI learning environment (Ali et al., 2019; Toivonen et al., 2020), engage students by responding to their actions (Druga & Ko, 2021; Druga et al., 2019), and allow students to understand real-world applications, such as the ethical implications of AI technologies (Relmasira et al., 2023). Google Teachable Machine has been used to enhance interactive learning by enabling students to create machine learning models without coding (Relmasira et al., 2023; Vartiainen et al., 2020), utilizing media such as webcams, images, or sounds. Other researchers have used embodied intelligent agents, such as the Jibo robot, Anki's Cozmo robot, and Amazon's Alexa home assistant, to explore whether students change their perception of AI abilities following engagement and training in AI programming activities (Druga & Ko, 2021; Druga et al., 2019).

The findings of this review reveal that some educators use software programming tools to instill foundational skills in computational thinking (Du et al., 2022) and programming skills (Shamir & Levin, 2021, 2022) within AI literacy activities. In Dai et al., (2023, 2024), students engaged in Scratch activities integrated with AI systems to cultivate critical thinking, involving coding, designing simple algorithms, and debugging, to gain the technical skills essential for AI programming. Similarly, Druga and Ko (2021) introduced computational thinking through Cognimates AI, a learning environment incorporating AI concepts and in which students learn to train, code test, and program custom AI models.

A few studies embraced unplugged activities in AI literacy education, such as paper prototyping activities (Ali et al., 2019), writing stories with robots (Ng et al., 2022), and Pictionary games (Relmasira et al., 2023). These activities served to build students' conceptual knowledge about AI.

RQ5: What assessment methods have been used to teach AI literacy in primary schools?

A variety of assessment methods have been employed: survey and questionnaires (n = 19), interviews (n = 11), artifacts and performance-based evaluations (n = 8), observations (n = 3), reflections (n = 1), and field visits (n = 1). The three major assessment methods used are discussed in this section (also see Table 8).

A majority of the studies (19 of the 25 studies) employed quantitative methods such as surveys and questionnaires. These quantitative collection methods were used mainly to assess students' behavioral intentions (Chai et al., 2020a), readiness for AI literacy learning (Chai et al., 2020b), and AI knowledge acquisition (Dai et al., 2023), as well as to evaluate students' understanding of self-efficacy, computational action, algorithmic bias, social impact (Du et al., 2022), and ethical awareness (Dai et al., 2024). For example, Dai et al. (2023) used multiple-choice questions to assess students' AI knowledge according to Bloom's Taxonomy (e.g., "*We design an image recognition algorithm to recognize apples. Which of the following features is not suitable for representing information about apples? Color, skin texture, shape or deliciousness?*").

Table 7 AI learning tools for primary school students

AI learning tools	Definition	Learning artefacts examples	N
Intelligent agents	Incorporate with AI to perform tasks autonomously, make decisions, and adapt to its environment based on the input it receives	Google's Teachable Machine (Vartiainen et al., 2020); Machine Learning for Kids (Dai et al., 2023, 2024); embodied intelligent agent such as Jibo robot, Cozmo robot (Druga & Ko, 2021)	N = 15
Software-focused devices	Use digital devices to operate computers how to perform specific tasks	Scratch and Kitten (Dai et al., 2023, 2024); Cognimates AI (Druga & Ko, 2021); MIT App Inventor (Du et al., 2022)	N = 8
Unplugged learning	Uses learning activities to learn AI without the need of computer or technological devices	Paper prototyping activity (Ali et al., 2019); writing stories with robots (Ng et al., 2022); pictionary game (Relmasira et al., 2023)	N = 3

Table 8 Assessment methods

Assessment Methods	Sample Studies	Examples	N
Survey, questionnaires	Chai et al. (2020b); Du et al., (2022); Shamir and Levin. (2021)	Questionnaire based on constructionist-validated machine learning (e.g. "*A machine learning system trained to recognize pictures showing a crosswalk should be good at which of the following tasks? (a) Identifying pictures of crosswalks (b) Identify pictures of a person crossing a road. (c) Identify pictures of fruits d) Identify pictures of traffic lights*") (Shamir & Levin, 2021)	N = 19
Interviews, focus group	Dai et al., (2023 Lee et al. (2021); Shamir and Levin (2022)	"*What do you think about the in-class activities?*", "*What do you see as the most helpful/difficult activities?*", "*How do your views about AI compare before and after the course?*", and "*Which activity or content triggered a change in your view?*" (Dai et al., 2023)	N = 11
Artefact and performance-based evaluation	Melsion et al. (2021); Shamir and Levin (2021); Shamir and Levin (2022)	Rubric for artifact-analysis rubric (e.g. correctly programmed the neuron; programmed a tutorial agent which explains relevant topics such as AI system, neuron, system parts, gate, truth table, output status and training process) (Shamir & Levin, 2021)	N = 8
Observations, video recording	Druga and Ko (2021); Henry et al. (2021); Vartiainen et al. (2020)	Video recording and observations showing how child-agent interact and record students' body language and non-verbal interactions (Druga & Ko, 2021)	N = 3
Reflection paper	Relmasira et al. (2023)	Reflections about how well students have done, their struggles, and new things learned (Relmasira et al., 2023)	N = 1
Field visit	Gong et al. (2020)	Urban and suburban public and private school visit to understand issues and challenges (Gong et al., 2020)	N = 1

In contrast, qualitative data were collected mainly through interviews (n = 11) and artifacts (n = 8) to examine students' learning outcomes, such as their conceptual and cognitive understanding of AI. In Ng et al.'s (2022) study, students were interviewed to reflect on their learning experience (with questions such as "*Do you know what AI is? What AI concepts have you learned in terms of knowing about AI, using AI, creating with AI, and AI ethics?*"). The interviews helped students internalize their thoughts, beliefs, and understanding of AI concepts. Furthermore, students were asked in the interviews about the ways in which they thought a machine learning system could help people (Shamir and Levin (2022) (e.g., "*How would you describe machine learning (ML) to friends or family? How can an ML system help people? If you had the opportunity to interact with any type of ML system, what would you like it to be able to classify*?").

Artifacts were embedded in a few studies to evaluate the learning outcomes of students regarding neural network construction (Shamir & Levin, 2021, 2022), data bias (Melsion et al., 2021), and creativity (Ali et al., 2019). For example, through artifacts, Shamir and Levin (2021) developed an artifact scoring system to evaluate whether students understood the process of data training and programming a neural network (e.g., decomposition, pattern recognition, abstraction, and algorithm design). The artifact and interaction analysis of Melsion et al. (2021) involved a treatment group (those learning AI with an explanation of data bias) and a control group (those learning AI without such an explanation) to measure students' understanding of bias, its impacts, unrelated bias, and machine learning concepts.

RQ6. What outcomes have been identified in relation to AI literacy in primary schools?

In 15 of the 25 selected articles, academic outcomes, affective and behavioral outcomes, and level of course satisfaction were reported. Other studies did not report learning outcomes, due to their emphasis on students' conceptions of AI (Ottenbreit-Leftwich et al., 2023), the determining factors affecting students' AI readiness (Chai et al., 2020b; Dai et al., 2020), students' perceptions (Chai et al., 2021; Mertala et al., 2022), or their behavioral intentions (Chai et al., 2020a).

Academic outcomes

Several studies reported positive academic results, such as improvements in students' knowledge and skills. These findings were based on different data collection methods, including analyzing student artifacts, students' self-report surveys, tests, observations, as well as interviews with the students. In general, students exhibited a fair understanding of AI concepts, such as understanding and programming a neural network (Shamir & Levin, 2021), recognizing predictions, training in machine learning (Rodríguez-Garciá et al., 2021; Toivonen et al., 2020), societal and ethical impacts (e.g., algorithmic bias and the consequences of misuse of AI) (Ng et al., 2022), and the role of data in recognizing bias (Melsion et al., 2021). Shamir and Levin (2022) showed that students' competency in training and machine validation practice increased from 4.6 to 5 on a 5-point Likert scale. According to Ng et al. (2022), the artifacts created by students demonstrated their understanding of AI concepts and skills (e.g., the nature of AI, supervised learning, neural networks, and AI-driven tools) and their achievement of higher order thinking skills related to using and applying AI in their AI learning. Others reported that digital role-playing games (Voulgari et al., 2021) and design-based pedagogy (Shamir & Levin, 2021) scaffolded the effectiveness of constructing machine learning algorithms for AI learning. By designing and programming a robot, students understood bias in AI (Melsion et al., 2021).

In addition, various soft skills, such as computational thinking (Vartiainen & Valtonen, 2020), creative skills (Ali et al., 2019; Ng et al., 2022), problem-solving skills (Dai et al., 2024; Ng et al., 2022; Rodríguez-Garciá et al., 2021), and the critical ability to improve AI systems by identifying the data essential to the prediction model (Melsion et al., 2021) were developed.

Affective and behavioral outcomes

The affective and behavioral outcomes of students were identified in AI literacy studies. In terms of affective outcomes, the findings revealed that students' motivation to learn AI was enhanced (Shamir & Levin, 2021, 2022). For example, students used words such as "fun" and "nice" to describe the process of exploring a teachable machine, which fostered their intellectual curiosity in computational thinking and machine learning (Vartiainen et al., 2020). Other students took pleasure in learning AI while having fun and "using their brains" to instruct and teach AI agents in their games (Voulgari et al., 2021).

From a behavioral perspective, high student engagement was reported in play/game-based and constructivist learning settings (Ali et al., 2019; Lee et al., 2021; Shamir & Levin, 2021, 2022). Students evaluated themselves as having a high rating for self-efficacy in training and validating an AI system (Shamir & Levin, 2021). Their imitation of social robots' inventive behavior was also a positive outcome of robot interaction in the design of AI creativity games (Ali et al., 2019). The creative, play/game-based pedagogy was age-appropriate, and students were eager to recommend games to their friends to learn AI (Voulgari et al., 2021). These creative pedagogical strategies, together with appropriate learning tools, could motivate students and improve their concentration.

Course satisfaction

The constructivist pedagogy, the learning by design/teaching approach, and the programming learning environment were found to affect students' level of satisfaction in AI literacy studies (Shamir & Levin, 2021, 2022). Through the adoption of an inquiry-based and creative approach, the learning content was scaffolded with age-appropriate learning tools (such as Quick Draw and AI for Oceans), and students were satisfied and able to better engage with the AI learning materials through digital story writing activities (Ng et al., 2022).

RQ7: What challenges, limitations, and recommendations have been identified in relation to AI literacy in primary schools?

The findings revealed that there are three major challenges educators face in AI literacy education: (1) ineffective AI teaching tools; (2) lack of a systematic AI curriculum and measurements of learning outcomes; and (3) student perceptions and readiness, and gender differences in AI literacy learning.

Firstly, the AI interfaces and tools currently used in educational settings are technologically outdated compared to the advanced AI technologies they are intended to teach, highlighting the need for these interfaces and tools to be upgraded in schools (Gong et al., 2020). Furthermore, the high computational demands and extensive training time required by platforms like Google Teachable Machines makes their large-scale implementation in schools difficult (Shamir & Levin, 2022; Toivonen et al., 2020). In addition, without age-appropriate learning interfaces, it is challenging to introduce complex concepts such as unintentional bias to students (Ali et al., 2019; Melsion et al., 2021).

Secondly, the lack of systematic AI literacy curriculum, measurements, and meaningful integration of AI literacy into existing school curricula presents another significant challenge (Chai et al., 2020a; Gong et al., 2020). As AI literacy education tends to focus on technical aspects, it often overlooks the ethical and societal implications of AI (Ali et al., 2019; Henry et al., 2021). Chai et al. (2021) advocates the inclusion of AI for social good in AI literacy teaching to enhance student's motivation to learn. Furthermore, as Melsion et al. (2021) argue, improving students' conceptual understanding of AI requires addressing the role of data in training AI applications (Melsion et al., 2021).

Third, the issues related to students' perceptions (Lee et al., 2021), misconceptions (Mertala et al., 2022), readiness (Chai et al., 2020a), and gender differences (Chai et al., 2020b) in AI literacy learning have not been fully considered in the process of instructional design (Chai et al., 2020b). More importantly, according to Dai et al., (2020), male students have reported a higher level of confidence, relevance, and readiness in AI than female students, which points to a gender gap in engagement within AI literacy education. Similarly, Lin et al (2021) found that female students were less motivated to learn AI than male students. A key challenge for achieving equity and inclusive AI literacy education is engaging girls in AI literacy learning (Chai et al., 2020a, b).

In terms of recommendations, a holistic curriculum design is advocated for the promotion of interdisciplinary AI literacy learning (Dai et al., 2024), which enhances students' self-efficacy (Chai et al., 2020b) and integrates AI as a social good (Chai et al., 2021), while addressing unintentional bias (Melsion et al., 2021) and the important role of data (Mertala et al., 2022). Chai et al. (2021), finding that self-efficacy was the most crucial factor in predicting behavioral intentions, have recommended that student's self-efficacy be fostered and the potential of AI as a social good be promoted in the design of AI curriculum. In addition, Chai et al., (2020b) have provided evidence that motivation is another key factor that predicts AI readiness, offering curriculum designers a way to explore the effects of their curricula on enhancing students' readiness.

Secondly, given the lack of AI knowledge among many teachers, professional development is crucial, and a greater emphasis should be placed on training teachers in developing appropriate activities as well as raising their content knowledge of AI (Henry et al., 2021; Lee et al., 2021). Thirdly, inclusion and democratizing access to AI literacy are critical issues, particularly because students come from diverse social, economic, and cultural backgrounds, each with their attitudes towards and experiences with AI (Voulgari et al., 2021). Moreover, AI is a unique field, distinct from programming and computational thinking, both of which are broadly interdisciplinary. To facilitate effective interdisciplinary learning, AI education must not only teach technical skills but also integrate knowledge from various other disciplines (Dai et al., 2024). This approach will ensure that AI literacy is accessible and relevant to all students, reflecting their diverse backgrounds.

In terms of the limitations of the selected studies, small sample size, and potential bias in answers are commonly mentioned. For example, Vartiainen et al. (2020) involved six young children exploring the Google Teachable Machine in an informal educational setting. In contrast, Dai et al. (2024) focused their study on a single primary school in China, with participants primarily from middle-class families. This limitation prevents the generalization of their findings to other cultural contexts or age groups. Dai et al. (2020), on the other hand, recruited 707 primary school participants, which only barely met the minimum sample size requirement of the statistical optimization outputs in latent variable analysis. Moreover, there was a potential bias in answers as student participants were young and therefore may not have understood the full implications of AI technology when completing the self-reported survey (Dai et al., 2020). Chai et al. (2021), meanwhile, declare that their study captured positive attitudes to AI learning but did not consider adverse psychological factors such as anxiety. Other studies included online mode of learning (Shamir & Levin, 2021; Rodríguez-Garciá et al., 2021), suggesting that they potentially contained unwanted bias due to, for example, students being helped by their parents in the knowledge assessment.

Discussion

The findings of this study align with the conclusions drawn by Casal-Otero et al. (2023) and Su et al. (2023a) that AI literacy is relatively new research field. Notably, this study found that there was a positive trend over the past four years in the number of publications regarding AI literacy education in the primary school context. This review reveals that AI literacy encompasses several key components: digital literacy for using AI, interaction and collaboration with AI systems, data literacy for working with data, computational thinking for problem solving, and AI ethics for understanding responsibilities. These elements form the core of AI literacy as defined by Yim (2024a). Furthermore, this review emphasizes the critical construct of AI ethics in AI literacy learning, echoing the reviews of Rizvi et al. (2023), Ng et al. (2021), and Yim and Su (2024). These studies underscore that AI is an interdisciplinary and multifaceted field, asserting that AI literacy education should position AI ethics at the center stage rather than relegating it to a supporting role (Yim, 2024b).

Previous systematic reviews have not thoroughly explored the theoretical foundations of research on AI literacy in primary school (Ng et al., 2021; Su et al., 2023b). The findings of this review contribute to the literature by revealing that many studies have employed a variety of theories, such as constructionism and constructivism, to frame their empirical research. This review adds that constructivist pedagogies, particularly project-based and programming approaches, have been extensively adopted. The review's findings also reveal a consistent emphasis on constructivism in the curriculum of some countries, including the United States (Druga & Ko, 2021; Du et al., 2022) and Israel (Shamir & Levin, 2021, 2022), where computational thinking is a vital part of AI literacy. In that approach, students are encouraged to construct artifacts as a means for constructing knowledge as well as developing AI literacy through computational thinking, primarily via coding and programming. This echoes Chiu et al. (2021), who argue that AI literacy education has been predominantly taught through computer science and programming education. Although teaching computational thinking has shown some effectiveness in enhancing primary school students' motivation to learn, as well as their technical AI knowledge (such as their understanding of algorithms and their practical application of machine learning models), it may not adequately cover the interdisciplinary aspects required for comprehensive AI literacy learning (Yim, 2024a). There is a need to develop an inclusive AI literacy competency framework to address the interdisciplinary nature of AI (Yim, 2024a).

Meanwhile, learning outcomes in AI literacy may be significantly influenced by students' prior experience with computers and programming. For instance, Shamir and Levin (2021, 2022) highlight the importance of students possessing prerequisites in computational thinking or coding. The findings of the present review correspond with Rizvi et al.

(2023) and Lee and Kwon (2024), who state that prior programming experience plays an influential role in shaping the learning outcomes and perceptions of K-12 students in the context of AI literacy education. The current educational focus on AI within the confines of computer science may therefore serve to neglect building a conceptual understanding of AI literacy for a diverse background and for those students with no prior computer science experience. In response to this, Su et al. (2024b) as well as Yim and Wegerif (2024) emphasize the need to design new pedagogies to expand AI literacy education for young students.

The growing number of empirical studies on AI literacy education in primary schools aim to address gaps in learning tools, pedagogy, and learning outcomes, as previously identified by Casal-Otero et al. (2023) and Yue et al. (2022) in the broader K-12 context. This review also revealed a growing tendency in research studies on AI literacy in primary education to use mixed methods for result triangulation, which contrasts with Yue et al. (2022), who report that qualitative methods are dominant in AI literacy education for young students.

Moreover, this review reveals that a variety of assessment methods, such as self-assessment surveys for knowledge acquisition, as well as artifact and performance-based rubric tests, are often adopted in AI literacy educational settings. These findings echo the reviews by Laupichler et al. (2022) and Almatrafi et al. (2024), who call for the development of more validated scales to measure AI literacy.

Future directions

This review enriches the existing body of knowledge by identifying research gaps in current AI literacy primary education. First, some of the selected studies in this review arguably overemphasize technical and programming practices, which may contradict the assumption that AI literacy is useful for everyone (Long & Margeko, 2020; Yim, 2024b). This review suggests that, rather than emphasizing AI technical skills, young students should be encouraged to focus more on effectively collaborating and interacting with AI to enhance AI concept learning and develop thinking and creative skills. Human-agent interaction and collaboration learning, such as via the use of generative AI, are presented as newly emergent pedagogical opportunities (Cheng & Yim, 2024; Watson & Romic, 2023). Future research may further explore these possibilities and, in particular, consider how generative AI technology can be employed in an imaginative way, such as serving as a human thought partner, to build students conceptual understanding of AI and develop their thinking and creative skills. Second, to a certain extent, constructionist methodologies and programming approaches in AI literacy education demonstrate their effectiveness in enhancing students' affective and cognitive skills; however, more innovative and inclusive pedagogies (Su et al., 2024b; Yim et al. 2024), such as an arts-based approach to lower existing entry barriers, should be encouraged to allow more students without prior computer and coding experience to access AI literacy education (Yim, 2023). Third, this review shows that empirical studies have only been conducted on certain primary school students and short-term AI literacy interventions. The impact of gender differences and cultural contexts in AI literacy education may therefore be worth exploring, and longitudinal studies could be considered to analyze changes over time. Future studies could also explore the readiness of students, parents, and teachers, as well as relevant professional training requirements.

Lastly, this review identifies a critical gap in the current AI literacy education, its focus primarily on technical skills such as computational thinking and programming, which could lead to the neglect of the broader ethical and social implications of AI. Future research could therefore consider whether students' overall learning outcomes would be enhanced by AI literacy education's inclusion of more diverse and innovative pedagogies as well as the development of an inclusive AI literacy competency framework and appropriate learning content and assessment criteria for primary school students.

Conclusion and limitations

Recently, AI literacy education has been increasingly investigated in the field of education, especially for young students (e.g., Ng et al., 2022; Su et al., 2022). However, to the authors' knowledge, no review studies have focused on AI literacy in the primary school context. This study is the first systematic review to inform educators about theoretical frameworks, pedagogical strategies, learning tools, assessment methods, educational outcomes, and related recommendations in the primary school context. Reviewing 25 evidence-based studies conducted in a primary school context over four years (2019 to the end of March 2024), this study offers insights into the constructs encompassed by the term "AI literacy". It evaluates the current state of the literature on AI literacy and discusses theoretical frameworks applied in primary school contexts, serving as a reference for policymakers setting objectives regarding appropriate pedagogy, learning tools and assessment for sustainable AI literacy education.

Finally, this review has several limitations. First, given that the number of articles included in this analysis was very small, there may be some gaps in the research findings. Second, this study included only the Scopus and Web of Science databases, which are not comprehensive representations of all the papers available. It is hoped that future research can widen database sources to determine if a similar outcome would be produced as well as to include meta-analyses with effect sizes to provide further insights into AI literacy education for primary school students.

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Declarations

Conflict of interest None.

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