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Conceptualizing AI literacy: An exploratory review

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ABSTRACT

Artificial Intelligence (AI) has spread across industries (e.g., business, science, art, education) to enhance user experience, improve work efficiency, and create many future job opportunities. However, public understanding of AI technologies and how to define AI literacy is under-explored. This vision poses upcoming challenges for our next generation to learn about AI. On this note, an exploratory review was conducted to conceptualize the newly emerging concept "AI literacy", in search for a sound theoretical foundation to define, teach and evaluate AI literacy. Grounded in literature on 30 existing peer-reviewed articles, this review proposed four aspects (i.e., know and understand, use and apply, evaluate and create, and ethical issues) for fostering AI literacy based on the adaptation of classic literacies. This study sheds light on the consolidated definition, teaching, and ethical concerns on AI literacy, establishing the groundwork for future research such as competency development and assessment criteria on AI literacy.

1. Introduction

Artificial intelligence (AI) was first defined as "the science and engineering of making intelligent machines" in 1956 (McCarthy, 2007, p. 2). Throughout several decades of the 20th century, AI has evolved progressively into intelligent machines and algorithms that can reason and adapt based on sets of rules and environment which mimic human intelligence (McCarthy, 2007). Wang (2019) broadened the definition of AI which can perform cognitive tasks particularly learning and problem-solving with the exciting technological innovations such as machine learning, natural language processing and neural networks (Zawacki-Richter, Marín, Bond, & Gouverneur, 2019).

Artificial intelligence will eventually affect many facets of human life rather than merely computer industries and everyone should learn AI. Currently, the use of AI has spread across industries (e.g., business, science, art, education) to enhance user experience and improve efficiency. Applications of AI exist in many parts of our everyday life (e.g., smart home appliances, smartphones, Google, Siri). Vast majority of the public acknowledges the existence of AI services and devices, but seldom do they know about the concepts and technology behind, or aware of potential ethical issues related to AI (Burgsteiner, Kandlhofer, & Steinbauer, 2016; Ghallab, 2019). Although AI will generate significant benefits for users, businesses and economies, and lift productivity and economic growth, AI is poised to eliminate millions of current jobs and cause declines in some occupations (Davenport & Ronanki, 2018; Manyika et al., 2017).

Second, studies reflect that the rise of AI will create many job opportunities in various industries, and AI will probably replace tomorrow's workplace. Even though not all disciplines are not going to be replaced by AI, people with AI knowledge will replace those that do not in the future of work. In a MicKinsey report, Manyika et al. (2017) estimated that 15% of the global working hours will be automated and 47% of American jobs are at high risk of automation by 2030. Furthermore, the situation could be worse among women since over 160 million women worldwide may need to transition between occupations often into higher-skilled roles. Among different natures of work, clerical work such as secretaries and bookkeepers will be mostly easily eliminated by AI, given that 72% of those jobs in advanced economies are held by women (Manyika et al., 2017). As such, to gain a competitive advantage at work, similar to classic literacy which includes reading/-writing and mathematical abilities, AI literacy has emerged as a new skill set that everyone should learn in response to this new era of intelligence.

Literacy was popularly understood as an ability to read and write (McBride, 2015). In today's digital era, the emergence of the knowledge-based society implies that every citizen must be 'digitally literate' and possess basic competencies in order to be on a better footing in terms of equal opportunities in their workplaces (Bawden, 2008, p. 102). This

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term has been extended to new literacies such as media, digital, information, computer and AI literacy (Kong et al., 2021). In the twenty-first century, students who are equipped with these skills could use related technologies and computers in very advanced ways to learn new knowledge and skills with their counterparts (Bell, 2010; Griffin & Care, 2014; Larson & Miller, 2011). Nowadays, AI technology emerges and becomes essential skills to play critical roles across disciplines and industries (Ng et al., 2021; Touretzky et al., 2019). Students need to learn how to use AI technologies judiciously, as well as to discriminate between ethical and unethical practices (Robinson, 2020; Rodríguez-García, Moreno-León, Román-González, & Robles, 2020). AI potentially becomes one of the important technology skills in the twenty-first century. As such, to combine AI and literacy, AI literacy means having the essential abilities that people need to live, learn and work in our digital world through AI-driven technologies, and this should be taught at the K-12 levels (Steinbauer et al., 2021).

AI learning started in university computer science education which required advanced programming competencies that were not at an appropriate level for K-12 learners. Educators faced challenges in scaffolding K-12 children to understand AI concepts through syntax-based programming (e.g., McCarthy, 2007; Wong et al., 2020). The emergence of more age-appropriate hardwares and softwares enabled educators to improve the learning process for younger learners in recent years. The access to a wide range of technologies in day-to-day life, such as chatbots and translation apps, presents opportunities for everyone to understand and use AI in everyday life. This enables educators to leverage on the availability of AI technologies to inculcate AI literacy for young learners. For example, prior studies discussed the potential to incorporate AI learning in K-12 STEAM education via playful experience such as gamified and social media tools to prepare children for future science, technology, engineering, art and mathematics workforces (e.g., Ng, 2021; Ng & Chu, 2021; Zou, Wang, & Zhao, 2019).

Knowing and using AI for future careers is only one aspect of teaching AI literacy for educators. Any technology as potent as AI would also bring new risks due to algorithmic bias and malicious uses of AI (Brundage et al., 2018). People often overlook the importance of the roles of AI ethics, which is considered as extraneous or surplus to technical concerns in work settings (Hagendorff, 2020). Software developers usually feel a lack of accountability and moral significance of their work, especially when economic incentives are easily overriding commitment to ethical principles and values (Hagendorff, 2020). As such, educating both citizens and computer scientists AI ethics is essential to strengthen their social responsibility, and consider social inclusion and diversity to apply AI for societal good (Dignum, 2019). In this review, we examine the published studies to evaluate the ethical concerns in the domain of AI literacy.

According to Google Scholar search, there is a dramatic increase in AI literacy publications from 2014 to 2021 (see Fig. 1). As AI becomes more and more important in work settings and everyday life, researchers began to define AI literacy based on the term 'literacy' which has been applied to define skill sets in varied disciplines (Long & Magerko, 2020). However, few studies have provided comprehensive explanations on how to conceptualize AI literacy. To achieve a better understanding of the concept of AI literacy, we categorize how researchers define the term in four aspects, inspired from the cognitive domains in Bloom's taxonomy. Then, we evaluate how educators help learners develop AI literacy skills with emerging technological tools, and evaluate their assessment accordingly. To fill this gap, this study reviewed the relevant literature, and analysed how scholars define "AI literacy", how it can be learned, and what are the ethical concerns. Specifically, the present study poses the following four research questions:

1. How do researchers define the term "AI literacy"?
2. How do educators help learners develop AI literacy in terms of learning artefacts, pedagogical approaches and subject matters?
3. How do researchers evaluate students' AI literacy skills?
4. What are the ethical concerns in the domain of AI literacy?

2. Method

2.1. The search and manuscript selection process

As AI literacy is an emerging field in the twenty-first century, hence available literature is limited. In search for literature on AI literacy, both peer-reviewed scholarly articles and conference papers from K-12 to higher education levels published from 2016 to 2021 through the Web of Science, Scopus, ProQuest Education Collection, IEEE and ACM digital library were included in this review. The first publication year found in the databases was 2016. The aforementioned databases were considered among the world's most trusted citation indices platforms for evidence-based quality scientific research and hence helped us to ensure the inclusion of quality scientific content (Mongeon & Paul-Hus, 2016). The articles that contained the phrase "AI literacy" OR "Artificial intelligence literacy" in either the title, the abstract, main text or keywords were downloaded and reviewed by the researchers. The search resulted in 46 articles.

After excluding irrelevant studies, as of Apr 11, 2021, a total of 30 articles were identified. The articles were downloaded and reviewed by our researchers during the document review. The selected articles then were examined by two researchers to determine whether they were suitable for the purpose of this study. During this examination, a set of inclusion and exclusion criteria were adopted to ensure generalisation of the findings and avoid biases in the studies selection (see Table 1). For example, Sharma (2019) focused on the impact made by AI in entrepreneurial activities including encouraging social innovation, improving the institutional environment and gaining support from international organizations, instead of integrating AI in educational settings.

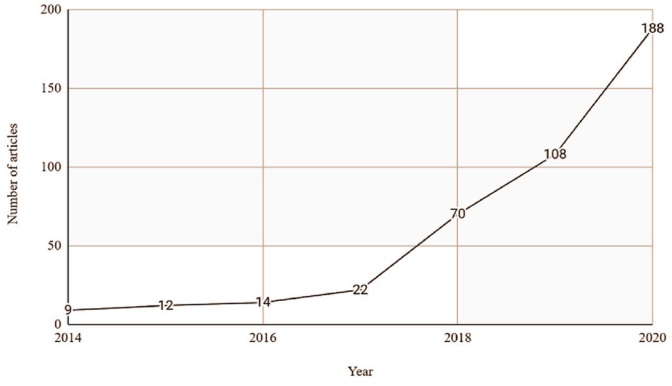

Fig. 1. AI literacy articles from google scholar published by year.

Table 1
Inclusion on and exclusion criteria.

Inclusion criteria	Exclusion criteria
(1) the studies had to review articles, empirical papers, articles, case studies or conference proceedings published in the journals indexed by the aforementioned databases. (2) the studies had to be in the field of education which was related to AI literacy. (3) the studies should provide descriptions of the underlying theory and methods.	(1) Editorials and books are excluded due to the lack of peer review. (2) Articles that mention the term "AI literacy" are actually about how AI is applying in particular fields and unrelated to education.

2.2. The data coding and analysis processes

This study began with formulating the study objectives, followed by a review and analysis of AI literacy research trends according to the four research questions. Then, the full text of the chosen articles was qualitatively classified using the constant comparative method espoused by Glaser (1965), which was used in other recent systematic reviews (e.g., Hew & Cheung, 2014; Terras & Warwick, 2013). Through studying the main content in the selected articles, similar meaningful concepts were identified and extracted for further thematic analysis. Corresponding text segments were coded under the coding schemes in each research question. To establish coding reliability, six (30%) of the articles were randomly picked, blind-coded and analysed by the two researchers. Two experienced researchers then read and categorized the papers based on the coding scheme. Disagreements were resolved through discussing the disputed studies. Cohen's kappa coefficient (0.9) was found to be excellent to show inter-rater reliability between coders (Miles & Huberman, 1994). After validating the coding scheme, the data findings were then descriptively analysed and summarised in terms of frequency, percentages and identified themes. In the case of discrepancy, the coders resolved this and reached a final decision through discussion.

3. Results and discussion

In this section, background information (i.e., publication year, country, levels of education and research method) of the 30 selected studies is first described (see Table 2). Then, we present the results and discuss these results according to the four research questions. The publications of AI literacy papers increase from 2016 (2 articles) to 2019 (8 articles). Nineteen published articles were found between 2020 and April 2021. Although the number of publications found in the abovementioned databases were limited, it is observed that the increasing trend of publications is consistent with Google Scholar's trend. In addition, we listed the nationality information of the first author in the AI literacy paper and observed that many countries have begun conceptualizing AI literacy. The regions that published two or more AI literacy articles include: the United States (9), China (4), Hong Kong (4), Spain (3) and Austria (3).

Researchers conducted studies and implemented AI literacy interventions across various educational levels. Most of the articles focused on primary school (14) and secondary school (14) students that covered almost half of the reviewed studies. Only a few studies were implemented for citizens (4), university students (4) and teachers (2). Finally, some articles studied AI literacy in less conventional settings in AI to bring up students for their future work, including libraries (1), medicine (1) and meteorology (1). About one-third of the studies (9) were conducted in an informal setting, which included after-school programs, out-of-school activities and poster presentations. Seven studies were conducted in regular lessons in a formal setting. The remaining papers did not specify whether the settings are formal or informal. One possible reason is that AI literacy is an emerging field, and most researchers tend to conduct preliminary studies to explore their interventions in an informal setting or merely write opinion papers based on their observation.

Overall, there are 1 review paper, 4 conceptual articles and 25 empirical studies. Regarding the research method, most of the empirical studies adopted qualitative (12) methods (see Table 3). Researchers used quantitative methods (5) to assess students' AI concepts, perceived abilities and other constructs such as confidence in using AI and social skills. Seven studies adopted a mixed-method approach (8) to collect data via multiple data sources including ability tests, questionnaire surveys, field notes, interviews and observations. We found one review article (i.e., Long & Magerko, 2020) in which they searched broader terms such as "AI education", "learning about AI" and "AI school" to map the key concepts underpinning AI literacy on their AI4K12 mailing list and selected papers. Since AI literacy articles emerged these few years, this review discusses how researchers use the specific term "AI literacy" instead of teaching and learning AI.

Table 2
Frequency (N, %) of the characteristics of the reviewed articles.

Variables	Categories	N	Percent
Year	2016	2	6.7%
	2018	1	3.3%
	2019	8	26.7%
	2020	17	56.7%
	2021	2	6.7%
Countries	Austria	3	10.0%
	Belgium	1	3.3%
	China	4	13.3%
	Denmark	1	3.3%
	Hong Kong	4	13.3%
	India	1	3.3%
	Singapore	1	3.3%
	Spain	3	10.0%
	Sweden	1	3.3%
	Turkey	1	3.3%
	USA	9	10.0%
	UK	1	3.3%
Publication type	Research paper	25	80.0%
	Conceptual paper	4	13.3%
	Review paper	1	3.3%
Educational level	K-elementary	14	46.7%
	Secondary school	14	46.7%
	Higher education	4	13.3%
	Citizen	4	13.3%
	Teacher	2	6.7%
Learning artefacts	AI-related agents	11	36.7%
	Hardware-focused artefacts	8	26.7%
	Software-focused artefacts	6	20.0%
	Unplugged artefacts	7	23.3%
Educational setting	Formal	7	23.3%
	Informal	9	30.0%
	Not specified	14	46.6%
Research methods	Qualitative	12	40.0%
	Quantitative	5	16.7%
	Mixed research	8	26.7%
	Review articles/conceptual papers	5	16.7%

3.1. RQ 1. how do researchers define the term "AI literacy"?

Of the 30 articles, 17 articles defined AI literacy based on the ideas of 'literacy'. Prior to AI literacy, the term "digital literacy" emerged to assess basic computer-related concepts and skills when computer applications gained popularity across industries in the 1970s. It was necessary for users to become competent in using computer systems related to their specific task or job. The importance of digital literacy increased as more people depend on the use of computer technologies to develop new social and economic opportunities (Leahy & Dolan, 2010).

Table 3
Research methods.

Research methods	N	Studies
Qualitative	12	Burgsteiner et al. (2016); Han et al. (2018); How and Hung (2019); Kaspersen et al. (2021); Leander and Burriss (2020); Long et al. (2019); Rivero (2020); Robinson (2020); Rodríguez-García et al. (2020); Schaper et al. (2020); Vazhayil, Shetty, Bhavani, & Akshay (2019); Watkins (2020).
Quantitative	5	Chai, Wang, and Xu (2020); Chai, Lin, et al. (2020); Dai et al. (2020); Gong et al. (2020); Karaca (2020).
Mixed method	8	Druga et al. (2019); Julie et al. (2020); Kandlhofer et al. (2016); Lin et al. (2021); Wan et al. (2020); Williams, Park, & Breazeal (2019); Register & Ko (2020); Rodríguez-García et al. (2020).
Review articles	5	Long and Magerko (2020); Pegrum et al. (2018); Wong et al. (2020); Xu (2020); Zou et al. (2019).

In succession to digital advancement, AI started to arise and imitate human intelligence in machines for computers to learn, reason and perceive. It was initially used in scientific research and academic environments but had yet become ubiquitous in our daily lives. In summary, four aspects of fostering AI literacy were identified from the review (see Table 4).

3.2. Know and understand AI

Twenty-seven articles conceptualize AI literacy as educating learners about acquiring fundamental concepts, skills, knowledge and attitudes that require no prior knowledge. On top of being the end users of AI applications, learners should understand the technologies behind. Burgsteiner et al. (2016) and Kandlhofer et al. (2016) defined AI literacy as the ability to understand the basic techniques and concepts behind AI in different products and services. Moreover, some researchers associate AI literacy with perceived abilities, confidence and readiness in learning AI. In K-12 education, Druga et al. (2019) and Lin et al. (2021) designed learning curriculums and activities that foster AI literacy that focuses on how learners gain AI concepts.

3.3. Use and apply AI

All 30 articles emphasized the importance of educating learners to know how to apply AI concepts in different contexts and applications in everyday life. For example, Rodríguez-García et al. (2020) evaluated LearningML, a machine learning model builder, to educate citizens to understand AI applications and how it can affect our lives, as well as knowing the ethical issues regarding AI technologies. In addition, half of the studies (19) discussed the human-centered and ethical considerations and focused on using AI concepts and application ethically, which would be further discussed in RQ4. Eight articles borrowed the ideas of computational thinking to interplay AI literacy and AI thinking (see Table 5). AI thinking refers to the construction of logic and algorithms in order to support students' understanding of how to use knowledge bases for problem-solving, processing semantics and handling unstructured data (Vazhayil et al., 2019). For example, How and Hung (2019) leveraged AI thinking through conducting data analytics with computing, and interpreted new findings from the machine-learned discovery of hidden patterns in data.

3.4. Evaluate and create AI

AI augments human intelligence with digital automation and 19 articles alluded AI literacy to engage learners in higher-order thinking activities. Other than knowing and using AI with concepts and practices, some studies had extended AI literacy to two other competencies that enabled individuals to critically evaluate AI technologies, communicate and collaborate effectively with AI (e.g., Long & Magerko, 2020). For example, Han et al. (2018) enhanced students' scientific and technological knowledge which then was applied in scientific research-based learning to solve practical problems. Long et al. (2019) engaged citizens in co-creating AI amenities in public spaces to broaden their public AI literacy and experiences. Participants could engage with public interactive artworks progress sequentially from being initially attracted to an AI-enabled installation to relate their interaction with the installation and other people.

Overall, although these articles showed slight variations on the definition of AI literacy, they support the notion that everyone, especially K-12 children, acquire basic AI knowledge and abilities, enhance motivation for future career, as well as use AI-enabled technology (Chai, Lin, et al., 2020). In addition to knowing and using AI ethically, AI literacy serves as a set of competencies that enables individuals to critically evaluate AI technologies, communicate and collaborate effectively with AI (Long & Magerko, 2020).

3.5. Bloom's taxonomy

Specifically, a definition for AI literacy learning is presented in the aforementioned three aspects. In fact, the abilities and skills involved in each aspect could be potentially mapped to the cognitive domains in Bloom's Taxonomy. Bloom's Taxonomy is an approach to categorize the levels of reasoning skills and ordered thinking required across different learning contexts. There are six levels in the taxonomy, each requiring a higher level of complexity and ordered thinking from the students. The levels are understood to be successive, so that one level must be mastered before the next level can be reached (Bloom, 1956; Huitt, 2011). The reason why we adopted the Bloom architecture is that AI literacy is novice to educators and a classification of levels of cognitive processes has not yet been developed in the context of AI learning. However, this model is a classic pedagogical theory that establishes the core foundation of AI taught to young learners. In our review, it is proposed to assign these three aspects (i.e., know and understand, use, and evaluate and create AI) into the cognitive levels of Bloom's Taxonomy. "Know and understand AI" is assigned to the bottom two levels; "use and apply AI" in applying concepts and applications is assigned to the apply level; "evaluate and create AI" are assigned to the top three levels to analyse, evaluate and create AI (see Fig. 2).

In our review, most studies discussed how to foster learners' AI literacy in knowing and understanding AI (27), as well as how to use AI applications in everyday life and apply its underlying concepts in different contexts (30). Only 19 articles (63.3%) mentioned how to enhance students to analyse, evaluate and create AI applications through higher-order thinking activities. A possible reason that existing AI literacy studies focused more on general skills and knowledge about AI is that AI literacy is a set of fundamental skills and abilities in helping everyone, including children and citizens, to acquire, construct and apply knowledge. They may not necessarily handle how to abstract and decompose AI problems, nor build AI applications; instead, they need to know the basic concepts and use AI ethically. As such, most of our

Table 4
Coding framework of AI literacy.

AI literacy	Definitions	N	Sample references	Sample studies
Know & understand AI	Know the basic functions of AI and how to use AI applications.	27	*Even though transparency in algorithms and AI in general has been **acknowledged** to be ethically important, the public lacks understanding of even the basic functions of AI. Efforts to make AI more comprehensible exist (Robinson, 2020).*	Lin et al. (2021)Lin et al. (2021); Kandlhofer et al., 2016); Robinson (2020).
Use & Apply AI	Applying AI knowledge, concepts and applications in different scenarios.	30	***Apply** k-means clustering in science contexts.. explore the mapping relationship between facial features and data values and **apply** the concept to brainstorm other objects such as Lego (Wan et al., 2020).*	Druga et al. (2019); Julie et al. (2020); Vazhayil et al. (2019).
Evaluate & create AI	Higher-order thinking skills (e.g., evaluate, appraise, predict, design) with AI applications.	19	***Design** & **build** experiences: Technology exploration and **creation** activities supported students in making sense of the underlying AI concepts. (Lee, 2020).*	Druga et al. (2019); Han et al. (2018); How and Hung (2019).
AI ethics	Human-centered considerations (e.g., fairness, accountability, transparency, ethics, safety).	19	***"AI for social good"** measures an individual's perception of the social environment surrounding the behavior, which is related to subjective norms (Chai et al., 2020).*	Chai et al. (2020); Druga et al. (2019); Gong et al. (2020).

Table 5
Interplay between AI and Brennan-Resnick's (2012) computational thinking.

Elements	Descriptions	Examples
AI concepts	Technical and conceptual understanding of the basic AI concepts.	● Understand the basic AI concepts and their origins such as machine learning, deep learning and neural network.
AI practices	The techniques and strategies used when applying AI.	● Appreciate the real-world applications of AI concepts such as speech recognition, robotics. ● Training, validation and testing. ● Remixing or reusing code.
AI perspectives	Attitudes and dispositions adopted while solving problems.	● Collaborating to solve problems, understanding of technology as a problem-solving tool. ● Consider the ethical and safety concerns when applying AI technologies in real-world applications.

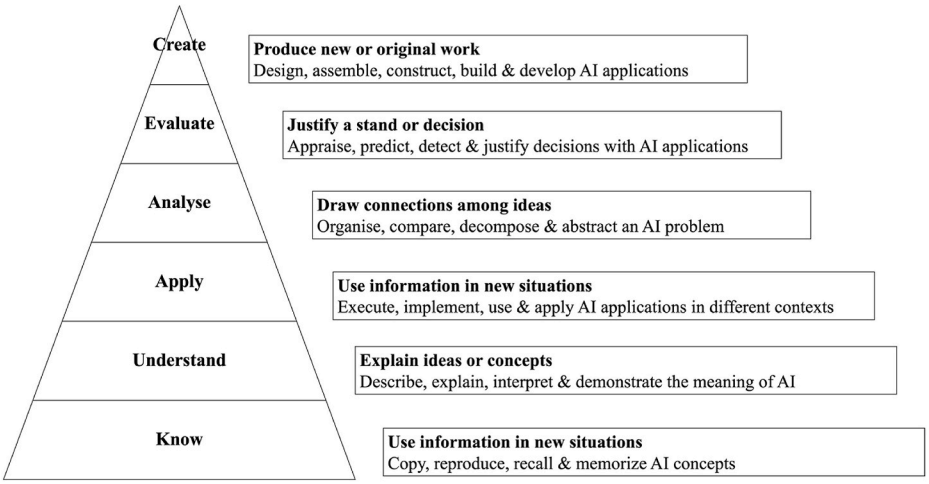

Fig. 2. Bloom's Taxonomy and AI literacy.

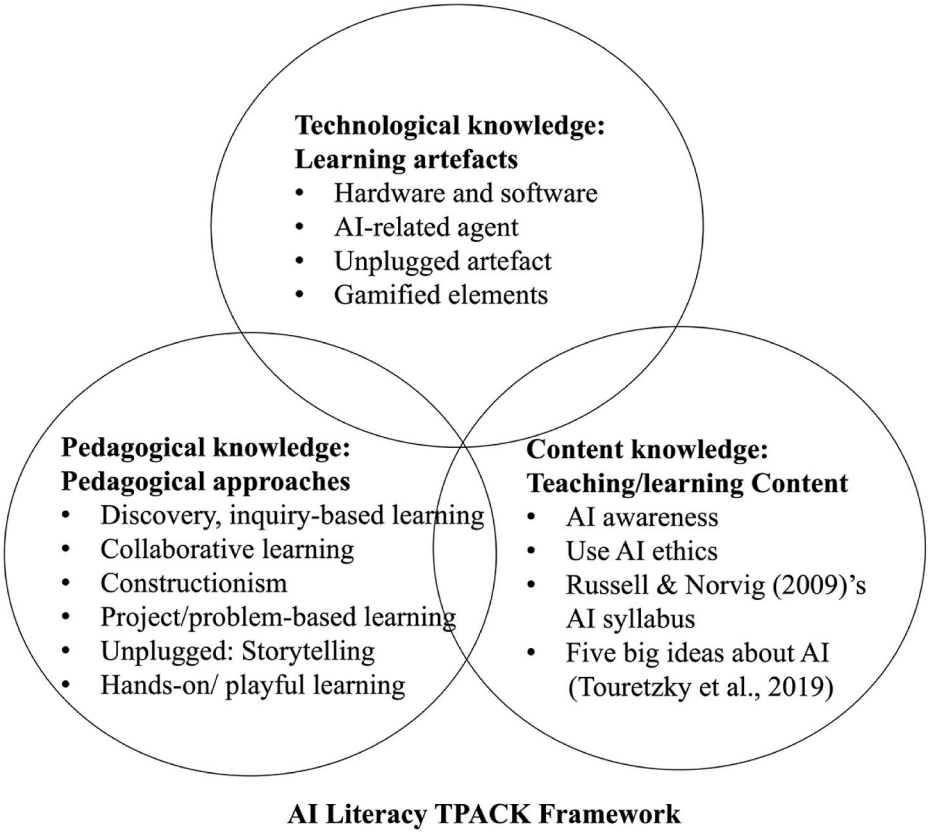

Fig. 3. AI literacy TPACK framework.

selected AI literacy studies put more emphasis on engaging learners in lower-level thinking activities. However, when students are promoted to secondary schools and universities, they become knowledgeable to apply their prior knowledge to create their own artefacts and justify decisions with AI applications and algorithms.

3.6. RQ 2. how do educators help learners develop AI literacy in terms of learning artefacts, pedagogical approaches and subject matters?

This review aims to fill recognized gaps in knowing the effective means to integrate AI literacy into school curricula and how educators help learners develop AI literacy. The elements found in our studies into the Technological, Pedagogical and Content Knowledge (TPACK) framework are categorized in terms of learning artefacts, pedagogical approaches, and subject matters (see Fig. 3). The reason that we adopt the TPACK model is that it is widely used across studies to identify how teachers can incorporate technologies into their pedagogical methods and content knowledge, and conceptualizes their capacity and knowledge that is needed to integrate relevant technologies in AI literacy education (e.g., Graham, 2011; Koehler et al., 2013). It provides a map for understanding how to integrate AI literacy into classrooms effectively. For example, Kim et al. (2021, pp. 1–13) based on AI learning resources to conceptualize TPACK to improve teaching for K-12 AI education, which offers core foundations of AI taught to young learners. Among the three knowledge, technological knowledge involves the affordances and use of domain-specific learning tools such as hardware and software in AI literacy education, AI-enabled tools (e.g., intelligent agents), and unplugged learning tools (e.g., role-playing). Second, pedagogical knowledge relates to teaching methods and their application to promote student AI literacy learning, which entails teaching strategies and scaffolding, feedbacking students' learning processes (Janssen et al., 2019). Third, content knowledge concerns knowledge about the AI literacy subject matter that specific subjects should be covered in the curriculum.

Learning artefacts: Given the complexity of AI, age-appropriate learning artefacts were important to scaffold students' AI conceptual understandings and stimulate their motivation and interest in learning AI. In recent years, there has been an increase in hardware and software that enhance AI concepts accessible to younger learners. Table 6 provides an overview of the types of AI learning artefacts ranging from hardware (8) to software-focused artefacts (6), intelligent agents (11) and unplugged learning tools (5). The democratization of current AI technologies encourages students to make intelligent agents and machine learning models without needing to program such as ML-for-kids and Teachable Machine (Kaspersen et al., 2021; Long & Magerko, 2020). In this context, we can see an opportunity for educators to democratize access to AI literacy and reinforce the AI concepts through these emerging tools. In addition, AI-driven tools such as chatbot, writing assistants and web mapping encourage students to experience the societal impact and technological affordances of AI applications. Alternatively, five studies designed unplugged learning activities to foster students' AI literacy without using a computer through engaging approaches such as case study, role-playing and storytelling (e.g., Julie et al., 2020; Rodríguez-García et al., 2020). On the whole, most researchers restricted the development of AI literacy skills within Computer Science-related learning artefacts, while some researchers extended AI literacy skills to non-CS elements such as role-playing and storytelling.

Table 6
Learning artefacts.

	Definition	Learning artefacts examples	Sample studies
Hardware-focused artefacts	Use physical artefacts to learn AI such as robotics, sensors and Arduino devices.	Bee-bots, LEGO Mindstorms NXT, Cubelets, alpha dog robot, Kinect LuminAI, VR Robot Improv Circus, Sound Happening, Shape of Story AI home assistants: Jibo robot, Anki's Cozmo robot and Amazon's Alexa Lego Mindstorms NXT	Kandlhofer et al. (2016) Chai, Wang, and Xu (2020) Long et al. (2019) Druga et al. (2019) Burgsteiner et al. (2016)
Software-focused artefacts	Use digital artefacts to learn AI such as block/ syntax-based programming and simulation.	Google maps, Golog, YAGI, ASRAEL SmileyCluster, A* algorithm in C#	Kandlhofer et al. (2016)Wan, Zhou, Ye, Mortensen, & Bai (2020) Burgsteiner et al. (2016)
AI-related agents	Use intelligent agents such as expert systems, machine learning trainers, chatbots to build their custom machine learning models without coding.	Scratch, Google's Teachable Machine, Generative Adversarial Networks (GANS), Watson AI services, Bayesialab, AI home assistants: Jibo robot, Anki's Cozmo robot and Amazon's Alexa	Lin et al. (2021) Vazhayil et al. (2019) How and Hung (2019) Druga et al. (2019)
Unplugged	Use learning activities to learn AI without a computer such as lecture, case study, role-playing and storytelling.	Lectures, career talk, textbook, case study, webinar, role-playing, storytelling	Lin et al. (2021) Dai et al. (2020) Schaper et al. (2020) Rodríguez-García et al. (2020) Julie et al. (2020)

3.7. Pedagogical approach

The pedagogies including teaching methods and strategies are classified according to the levels of education. One of the aims of AI literacy education for primary schools is to familiarize children with the basic concepts of AI/computer science and encourage them to discover the connection between AI applications and the underlying concepts. For example, researchers introduced children to AI concepts in playful and inquiry approaches via high-order thinking activities such as creating digital stories (Kandlhofer et al., 2016), performing Turing Test with intelligent agents, creating chatbot and inference algorithms (Wong et al., 2020), and building applications through blockly-based programming (Gong et al., 2020). In addition to understanding the connection between those AI techniques and common AI applications, secondary school students should have the abilities to apply prior AI knowledge in practical group projects to analyse and solve problems independently (Kandlhofer et al., 2016). Thus, educators could design real-world, collaborative projects based on the principles of constructionism and instructionism (Kandlhofer et al., 2016). Researchers suggest various hands-on activities such as robot constructions (Williams et al., 2019), data and comparative visualization (Wan et al., 2020), as well as training AI models (Vazhayli et al., 2019) as possible means to promote AI literacy in secondary school levels.

Adult learners are categorized as university students and the general public. Since university students have obtained fundamental AI understanding, they are more ready for further developments in this field. They could conduct projects or research to describe problems formally and on a higher abstraction level (Kandlhofer et al., 2016). As such, they could apply AI skills and knowledge to solve real-world problems for future academic and career challenges (Chat et al., 2020).

To cultivate the general public to understand and use AI applications ethically, free online resources and courses (Robinson; 2020), public art installations and museum exhibits (Rodríguez-García et al., 2020) are viable approaches to establish a collaborative, creative, robust and safe society.

3.8. Content knowledge

In K-12 education, studies that involved the design of learning curricula and activities focus on how learners gain AI concepts, and how they apply AI to contexts of their interests (e.g., Druga et al., 2019; Lin et al., 2021). Long and Magerko (2020) and Rodríguez-García et al. (2020) mentioned Touretzky et al. (2019)'s five "big ideas" of AI have set a sound framework for future research on fostering AI literacy:

- Perceptions: Computers perceive the world using sensors.
- Representation and reasoning: Agents maintain representation of the world and use them for reasoning.
- Learning: Computers can learn from data.
- Natural interaction: Intelligent agents require many kinds of knowledge to interact naturally with humans.
- Societal impact: AI can impact society in both positive and negative ways.

Inspired by this framework, Wong et al. (2020) further categorized AI literacy in K-12 into three dimensions: AI concepts, applications and ethics. In another study, Rodríguez-García et al. (2020) evaluated LearningML, a machine learning model builder, to develop critical thinking. This model builder teaches K-12 students on AI fundamentals to understand the applications of AI, how it can affect their lives, and the ethical issues that arise from AI technologies.

In higher education, AI knowledge and skills become more advanced to meet the future job demands. Kandlhofer et al. (2016) and Burgsteiner et al. (2016) listed a set of AI concepts that have potential to become the basis for careers in science and engineering: automata, intelligent agents, graphs and data structures, basics of computer science, machine learning, etc., based on the "Artificial Intelligence: A Modern Approach" written by Russell Stuart and Norvig (2009). Four studies mentioned the importance of educating citizens on fundamental AI concepts, and the impacts of AI technologies on their everyday lives. For example, Robinson (2020) mentioned that the Norwegian policy document, in a section titled "AI for everyone: Elements of AI" (p. 44) asserts the government will make AI learning courses globally accessible in 2020, which conceptualizes AI literacy as educating their citizens about the elements of AI that require no prior knowledge (Robinson, 2020). In addition, three studies focused on AI learning in specific disciplines (i.e., meteorology, medicine and library) to describe how AI can be applied in vocational training and workplace application (e.g., using healthcare-AI technologies for delivering prevention, diagnosis, treatment and rehabilitation services) (Karaca et al., 2021; Rivero, 2020; Zou et al., 2019).

3.9. Teacher education

From the review, four articles discussed how learning programs could strengthen teacher preparation especially for those without prior knowledge so that they could incorporate AI literacy into school curricula (Vazhayil et al., 2019; Xu, 2020). Vazhayil et al. (2019) explored how 34 Indian teachers perceived AI literacy learning after the workshop (e.g., "How did you find the teaching methods used during the training?", "Do you think this workshop will enjoy you the most?") (p.74). Teachers need to first update their knowledge of AI concepts that potentially be introduced in their schools. Then, they design suitable teaching methods and strategies (e.g., collaborative problem-solving) and choose age-appropriate learning materials to stimulate students' interest. They also need to consider various teaching challenges such as insufficient funding, immature AI curricula, tools and evaluation methods (Gong et al., 2020), as well as technical concerns that whether their schools' internet infrastructure is ready for students to compile AI-enabled algorithms and applications (Vazhayil et al., 2019).

Apart from updating teachers' AI knowledge to solve teaching challenges, educators need to know and use suitable AI-enhanced technologies such as adaptive learning systems to facilitate their daily teaching practice and management, and promote personalized learning to understand students' learning progress and needs (Xu, 2020). Xu (2020) proposed the importance of learning AI for educators that "teachers who know how to use AI may replace the teachers who do not know how, because AI can empower teachers and promote their role transformation which greatly improve the efficiency of management and the level of decision-making" (p.290). In addition, teachers should enable students to use AI-enhanced learning tools such as intelligent tutors and adaptive learning systems to facilitate personalized learning (e.g., self-diagnosing, providing automatic feedback and promoting online collaboration among learners) (Cavalcanti et al., 2021).

3.10. RQ 3. how do researchers evaluate students' AI literacy skills?

Among 30 studies, researchers adopted quantitative (13) and qualitative (18) evaluation methods to examine how to assess students' mastery and application of AI literacy-related skills (see Table 7), provided that we double-coded "mixed-method research" into quantitative and qualitative evaluation methods. In addition, Robinson (2020) is not

Table 7
Assessment constructs and tools to evaluate students' AI learning.

Research methods	Constructs and tools	Some examples	Sample studies
Quantitative (13)	Use knowledge tests to assess students' AI cognitive gain and abilities	*Could you order the major steps for the k-means clustering algorithm? (Wan et al., 2020)*	Kandlhofer et al. (2016); Wan et al. (2020).
	Use perceived questionnaire to assess the non-cognitive aspects, including: perceived ability, confidence in using AI, intelligence, truthfulness, perceived understanding, subjective norms, AI anxiety, perceived usefulness of AI, AI for social good, attitude toward using AI, confidence in learning AI, learning behavioural intention, AI optimsm, relevance, AI awareness, career adaptability skills.	*How would you rate your knowledge about search algorithms?* (Kandlhofer et al., 2016)	Chai, Wang, and Xu (2020); Chai, Lin, et al. (2020); Dai et al. (2020); Druga et al. (2019); Gong et al. (2020); Julie et al. (2020); Lin et al. (2021); Wan et al. (2020).
Qualitative (19)	Use videos, documents, pictures, presentations, students interactions with AI agents and projects to examine students' AI cognitive and non-cognitive abilities.	*Through a follow-up interview, they found that children were able to apply their new knowledge of ML to their own life and to think up personally meaningful applications using ML* (Kaspersen et al., 2021). *The author compares how the three values of trust, transparency, and openness are defined and explored in Nordic AI policy documents (Robinson, 2020).*	Burgsteiner et al. (2016)*; Druga (2019); Julie et al. (2020); Kandlhofer et al. (2016); Schaper et al. (2020); Wan et al. (2020).

coded in RQ3 since this study aimed to compare how trust, transparency, and openness are defined and explored in AI government policy documents in different countries.

Quantitative methods: To evaluate K-12 students' AI literacy, one important component is to promote their intention to learn and possess basic knowledge about AI. Thirteen studies used quantitative methods to assess the knowledge acquisition of K-12 and university students via pre- and post-knowledge tests (e.g., What are the characteristics of depth-first search?), and students' perceived abilities (e.g., How would you rate your knowledge about search algorithms?) (Kandlhofer et al., 2016; Wan et al., 2020). Furthermore, studies discussed other quantitative aspects via surveys to understand students' perceptions (non-cognitive aspects) towards AI literacy education such as confidence in using AI, motivation and AI for societal good.

Qualitative methods: Nineteen researchers collected qualitative data by taking pictures, field notes during teaching, and interviewing students to understand their motivations, expectations and lessons learned. For example, Druga (2019) recorded students' interaction with AI agents through field observations and adopted a three-attribute AI perception questionnaire to evaluate how 102 children (7–12 years old) interacted and perceived their AI agents in their lessons. These three attributes measure whether the agents are smarter, truthful and understand them (e.g., "What do you think of Google Voice, an AI-enabled agent?"). Children replied that the most fun features were playing beat-box and music, taking pictures and playing games. Watkins (2020) collected exhibition feedback from 367 participants to present the most frequently asked questions in a poster session (e.g., "Will librarians be able to develop programming with this tool?") (p.17).

3.11. Tools for assessing AI literacy

To examine AI literacy assessment, researchers and AI educators now use quantitative and qualitative tools to examine students' AI literacy development. To better understand the interplay between cognitive and non-cognitive constructs of fostering AI literacy, studies began to explore the changes in attitudes, behaviours and cognitions toward statistics in different AI educational contexts. Table 7 demonstrates the assessment constructs and tools to evaluate students' AI cognitive and non-cognitive development. To further understand how to examine AI literacy through quantitative and qualitative tools, we categorized three major assessment types that have been found in the literature, including knowledge tests, survey, portfolio assessment and artefact-based interviews. Some studies adopted more than one assessment type to triangulate the learning outcomes of students' AI literacy.

Knowledge test: Six studies developed selected or constructed-response questions such as multiple choice and structured questions which are evaluated by correctness and completeness for summative purposes. Kandlhofer et al. (2016) used paper-and-pencil exercises to assess students' existing knowledge of AI concepts such as graphs, trees and data structures as evidence of student AI proficiency. Students' AI knowledge acquisition and retention of AI skills was assessed in Lin et al. (2021), Wan et al. (2020) and Rodríguez-García, Moreno-León, Román-González, & Robles, 2021 studies via some pre-post knowledge tests. Lin et al. (2021) administered AI concepts tests to address common core AI concepts including decision tree, logics system, neural network and machine learning. Wan et al. (2020) conducted pre-post questionnaires with written answers to questions relating to clustering, similarity comparison and k-means clustering process whereas Rodríguez-García, Moreno-León, Román-González, & Robles, 2021 selected and modified 14-item questions from other available tests and online resources, such as Machine Learning for Kids website and MOOC platforms on AI. Williams et al. (2019) developed three or four multiple-choice questions on a tablet or paper to probe what kindergarten children understood about AI knowledge such as classification and generative AI to triangulate students' learning behavior observation in relevant activities.

The usage of this traditional knowledge test suggests that AI literacy can be considered as knowledge and skills gained which could be regarded as quantifiable mastery of knowledge regarding AI components. Since AI will be more widely taught in K-12 and non-computer science university programs, it is observed that there will be more reliable and valid knowledge assessment which can be conveniently adapted into learning interventions to understand students' AI knowledge for a summative assessment purpose.

Survey: Surveys are widely used to investigate perceived ability, affective and non-cognitive learning outcomes (e.g., motivations, attitudes toward AI learning) in educational research. Eleven studies developed surveys designed quantitative items to understand students' perceptions of AI, and open-ended questions to collect student self-report responses. Although surveys were often used to examine students' non-cognitive outcomes, several studies used surveys to elicit students' perceived AI understandings. For example, Chai, Wang, and Xu (2020) and Chai, Lin, et al. (2020) designed a 6-item questionnaire to understand students' confidence, perceived relevance of learning AI and readiness towards AI. The survey was then modified by Lin et al. (2021) who employed structural equation modeling to validate primary students' motivation for learning AI for the future development of AI curricula and instruction. It is found that AI literacy is significantly associated with the aspects including subjective norms, perceived usefulness of AI, AI for social good, attitude toward using AI, AI optimism and confidence in learning AI (Chai, Wang, & Xu, 2020; Lin et al., 2021). Another study Register & Ko (2020) applied qualitative thematic analysis of students' open-ended responses about how machine learning systems work, as well as other aspects including ML model transparency, critical thinking and learners' interests and backgrounds. One advantage of using surveys is that it consists of convenient data collection from a large sample size which could produce quantifiable results. However, it limits students' rich description from their learning exposure. To fill this gap, the usage of project portfolio analysis and artefact-based interviews could be incorporated into knowledge tests and surveys to triangulate students' AI learning.

Project portfolio analysis and artefact-based interview: Project portfolio analysis refers to a purposeful and systematic process of collecting and evaluating various types of students' learning artefacts such as products, projects and programs (McMillan, 2013). With students' project portfolios, researchers and educators can interview students to examine their AI concepts and practices. Five studies applied project portfolio analysis with a follow-up interview to examine the attainment of learning targets. For example, Kaspersen et al. (2021) evaluated students' AI models and user interface design through collecting and labelling data, and building, testing and evaluating models. After analysing the artefacts in students' projects, researchers found that children were able to apply their new knowledge of machine learning (ML) to their own life and to think up personally meaningful applications using ML. Another study Watkins (2020) asked participants to create 2D visualization and related kiosk applications that were demonstrated in the makerspaces and libraries at universities, and further invited visitors to perceive their AI applications in Cosmology. Kandlhofer et al. (2021) studied students' picture taking, field notes, interaction and project demonstrations during each teaching unit. Then, they performed semi-structured interviews and content analysis to examine how students foster their AI understandings. However, it is observed that researchers did not generate a grading rubric to indicate the levels of achievement for each dimension of AI learning performance and whether a criteria is met. Future research could design rubrics to analyse students' AI concepts that could be graded by human raters and/or AI education systems such as chatbots, expert systems and intelligent tutors (Zhang & Aslan, 2021).

Through artefact-based interviews, it is useful to understand which AI components students could understand and use more frequently through communication and students' projects. Since AI learning is novice to K-12 educators, the application of portfolio assessment and follow-up interviews could capture a holistic view of what extent of

knowledge and skills students need to obtain, and how educators design and choose their learning materials and tools in their learning design. In addition, this also encourages educators to use in classrooms and across platforms to formatively assess students to offer them feedback that is potentially beneficial to their future AI learning.

With the great potential of using artefact-based interviews, researchers usually employed interviews to support and elaborate on students' portfolio assessment by specifying their thinking processes of using AI skills to solve problems (e.g., how they got started, how the project evolved, what was important for them to know to make the project, what problems they encountered throughout the process, and how they dealt with those problems). Furthermore, students could reflect on themselves when working on the hands-on projects, such as what they were most confident of, what they might want to further improve, and what engaged them. However, the challenges of using interviews include its high cost and long time spent on interviewing and coding the data as well as its small distribution to students, which makes it difficult to be quantified (Tang et al., 2020). Throughout artefact-based interviews, researchers were able to have detailed discussions about different AI elements in students' projects, and to develop rich descriptions of their development practices.

3.12. RQ 4. what are the ethical concerns in the domain of AI literacy?

As AI plays an important role in day-to-day decision making, misused or poorly designed AI could cause irreparable harm to humans and the society (Fourtané, 2020). AI-concerned scientists and engineers like Elon Musk expound on the horrors that future AI technologies may wreak on humanity in decades to come (Johnson, 2019). In our review, Schaper et al. (2020) reflected that international organizations such as UNICEF and OECD argue for the need of transparency and explainability in AI to offer meaningful information to understand AI systems, user interactions and societal impacts (Vincent-Lancrin & Van der Vlies, 2020; UNICEF, 2019). Nineteen studies had mentioned human-centered considerations, and raised attention to educate citizens to become socially responsible and ethical users (Ahmad, Teredesai, & Eckert, 2020). Gong et al. (2020) found that students pay little attention to ethical concerns such as bias in AI and legal responsibility, and intellectual property. In this regard, researchers began to notice the importance of AI human-centered concerns such as inclusiveness, fairness, accountability, transparency, and ethics, instead of merely enhancing students' AI abilities and interests (Hagendorff, 2021; Microsoft, 2021). For example, Lin et al. (2021) designed a middle-school curriculum to develop AI literacy through combining AI concepts, ethics, awareness and careers. Their study envisioned that the foundation of future AI industries would be built on "principles of inclusivity, provide equitable access, include consideration of multiple stakeholders and potential users, and minimize the potential for bias" (p.191). To summarize, conceptualizing AI literacy with human-centered considerations is crucial to building a future inclusive society.

To bring up future responsible citizens who are competent in using AI in a reliable, trustworthy and fair manner, broadening participation in AI for everyone and ensuring inclusive AI learning designs are necessary. Teachers should address the learning needs of under-represented groups including, but not limited to, gender, ethnic minorities, social-economic status and cultural background when teaching AI. For example, Druga (2019) found that low social-economical children tend to have a harder time advancing AI concepts because they had less experience with coding and interacting with these technologies in their everyday life. She proposed a set of guidelines to make AI learning inclusive by avoiding deceiving technologies, offering ways for children to customize their machines, and encouraging collaboration to share each other's work (Druga, 2019).

4. Conclusion

In this review, a variety of definitions of AI literacy was identified. Most defined AI literacy based on different types of 'literacies', which had recently been applied to define skill sets in other disciplines. Most researchers advocated that instead of merely knowing how to use AI applications, learners should learn about the underlying AI concepts for their future careers and understand the ethical concerns in order to use AI responsibly.

Since AI literacy is an emerging field that there is a lack of journals published in this field, several limitations were identified. The keyword search limited the scope of domain specificity within the AI context while other subfields of AI like machine learning, neural network, etc. could potentially be related to this study but were not captured in the current review. Second, some articles in this review involved interventions and learning programs that were relevant to AI literacy. However, the articles did not explicitly define the term AI literacy. Third, a larger pool of studies discussing AI learning and teaching without mentioning the term "AI literacy" were not included in this review; however, their interventions could be comparable to AI literacy instructional design. This suggests that future review could broaden the scope of search to common AI themes and to capture more literature in AI learning and teaching.

The existing gaps and needs in the AI literacy research were derived to bring forth potential areas for future studies. In this review, the majority of the articles (22) are conference papers while the other eight are journal publications. Moreover, 19 of the articles used qualitative research methods and were exploratory research for preliminary studies. In the near future, it is foreseen that research design will shift to be more empirical and interventional (e.g., quasi-experiment, design-based research) with clearly documented treatment and control groups, as well as varied data analysis procedures (e.g., *t*-test, one-way analysis of variance, factor analysis, regression, structural equation modeling). Furthermore, there is a need to examine the quality of different AI literacy assessments. Only three studies examine the reliability and validity of scales for AI literacy skills by conducting exploratory and confirmatory factor analysis (Chai et al., 2020a, 2020b; Dai et al., 2020). To advance the AI literacy field, priority needs to be placed on proposing definitive frameworks to guide educators to create lesson designs with appropriate pedagogies, learning artefacts and assessment criteria. We hope this review will inspire scholars, educators, and government officers to begin the discussion on how to define, implement and evaluate AI literacy in the future.

4.1. Recommendations for future AI literacy education

The findings of this review present a preliminary overview of empirical research literature on AI literacy studies in the education field. This study contributes to addressing the aforementioned research gaps, and provides directions for future research on AI literacy education based on the prevalent research questions:

- AI becomes a fundamental skill for everyone, not just for computer scientists. In addition to reading, writing, arithmetic and digital skills, we should add AI to every learners' twenty-first century technological literacy in work settings and everyday life.
- Inspired by Bloom taxonomy, AI literacy possesses basic competencies to know and understand, use and apply, as well as evaluate and create AI. People need to equip themselves cognitively for future technological challenges in their workplaces. At the same time, it is important to foster their social responsibility and ethical awareness to use AI for societal good.
- Students are not only the end users but potentially be problem-solvers to use AI technologies in different scenarios, or even create possible AI-driven hardware and software solutions to make our society a better place to live in.

- AI literacy combines the ideas of data science, computational thinking and multi-disciplinary knowledge to interplay AI literacy and AI thinking.
- To facilitate educators' teaching, the technological, pedagogical and content knowledge framework needs to be considered to provide a map for understanding how to integrate AI literacy into classrooms effectively. Age-appropriate learning artefacts and curricula need to be designed to scaffold K-12 students' AI conceptual understandings and stimulate their motivation and interest in learning AI.
- Educators should update their AI knowledge to solve teaching challenges such as knowing and using suitable AI-enhanced technologies such as adaptive learning systems that facilitate their daily teaching practice and management, and promote personalized learning to understand students' learning progress and needs.
- Future researcher and educators will develop pedagogical strategies (e.g., collaborative project-based learning, gamification) and theoretical models (e.g., self-determination theory, constructionism) to increase students' motivation and engagement, promote interaction and collaboration, enhance motivation and attitudes, and develop numerous learning skills in the context of AI literacy.
- Future researchers and educators will develop quantitative and qualitative assessments to examine students' learning performance via post-knowledge tests, self-perceived surveys, learners' artefacts, projects and conversations.
- Human-centered considerations are important to raise attention to educate citizens to become socially responsible and ethical users such as inclusiveness, fairness, accountability, transparency, and ethics, instead of merely enhancing students' AI abilities and interests.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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