Computers and Education Open 6 (2024) 100171

Contents lists available at ScienceDirect

Computers and Education Open

journal homepage: www.sciencedirect.com/journal/computers-and-education-open

What are artificial intelligence literacy and competency? A comprehensive framework to support them

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ARTICLE INFO

Keywords:
AI literacy
AI competency
K-12 education
Machine learning
Data literacy
Generative AI

ABSTRACT

Artificial intelligence (AI) education in K–12 schools is a global initiative, yet planning and executing AI education is challenging. The major frameworks are focused on identifying content and technical knowledge (AI literacy). Most of the current definitions of AI literacy for a non-technical audience are developed from an engineering perspective and may not be appropriate for K–12 education. Teacher perspectives are essential to making sense of this initiative. Literacy is about knowing (knowledge, what skills); competency is about applying the knowledge in a beneficial way (confidence, how well). They are strongly related. This study goes beyond knowledge (AI literacy), and its two main goals are to (i) define AI literacy and competency by adding the aspects of confidence and self-reflective mindsets, and (ii) propose a more comprehensive framework for K–12 AI education. These definitions are needed for this emerging and disruptive technology (e.g., ChatGPT and Sora, generative AI). We used the definitions and the basic curriculum design approaches as the analytical framework and teacher perspectives. Participants included 30 experienced AI teachers from 15 middle schools. We employed an iterative co-design cycle to discuss and revise the framework throughout four cycles. The definition of AI competency has five abilities that take confidence into account, and the proposed framework comprises five key components: technology, impact, ethics, collaboration, and self-reflection. We also identify five effective learning experiences to foster abilities and confidences, and suggest five future research directions: prompt engineering, data literacy, algorithmic literacy, self-reflective mindset, and empirical research.

Introduction

Artificial intelligence (AI) is the ability of a digital machine to carry out tasks that are typically performed by intelligent beings. Its technologies that support AI includes computer vision, speech-to-text, and natural language processing [7]. The advancements in AI are having profound effects on our daily lives, entertainment, education, and jobs. It is critical to expand AI training beyond higher education and professionals. With the goal of preparing all citizens for AI based society, AI education has been included in non-expert community around the world, e.g., AI for all [24] and AI for K-12 [4,43]. We need all our young children to have good AI literacy and competency [3]. Therefore, AI education for K–12 is a global initiative, as evidenced in UNESCO's report on AI education. On the other hand, unlike in higher education, designing K–12 education must take into account implementation and variety in delivery. To address the global initiative, a few major frameworks were proposed for researchers and educators [4,42,43]. They focus on identifying content and knowledge for AI teaching and learning. They are very important at the beginning of this initiative because researchers and educators did not know what to include in the AI curriculum. However, AI education is more than content, because it addresses the learning outcomes (i.e., What are AI literacy and competency?) and experiences (i.e. How to nurture them?) [5,27,34].

Literature has defined and suggested what AI literacy is for non-AI professionals (e.g., [29,31]). Younger children might not benefit from the definition that was developed via an engineering perceptive. Long

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https://doi.org/10.1016/j.caeo.2024.100171
Received 30 January 2024; Received in revised form 12 March 2024; Accepted 12 March 2024
Available online 13 March 2024

and Margerko [31] stated that their definition needs to be reviewed in the future as research on AI education is still in its early stages. The technologies are emerging and disruptive, such as ChatGPT and Sora. These generative AI tools keep humans learning [9]. Therefore, this study argues that (i) the concepts of self-reflective mindsets should be included in the definition of AI literacy (i.e., AI competency), and practitioner perspectives should be taken into account for designing and developing K–12 AI education. Moreover, the two basic curriculum design approaches—process and praxis—describe how to nurture student literacy [20]. Accordingly, the primary goal of this study is to propose a framework for K–12 teachers to promote AI literacy and competency. This comprehensive framework explains core knowledge (the content) and pedagogy (the process of learning) that help students improve their AI literacy and competency (learning outcomes). In order to accomplish this goal, we defined AI literacy and competency and co-designed the framework with teachers. Since the learning needs of adults who have not received AI education are comparable to those of K–12 students, the framework can be applied to both non-AI professionals and K–12 students, i.e., AI for All and AI for K–12. The findings of this study will contribute to AI education by enhancing our knowledge of AI literacy and competency for K–12 students. Researchers and practitioners would use the definition and theoretical framework suggested by the findings to design research and learning activities related to AI literacy and competency.

Literature review

This study's conceptual framework is comprised of our definition of AI literacy and competency, as well as two approaches to curriculum design: praxis and process. The definition offers suggestions for the content and learning outcomes that should be incorporated in K–12 AI education; the two approaches recommend that effective pedagogies be used. The terms AI literacy and competency were initially defined in this section, along with the two approaches to curriculum design—process and praxis—discussed. Next comes the critical discussion of relevant papers on the AI education framework in order to identify research gaps.

AI literacy and competency

Initially, literacy refers to specific ways of thinking about and performing reading and writing in order to comprehend or express ideas or thoughts in writing within a particular context of use [26]. Digital literacy refers to the ability to appropriately use, assess, and apply digital tools, resources, and services to lifelong learning processes [17]. Clearly, digital competency encompasses more than just proficiency in operating devices and programs; it is also closely intertwined with the ability to communicate using technologies and digital skills. It should include a balanced view of technology for responsible and healthy use of digital technology. Knowledge and attitudes about privacy and security, legal and ethical considerations, and the role of digital technologies in society should be included [17]. Therefore, literacy is directly tied to skills and is more about knowing. Beyond that, competency is the ability to perform a task effectively and successfully [17]. Broadly speaking, literacy is more about knowing, and competency is more about applying the knowledge in an effective and beneficial way. It is related to confidence and attitude, and focuses on how well an AI user does.

Long and Magerko [31] define AI literacy as "a set of competencies that enables individuals to critically evaluate AI technologies, communicate and collaborate effectively with AI, and use AI as a tool online, at home, and in the workplace." They see this literacy as a set of 17 skills and as an operational definition. AI literacy is clearly related to other literacy such as digital, data, and computational literacy. The relationships could be mutually dependent but exclusive [31]. For example, AI literacy requires users to have a fundamental understanding of how to utilize computers in order to comprehend AI. Therefore, digital literacy, which refers to the ability to use computers to complete a task [33], is a prerequisite for AI literacy. Considering the close connection between data and machine learning (a branch of AI), data literacy refers to the capacity to understand, work with, evaluate, and argue with data as part of a more comprehensive process of inquiry into the world [45], which largely overlaps with AI literacy. Moreover, the other two literacies, such as computational and scientific, may not closely relate to AI literacy. Computational literacy involves exploring and communicating ideas through code [44]; therefore, it is not necessarily a prerequisite for AI literacy that does not require writing codes to understand how AI works. Similarly, AI literacy does not require scientific literacy, which refers to an appreciation of the nature, contributions, and basic limitations of science [22]. The definition of AI literacy is one of the first for non-AI professionals, which could give K–12 educators and researchers new insights about the content and skill assessments related to AI. Its development was based on a literature review done by two engineering professors. Most of the literature was published at engineering conferences around 2018–2019. These imply that this definition is driven by an engineering perspective and higher education. The definition may not be appropriate for K–12 education, which is supported by the major limitations of this definition raised by the authors [31]. They noted that AI education is still in its early stages and requires additional empirical studies, especially on teacher perspectives, to get a robust and accurate understanding of AI literacy for a non-technical audience [31]. Moreover, in the definition, the terms of literacy and competence were mixed use in the literature (e.g., [31]). However, as we discussed literacy and competency are related but different in educational research [17]. Therefore, it is necessary to redefine AI literacy and competency.

Process and praxis design approaches in AI education context

Adopting a specific curriculum design strategy has a significant impact on teaching and learning processes [38]. The four basic approaches to curriculum design are content, product, process, and praxis. The content approach views education as knowledge transmission, e.g., a syllabus with defined content [20,27]; the curriculum as product views teaching as grading and focuses on student performance [20,27], i.e., student learning outcomes. It often creates lists of competences, telling students what to learn and how to learn it, and emphasizes education with pre-defined outcomes. In AI education, these two approaches are informed by the definition of AI literacy and competency.

Instead of pre-defined content and outcomes, the process design approach stresses how teachers, students, and content adapt, and it also views teaching as development. Triadic interactions change learning goals [27]. The curriculum is a guide to teaching, not a set of items for instructors to cover and deliver [20]. Content is tailored to the needs and interests of the students; learning outcomes are determined by teachers and students but are not universally applicable. This approach values student-centered learning experiences. To make sense of what is being learned, the praxis design approach places a focus on how it may be used in the real world. Students, under the supervision of their teachers, collaborate on solutions to real-world problems and develop a strategy for learning the necessary material and obtaining the desired outcomes. Both the process of learning and its outcomes are constantly assessed. Therefore, problem-based learning is often adopted. AI education is still new to schools; its process and praxis approaches are not clear and require more empirical research.

Overall, the first two approaches create a set of documents for implementation, and the last two approaches advocate student-centered approaches, shifting the focus of the curriculum from teaching to learning [27]. Therefore, the definitions of AI literacy and competency and teacher perspectives on pedagogies would contribute to the development of an AI education framework for K–12.

Three major frameworks for AI education in K-12

A few key frameworks were suggested in the AI K–12 education research in the past 5 years. One of the first frameworks, known as "Five Big Ideas in AI," was suggested by Touretzky et al. [43]. In 2018, there was little external guidance from the literature on the content and scope of AI education for K–12 students [42]. The AI4K12 Steering Committee, which consists of David Touretzky, Christina Gardner-McCune, Fred Martin, and Deborah Seehorn, began their work by coming up with a list. This list serves as the organizing framework for the guidelines, which are developed based on the CSTA Computing Standards. Those standards are structured around the same five core ideas [11]. The five big ideas are:

- Perception: Computers use sensors to get information about their environment. Understanding what the senses are trying to tell us is what we call perception.
- Representation and Reasoning: Agents keep models of the world and utilize them to make decisions. Representations are the driving force behind reasoning, and reasoners use them.
- Learning: Computers can keep learning from data. By modifying the representations within a decision tree or neural network, a machine learning algorithm creates a reasoner.
- Natural Interaction: To communicate with people in a natural way, intelligent agents need access to a wide range of information. The information includes common sense, culture, human emotions, and knowledge of language.
- Societal Impact: There will be positive and negative effects of AI on society. The topics include the economic effects of automation, the fairness and transparency of automated decision-making systems, cultural considerations of AI algorithms, and the use of AI for social good.

These big ideas help educators and researchers set the goals of their designed AI education and identify the content needed. Accordingly, this framework used content and product approaches.

The second framework discussed was proposed by Chiu et al. [8] in their project AI4future. Education and engineering professors co-designed the framework with school teachers for middle school students. Fig. 1 shows an infographic presenting their proposed AI curriculum. In the core of the circle, the curriculum begins with an introduction to AI—big data, machine learning, and cloud computing. Another major focus is on ethical issues in the usage of AI applications as well as their societal impact. The middle pink circle depicts our coverage of various branches of AI: perceptual machine intelligence, e.g., "see" and "hear," human language technologies, e.g., "speak" and "read and write," integrated intelligences, e.g., machine reasoning, simulation for problem solving, and content creation and generation. The outside green circle depicts many AI-supported applications, many of which have significant societal ramifications, particularly for the future workforce. Similarly, the first framework also focuses on content and product approaches, helping AI educators create their learning and teaching content.

The last framework was drawn from teachers' perspectives in a school-university partnership project. Chiu [6] added pedagogy to the framework; see Fig. 3. The framework has three layers, shown in light blue, white, and dark blue. The core of the model in light blue shows the three core content components that should be included in AI education for middle school students. The content components are what AI is, how AI processes data, and what impact AI has. The middle layer in white suggests three pedagogies: student relevance, teacher-student communication, and flexibility. They are essential for the effective teaching of AI concepts and knowledge. Students should feel relevant when learning

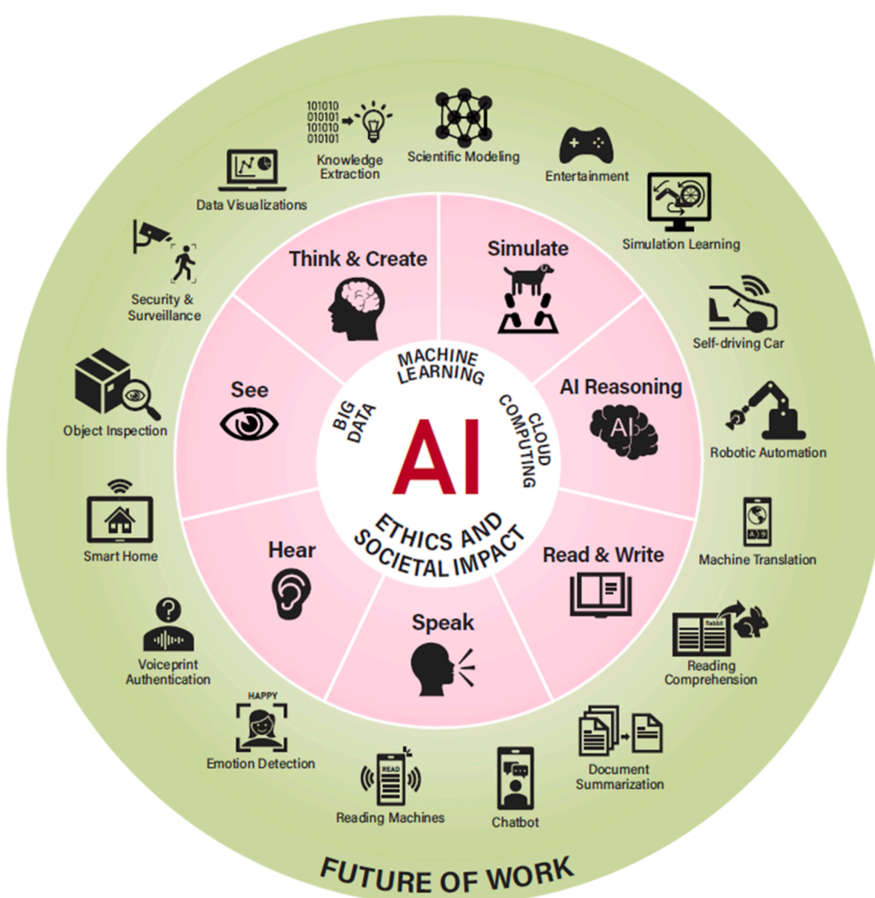

Fig. 1. Infographic for AI curriculum for K-12 [4].

AI, as it is around students' lives. Students should use design solutions for authentic problems. In teacher-student communication, teachers should utilize unfamiliar graphics and consistent language to convey AI terminologies and algorithms since they are too new and abstract for young children. This language is more likely to foster teacher-student communication. The last component is flexibility. Teachers can use module and level-up content that provides a learning pathway that directs and guides learning. The last layer in dark blue is the outcome of AI education. The model used the roles of students in an AI-based society. The outcomes include AI users, developers, researchers, and ethical designers. The approach makes the outcomes explicit to students. The process approach was added to the framework.

Research gaps

These three frameworks are significant as they set the content knowledge school students need to learn and suggest pedagogies for teachers. However, they were developed at an early stage [31]. AI learning for K–12 should provide education equality, reducing the digital divide [46]. Literacy (knowing) and competency (how well you do) are related, but different [17]. Literature on AI education interchanges the terms AI literacy and competency (e.g., [31]). We frequently settle with literacy instead of striving for competency since it requires less effort. AI education should focus on AI competency due to its disruptive nature. With the advent of generative AI tools such as ChatGPT and Sora, AI literacy and competency need to be revisited [3]. Self-reflective mindsets and life-long learning skills are important to AI education. Therefore, it is necessary to re-examine these three pieces of work for a more comprehensive framework from the perspective of experienced AI K–12 teachers, as teacher perspectives could refine the existing frameworks.

This study and method

Research goal

The two main goals of this paper are to (i) define AI literacy and competency for a non-technical audience, i.e., K–12 education, and (ii) suggest a more comprehensive framework for AI education. How teachers design AI teaching and learning activities directly impacts how and what students learn. Teachers' perspectives are crucial for making sense of any innovative education [14]. Accordingly, to achieve these two goals, we first presented the definitions of AI literacy and competency and co-designed the framework with experienced AI teachers. The definitions and the curriculum design approaches serve as a lens to reexamine the three major frameworks available in the literature.

The definitions of AI literacy and competency

Long and Magerko's [31] definition of AI literacy is exceedingly broad, possibly overly complicated, and unsuitable for the K–12 setting. The inclusion of self-reflective mindsets, which are critical for lifelong learning about emerging AI technology, in the definition was missing. AI technologies are expected to stay, evolve, and have an increasing impact on our lives, work, and studies. More students will learn with more advanced AI technologies; more employees will work with the technologies; and more people will live with the technologies. To succeed in the AI age, students must be able to continuously evaluate their own understanding of AI and stay up-to-date on its advancements. This is in line with the recommendations made by UNESCO about AI competency for educators and students: "The knowledge, skills, and attitudes students should acquire to understand and actively engage with AI in a safe and ethical manner in school and beyond.".

This study revised the definition of AI literacy to improve its suitability for K–12 education and defined AI competency by adding the aspects of student confidence and self-reflective mindsets to AI literacy, as follows:

- AI literacy is defined as "an individual's ability to clearly explain how AI technologies work and impact society, as well as to use them in an ethical and responsible manner and to effectively communicate and collaborate with them in any setting. It focuses on knowing (i.e. knowledge and skills).".
- AI competency is defined as "an individual's confidence and ability to clearly explain how AI technologies work and impact society, as well as to use them in an ethical and responsible manner and to effectively communicate and collaborate with them in any setting. They should have the confidence and ability to self-reflect on their AI understanding for further learning. It focuses on how well individuals use AI in beneficial ways.".

In this paper, we used technology, impact, ethics, collaboration, and self-reflection to label the confidences and abilities in the definition of AI competency to analyze the data collected, as follows:

- Technology: confidence and ability to clearly explain how AI technologies work
- Impact: confidence and ability to clearly explain how AI technologies impact society
- Ethics: confidence and ability to use AI technologies in an ethical and responsible manner
- Collaboration: confidence and ability to effectively communicate and collaborate with AI technologies in any setting
- Self-reflection: confidence and ability to self-reflect on their AI understanding for further learning. Individuals with stronger self-reflective mindsets are more likely to keep reviewing their AI knowledge and identify areas and needs for further learning.

Participants

There were a total of 30 teacher participants involved in this study, split evenly between 15 Hong Kong middle schools (2 teachers per school). The teachers' average age was 32, and there were 24 male and 6 female participants. All of them had at least three years of experience teaching AI. Their academic backgrounds included computer science, mathematics, the sciences, business, design, and technology. Each district had its own set of schools, which ranged in academic quality and social status. Another key participant was a researcher who is a professoriate staff member with an academic background in STEM education, particularly in mathematics and technology. The researcher has five years of experience promoting AI education in middle schools through the creation of learning materials, testing their effectiveness, and providing teacher training. By considering that AI education for K–12 has started in 2019, the participants were experienced.

Research design and procedure

This study used a co-design approach to propose the framework. The researcher was involved in the design processes and worked together with the teachers. An iterative co-design cycle involving data collection, analysis, and design was conducted. The researcher and teachers contributed to the development of the comprehensive framework through the definitions, design approaches, and three existing major frameworks discussed in the literature review.

The main researcher began running a 3-hour workshop on the four approaches, the three major frameworks, and the definitions of AI literacy and competency for all the teachers. There were four cycles of data collection. In each cycle, the researcher conducted a meeting with the teachers and collected their comments. The teachers were divided into five groups of six and drafted and revised the framework and learning experiences from the previous cycle (the first cycle used the three major frameworks discussed in the review). Each meeting lasted for 4 h with a

15-minute break. Thus, the researcher and the participants jointly proposed how AI education should be designed and delivered, and the teachers used the materials as evidence to support their ideas.

Analyses, reliability and validity

In each of the meetings (i.e., cycles), all the participants co-designed the framework and learning experience with the researcher. At the end of each cycle, the teacher participants voted on the changes to the framework and learning experiences using an immediate response digital platform. We used a 75 percent agreement (consensus) level, aligned with previous similar studies [41]. This level indicates the high reliability of the analysis.

We used six aspects to discuss the validity of this qualitative design and analysis [15,30]. Appropriateness: First, we used the three major existing AI education frameworks in the literature. Second, the main researcher has designed and delivered AI education for K–12 since 2018 and published more than 15 journal papers related to AI education. The participants were experienced AI education teachers. These show that the methods and materials used for gathering data were suitable for the context and research question. Triangulation: the teachers with different teaching subjects and schools were recruited to avoid individual (subject) biases and provide a more diverse view. Credibility: The credibility of qualitative research is determined by the researcher's competence in the research process. The authors had experience researching, designing, and teaching AI in different regions. Ethical procedures: The corresponding authors' university granted ethical permission for this work, addressing the moral implications of this date collection. All the participants understood their rights and gave consent. Transferability: the participants' major teaching subjects were diverse, which provides a wide possible range of data. Respondent validation: this study was supported by the three major AI education frameworks; thereby, it is credible and valid.

Results and discussions

The confidences and abilities and four curriculum design approaches were employed as a conceptual framework in this study to analyze the data obtained in each cycle. The first two meetings have identified the five key components of the proposed comprehensive framework; see Fig. 3. They are technology, impact, ethics, collaboration, and self-reflection. Each of the findings is explained in detail below.

The five components in the comprehensive framework

Technology

The first component concerns the core knowledge of AI, which is comparable to the two frameworks proposed by Five Big Ideas in AI and AI4future [4,43]. Content is critical for the design of universal education, i.e., K–12. K-12 education, unlike higher education, requires boundaries. Different schools in the same region must work on the same learning objectives. According to the teachers, core knowledge includes three topics: basic components, perception, and applications.

- In the basic components, the definition, history, and development of AI should be taught in schools [49]. The following definition of AI was agreed upon by all the participants: "AI refers to a machine's ability to do tasks equivalent to human learning and decision-making.". This definition is consistent with the findings of Chiu et al. [8] and Touretzky et al. [42]. The students must understand essential concepts such as big data, machine learning, and cloud computing. They must understand the five primary and inherent characteristics of big data, which are velocity, volume, value, variety, and veracity [19]. To properly understand how AI machines use data to enhance their skills, the topic of machine learning should encompass training models and learning algorithms [4,10]. Cloud computing is required for huge data processing in order to better train models and/or algorithms. Furthermore, the history and development of AI are critical topics in K–12. All the participants agreed that the students should understand AI history as well as contemporary advancements such as the "fourth industrial revolution" and generative AI, e.g., ChatGPT and Sora [12,49]. The students must comprehend how AI machines differ from non-AI machines. Non-AI machines, for example, have been designed to answer our problems by applying rules or algorithms, whereas AI machines use data to develop and regenerate the rules or models. They should understand that AI is changing the fundamental concept of how machines work and that "data are the new code" [49]. The students who have mastered the essential knowledge, in particular, should be able to recognize if the technologies they are employing are AI and comprehend the ramifications of this. They should also be required to describe what types of data AI collects, how AI analyzes data, and how AI learns from data.
- Perception is the second topic in core knowledge, which is consistent with the research of Chiu et al. [8] and Touretzky et al. [42]. The teachers indicated that the concept of perception in Touretzky et al. study [42] is too abstract. The students did not understand what this word meant. They chose human sensor concepts as perception subtopics. Human sensors—see, read, and write; speak and hear; think and create; reason and simulate—are terms that reflect the definition of AI. Because these terminologies are not overly technical, both students and teachers will understand what they need to learn or teach. The students should understand how each sensor collects and processes data.
- The third topic is AI applications. The teachers highlighted that the topic's breadth is more significant than its depth. The students should have a thorough understanding of AI applications, which should include most industries or aspects of daily life such as healthcare, entertainment, transport, logistics, etc. They should employ perception to describe how each application functions, as well as machine learning to construct and develop their own AI applications.

Impact

The second key component suggests three topics that foster student confidence and ability to clearly explain AI technologies impact on society: future of work, social good, and risks.

- On the topic of the future of work, young children place a high value on their future studies and employment. They need to understand that more future vocations demand AI literacy and that they are increasingly likely to learn with AI in their lives and work with AI in their jobs.
- The second subtopic is AI for social good. AI can have both positive and harmful effects on society. According to the teachers, the students should learn how AI solves complicated issues by addressing critical social, environmental, and public health concerns [23]. Other than the benefits AI brings to society, students should also learn the risks.
- The last topic is risk. All the participants agreed that the students should be aware of the potential risks associated with AI. They should investigate how emerging technologies cause trouble and harm in various contexts. These are aligned with the two frameworks [4,43] and other related studies [47,50].

Ethics

The third component is ethics, and there are concerns about AI ethics and human bias. The teachers discussed which concepts should be included in K–12 education. Existing principles or policies published for the public are very complicated. Some of them were used for legal and business purposes. They expressed that "the AI policies include 20 areas for ethical use." They are too complicated for young children or non-technical audiences. The teachers finally used IBM AI ethical principles as a starting point and reached a consensus on what to include in this topic. They chose five of them because they are more relevant to school students: fairness and biases; trust and transparency; accountability; social benefit; and privacy and security [18].

Collaboration

The fourth component is to foster student confidence and ability to communicate and collaborate with AI technologies in any setting. The teacher participants pointed out that these confidence and ability were associated with the three themes discussed earlier: technology, impact, and ethics. They suggested that "the students need to learn how to prompt effectively when using ChatGPT," "the students should examine the reliability of the prediction of an AI prediction system," "the students should be aware of their privacy rights when using AI systems," and "the students should be aware that AI systems may collect their data, such as locations and voices." This is likely to be fostered through case studies, project-based learning, and hands-on activities. Overall, this is aligned with some studies about prompt engineering, which is the technique of structuring text so that a generative AI model can comprehend and understand it. The promoter is a natural language text that enables more appropriate responses from the model [32,35].

Self-reflection

The last key component concerns student self-reflective mindsets that are strongly associated with confidence. A confident student is more inclined to consistently self-reflect on their AI knowledge compared to a less confident learner. Since AI is an emerging and disruptive technology, it is critical that the students constantly evaluate their knowledge of AI in order to stay up-to-date. This is cognitive but affected by its affective or emotional aspects, since cognitive engagement is associated with emotional engagement [4]. For example, students who are more enthusiastic about AI or technology are more likely to read articles and watch videos about the latest developments in AI-related technology [2,50]. This is very important for lifelong learning skills in an AI-based society.

The last two meetings in the study focused on discussing the process and praxis-based design approaches. The teachers reached a consensus that five essential learning experiences should be taken into account when designing AI teaching and learning activities.

Five essential learning experiences

Five learning experiences for AI education were identified in the meetings. All the teachers agreed that experience is essential for AI learning. The following discusses how learning experiences promote inclusive and diverse AI education.

- Community engagement: According to Cooper [13] and Mooney & Edwards [36], integrating student learning with the community is a purposeful pedagogical strategy used by instructors to make a connection between what is taught in the classroom and the students' local communities. As a result, students can apply their ideas based on personal observation and social interaction to design and find solutions to real-world problems in a community. They are more inclined to invest more in learning since the challenges are more relevant and encourage student participation. This community involvement will increase students' interest and enthusiasm [1,7,28], resulting in more inclusive and diverse AI education [46]. This community involvement will promote AI for social good while also cultivating students' positive attitudes toward AI. Furthermore, the teachers stated that the design thinking approach—empathize, define, ideate, prototype, and test—should be used to solve community problems. To have a greater impact, community participation may learn a lot from design thinking [4].
- Global and local case studies: One of the effective teaching methods proposed by the teachers is using media articles to educate about AI ethics and impact. School students can read various web articles, yet there are many biased options or fake news [16]. They are less mature and less capable of judging the reliability of the articles. Unlike ten years ago, more newspaper stories are being published as a result of AI advancement. They have recently become more accessible to both teachers and students. This method creates non-textbook learning, making it more authentic and relevant. Students can more actively reflect on ethical issues raised in newspaper stories [40]. Furthermore, this teaching style can be utilized to teach ethical principles while emphasizing the importance of data sources. This can be used by teachers to illustrate concepts such as fairness and bias, trust and transparency, and accountability.
- Hands-on activities: Students are surrounded by AI, but not so much in their classrooms. Hands-on activities could help students learn perception better because they put them more in the driver's seat through physical activity and active learning [48]. Physically active learning can support students' confidence and ability to model the world and generate creative ideas [48]. These connections may allow multipart tool design and use. Students can solve problems they cannot solve orally or visually by modeling physical systems with their hands [46]. Asking students to use their hands to model physical phenomena using AI will develop their conceptual understanding of AI perception. The teachers also suggested some practical ideas: students could investigate how AI can collect, understand, and identify images, i.e., learn how computers see images. Students can understand what they read and write since AI understands languages and text, and they can develop text analyzers to detect text moods. Furthermore, most students believe AI and robotics are the same technology. Students should learn how AI differs from robotics by doing a hands-on project in which they build a robot with reasoning and perception. According to the teachers, ethical principles, which were often taught using case-study approaches, can be taught through hands-on activities. Students could design one or more biased AI apps and explain how the dataset selection resulted in the biased results. As a result, hands-on activities can better cater to students with individual and learning differences and promote inclusive and diverse AI education [46].
- Exhibitions and presentations: This strategy is prevalent in the dissemination of student work, particularly in project-based learning. It allows students to consolidate their learning by communicating their processes, thinking about their products, and reflecting on their answers [21]. Teachers indicated in this framework that students should display their learning process and project work. The teacher highlighted in AI education that students should use core knowledge as criteria to present their work in the exhibition. For example, how did they acquire or create the data for building the perception? Are the data ethical? Is their use moral? What is the social impact of their work? What industry will acquire their products? Accordingly, presenting their project work encourages students to tap into their individual differences.
- Cultural learning: Human values and culture should be considered when learning AI. Data may be biased due to how it is obtained or chosen for usage. Human values and culture play a significant role in this. The answer to the questionAI bias or not"" may not be determined by AI knowledge but by human values and culture. These two elements must be considered by students while learning AI. For example, when developing AI projects to help the elderly, students are obliged to respect their culture and values (e.g., food and diets) but not change theirs. When discussing ethical issues related to driverless cars, students must be aware of local laws and religious beliefs (hurting cows in India may result in serious crimes).

Overall, the teachers' recommendations for five essential learning experiences would enhance inclusive and diverse AI education through social good (community participation), students' relevancy (newspaper articles), active learning (hands-on activities), collaboration, and communication (presentation) (Fig. 2).

Future research directions and recommendations

Compared to the existing major frameworks for AI K–12 education, this framework has two newly added aspects—confidence and self-reflective mindsets—and two newly added abilities: (i) collaboration: ability to effectively communicate and collaborate with AI technologies in any setting; (ii) self-reflection: ability to self-reflect their AI understanding for further learning. This paper focuses on discussing five future research directions to address these confidences and abilities.

- Prompt engineering: In this new technique, you may rephrase a query, select a style, provide more contextual information, or assign a role to AI when interacting with AI [32,35]. The current studies on this technique are restricted to ChatGPT. This is also related to our questioning skills. Most of the young children's questioning skills are developed in K–12 education. More studies should be conducted to understand how K–12 students interact with AI, i.e., prompt engineering or questioning skills for AI.
- Data science education: how to communicate with AI is associated with who to use and interpret data. Data literacy is strongly associated with AI literacy [31]. Data science education and data literacy may need to be included in K–12 education. Currently, this literacy is embedded in mathematics or AI subjects. More studies should be conducted to investigate how data literacy relates to AI literacy development.
- Algorithmic Literacy: To fully communicate with AI, algorithmic literacy may be needed. This literacy includes awareness and knowledge of algorithms, trust and confidence in algorithms, algorithm appreciation, and algorithm avoidance [25] This framework did not discuss this literacy. Future studies should be conducted to define algorithmic literacy and how it affects AI literacy.
- Self-reflective mindsets: this mindset is understudied in AI education. AI is different from other typical subjects, such as mathematics and sciences in K–12, and is emerging. Social cognitive theory is related to emotional engagement, and self-regulated learning concerns self-reflection. Future studies are recommended to use social cognitive theory and self-regulated learning to identify effective pedagogies to nurture students' self-reflective mindsets.
- Empirical research: AI education is still new; more empirical studies should be conducted to refine the definition of AI literacy and competency and the AI education framework.

Conclusion and limitations

Designing an effective AI education in K–12 appears to be quite difficult. A few frameworks—"Five Big Ideas in AI," AI4future, and a holistic approach—were presented in the literature to help teachers create their curriculum. They do, however, concentrate on recognizing AI content, tools, technical abilities, and thinking. They may not properly provide them with a fundamental understanding and get them ready for a future with AI. To address this issue, this study defined AI competency by adding the aspects of confidence and self-reflective mindsets to AI literacy and proposed a comprehensive framework for AI education in K–12. We believe that the framework promotes inclusive and diverse education, ensuring success for each student [39]. Teachers can design AI education to address students' needs [37].

We acknowledge two limitations in this study. First, the framework has not been put through its paces in the field, so more research is needed to investigate its usefulness. One way to do this would be to have a variety of schools (including those serving students with special needs) use the framework as a guide for developing and executing AI education initiatives. Second, this study did not address how teacher capacity affects learning design and development, which is a major limitation given that most teachers do not study AI topics in their education and undergo formal AI training. Learning how to design and implement AI teacher professional programs and the impact they have on learning design is an important area for future research.

CRediT authorship contribution statement

Thomas K.F. Chiu: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Zubair Ahmad:** Writing – review & editing. **Murod Ismailov:** Writing – review & editing. **Ismaila Temitayo Sanusi:** Writing – review & editing.

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.

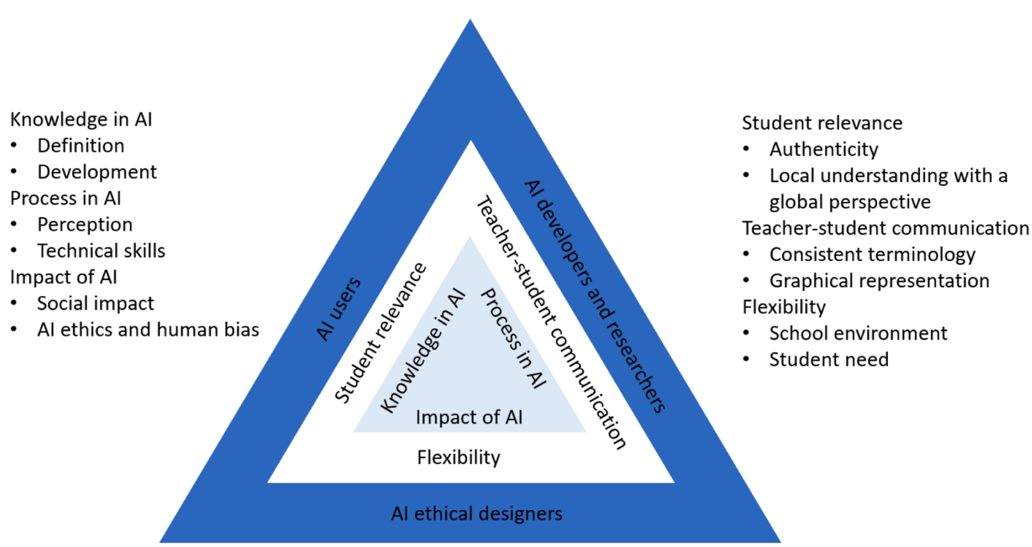

Fig. 2. A framework for designing a holistic approach for K-12 AI education (adopted from [5]).

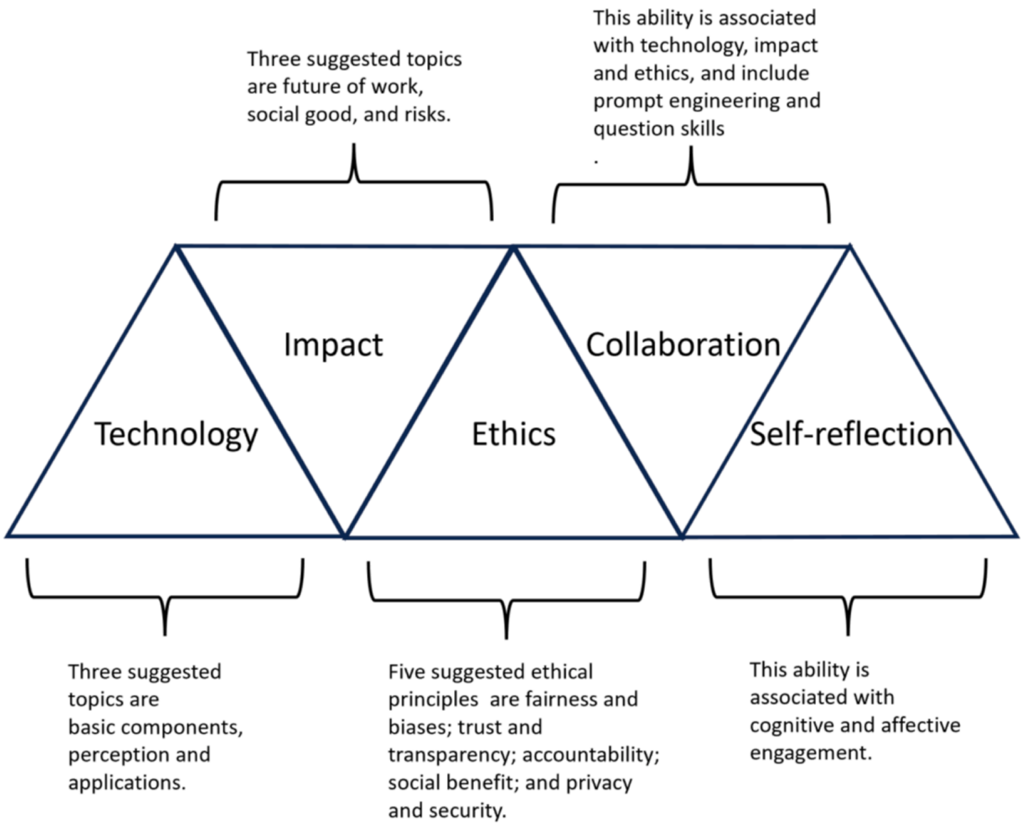

Fig. 3. The five key components in the comprehensive framework.

Data availability

The datasets used for the current study are available from the corresponding author on reasonable request.

Funding

This is supported by General Research Fund (project code: 14610522), Research Grant Council, Hong Kong, SAR.

Acknowledgements

The authors thank you for the school teachers for participate this study

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