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Artificial Intelligence (AI) Literacy in Early Childhood Education: The Challenges and Opportunities

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A B S T R A C T

Nowadays, Artificial Intelligence (AI) literacy has become an emerging topic in digital literacy education research. However, it is still under-explored in early childhood education (ECE) since the AI curriculum for young children has just been designed in recent years. A scoping review was conducted to examine the thematic and content analysis of 16 empirical papers from 2016 to 2022. This scoping reviews evaluate, synthesize, and display 16 studies on AI literacy in early childhood education, including curriculum design, AI tools, pedagogical approaches, research designs, assessment methods, and findings. The discussion of the AI literacy implementation in ECE contributes to providing references for educators and researchers to design interventions to engage young children in AI learning. Further, we identified a set of challenges and opportunities of AI literacy. Several challenges included (1) lack of teachers' AI knowledge, skills, and confidence; (2) lack of curriculum design; and (3) lack of teaching guidelines. Although educators meet challenges at the beginning stage of developing AI instructional design for young children, AI learning could bring learning opportunities and foster young children's AI literacy in terms of AI concepts, practices and perspectives. We foresee that there will be a growing number of age-appropriate curriculum and tools for the ECE level. At the end, we also make some recommendations for future researchers and educators to improve AI literacy research and learning design in early childhood education.

Keywords: AI, literacy AI, Education Learning and teaching AI, Early childhood, Education Challenges and opportunities

Introduction

In 1956, artificial intelligence (AI) was defined as "the science and engineering of creating intelligent machines" (McCarthy, 2007). AI re- fers to the science and engineering of making intelligent machines that solve different kinds of problems via natural language processing, neural network and machine learning (Mondal, 2020). It is transforming every walks of life such as medicine, psychology, science and public policy (Xu et al., 2021). In educational fields, AI can help teachers to predict stu- dents' learning status and performance, recommend learning resources, and automate assessments to improve students' learning experience via intelligent agent systems, chatbots, and recommendation systems (Liang et al., 2021; Mousavinasab et al., 2021; Su et al., 2022; Zawacki-Richter et al., 2019; Zheng et al., 2021).

Young children are growing up with these AI applications, yet little attention is paid to the important of developing AI literacy and its related impacts among them. They use AI products such as chatbots and recommendation tools to facilitate their everyday lives and study. Children may not know how to use AI, and the basic working principles behind these tools and they may have misconceptions about the tech- nologies. Moreover, AI may threaten their safety when it

gives wrong and misleading information or suggestions (Gaube et al., 2021). Therefore, it is necessary to develop young children's AI literacy, especially its limitations, ethical concerns and basic understanding about the technology (Kong et al., 2021, 2022; Long & Magerko, 2020; Ng et al., 2021a, b).

Recent researchers proposed the term "AIiteracy" to put forth the importance of ding AI to the 21st century digital literacy skills for everyone, including young children (Ng et al., 2021a, b). Learning programs and activities (e.g., Jibo robot, Anki's Cozmo robot) emerged to focus on how to foster young children's AI understandings and atti- tudes (Druga et al., 2021). AI literacy has become an essential literacy skill that is required for everyone (including young children) to know and use AI as a tool to live, learn, and work in our digital world, and it should be taught in grades K-12 (Burgsteiner et al., 2016; Kandlhofer et al., 2016; Ng et al., 2021a, b; Steinbaueret al., 2021). On top of merely becoming end users of AI tools, AI literacy is a set of competencies that enables people to critically evaluate, communicate and collaborate effectively with AI (Druga et al., 2021). Scholars started to suggest different models to conceptualize the term AI literacy (Ng et al., 2021b; Touretzky et al., 2019). For example, Touretzky et al. (2019) proposed the use of five big ideas about AI: (1) Computers perceive the world using sensors, (2) Agents maintain models/representations of the world and use them for reasoning, (3) Making agents interact comfort- ably with humans is a substantial challenge for AI developers, (4) Computers can learn from data, and (5) AI applications can impact society in both positive and negative ways. Ng et al. (2021b) further designed a framework of AI concepts, practices and perspectives that interplay between CT and AI that students can learn machine learning knowledge, model training skills, collaboration and communication skills.

In the past, AI learning began in university computer science education, which required advanced programming skills that were inappropriate for children decades ago (Ng et al., 2021a). Recently, the development of more age-appropriate software has enabled young learners to extend their possibilities to learn and explore AI. The ma- jority of current AI literacy research focuses on secondary or higher education (Ng & Chu, 2021; Kong et al., 2021; Eguchi et al., 2021; Su et al., 2022). For example, non-computer science undergraduates and secondary students started to develop AI concepts and ethical awareness to empower them to become educated digital citizens (Kong et al., 2023; Ng & Chu, 2021). However, these courses do not focus on complex computer science concepts or mathematical formulas. Instead, the courses enabled students to develop basic understanding of AI concepts, literacy and confidence of using AI (Kong et al., 2022; Ng et al., 2022a). In early childhood education, AI-powered toys are made to provide students with a playful experience to learn and interact with the robots and kits, and teach coding skills. With more well-designed AI toys and services, young children could develop their AI literacy even at a kindergarten level. They experience AI-driven robotic toys and services (e.g., PopBots, Quickdraw) (Williams, 2018; Williams et al., 2019a,b) to explore AI related concepts (e.g., knowledge-based systems, supervised machine learning, generative AI). Although young children may not know and understand the knowledge behind, they can explore and appreciate these AI technologies, and foster their digital literacy in their everyday lives.

Some may challenge whether kindergarteners and junior primary students are too young to explore and learn AI knowledge (Su et al., 2022). However, previous studies have brought AI tools into early childhood education (ECE) classrooms and shown their promising ef- fects (e.g., Lin et al., 2020; Tseng et al., 2021; Williams et al., 2019). In fact, early AI literacy is important for young children to improve many aspects of child development, such as theory of mind skills, creative inquiry, emotional inquiry and collaborative inquiry (Kewalramani et al., 2021; Su & Yang, 2022). For example, Kewalramani et al. (2021) investigated the use of interactive AI to cultivate inquiry literacy in early childhood education settings. However, only a few research efforts had been done on how AI literacy for children aged 3–8 years in ECE level relative to other age groups (e.g, primary 3-6, secondary education) to support the potential of AI literacy education for ECE settings. So far, only one review study has tried to discuss using AI in ECE settings (Su & Yang, 2022). However, this review did not discuss the mapping of existing learning outcomes, assessment methods, as well as opportu- nities and challenges of AI literacy in ECE settings (Su & Yang, 2022).

Literature review

This scoping review provides a starting point for early childhood researchers and educators in terms of promoting research and practice related to AI literacy education. This section first reviews the current status of both using AI, and the importance of AI literacy in early childhood education.

Artificial intelligence

Recent years, a growing number of researchers have started to discuss how to teach and learn AI from K-12 to higher education. Although the AI-related ECE studies is still in its infancy, researchers have started to discover how AI applications is used to facilitate kindergarten teachers' administration and students' learning through intelligent tutoring

systems for special education, chatbots for language education, and robotic kits in Computer Science education (e.g., Chen et al., 2020; Su & Yang, 2022). These AI applications facilitate students in computer-supported collaborative learning, teaching automation and evaluation, detecting learners' emotions, and recommend useful mate- rials for students. Several facts were uncovered in Chen et al. (2020)'s paper about how to use AI technologies in the educational industry. Although a growing interest in and the impact of research on AI in ed- ucation are identified, further effort is necessary to inform how to integrate advanced AI techniques and deep learning technologies into educational settings. Also, there exists a scarce number of studies that drive the use of AI technologies into educational theories. This is consistent with another review conducted by Hwang et al. (2021), which categorised AI applications into four general roles, including intelligent tutor, tutee, learning tool/partner, and policy-making advisor.

In early childhood education, educators tried to explore the use of AIED technologies to facilitate their work and enhance students' learning. For example, Jin (2019) explored the potential of AI applica- tions in four examples: AI evaluation of children, AI teaching system, AI educational robot, and AI virtual reality teaching, and further proposed the use of AI in family education and enhanced parental knowledge. Lin et al. (2020) interacted with a dialogue system that enabled students to interact with the chatbots to enhance language learning and visualiza- tion training. Nan (2020) used an AI teaching system to motivate stu- dents' learning in a collaborative AI-assisted environment and stimulate children's interest in learning. These studies provide ample evidence to show the effectiveness of using AIED technologies at kindergarten level. Furthermore, it is essential to equip children with digital skills and mindsets to get them ready for future studies and facilitate their everyday living.

AI literacy

The term "AI literacy" was first coined by Burgsteiner et al. (2016) and Kandlhofer et al. (2016) who describes the competencies to un- derstand the basic knowledge and concepts about AI. On top of this, Long and Magerko (2020) defined it as a set of competencies that en- ables individuals to critically evaluate, communicate and collaborate effectively with AI; and use AI as a tool online, at home, and in the workplace. Further, Ng et al. (2021a, b) added AI to every student's twenty-first century digital literacy in work settings and everyday life, and proposed it as a fundamental skill for everyone, not just for com- puter scientists. He widely incorporated the model of Bloom Taxonomy, Technological Pedagogical Content Knowledge (TPACK), and AI con- cepts, practices, and perspectives into the instructional design of AI literacy education.

AI literacy in ECE

AI education has posed challenges and opportunities to early child- hood education (or kindergarten education), including why young learners should learn AI in their early years, the subset of key AI con- cepts that can be understood by children, and how children were engaged in a meaningful experience for them to acquire these concepts (Yang, 2022). He pointed out several reasons why young children need to learn AI: (1) knowing and understanding the basic competencies of AI and using AI applications is important for all citizens to become AI lit- erates in today's digital world (Ng et al., 2021a, b); (2) children need to be empowered to understand, use, and evaluate AI with purposeful guidance (Williams et al., 2019a); (3) children should have the capa- bility to understand the basic functions of AI, especially when more well-designed AI toys appear in their everyday experience (Kewalra- mani et al., 2021). Su and Yang (2022) further identified AI in ECE studies that have introduced AI concepts to kindergarteners using AI learning tools such as PopBots and Zhorai.

Few prior researchers proposed what young children should learn and how to scaffold them to understand how AI senses, perceives, in- teracts, behaves and creates. Yang (2022) designed an "AI for Kids" Curriculum for young children to help them "highlight the role of AI-powered technologies in human's daily life and to enable children to learn about AI using an embodied, project-based approach" through AI toys, AI for Ocean at code.org and Quickdraw. Williams et al. (2019a) designed an AI-interfaced robot for young children to help them appreciate the abilities and limitations of AI agents and toys. Students can develop their relationships with these toys to learn knowledge-based systems, supervised machine learning, and generative AI through *Rock-Paper-Scissors game, Food Classification, Music Remix activities*. Through these age-appropriate activities and tools, students could recognise the basic knowledge about AI and understand the ethical is- sues and limitations behind these tools. These studies provide the rationale and practices on how teachers can scaffold young children's understanding using these age-appropriate activities and tools (Ng et al., 2022c; Su & Yang, 2022; Yang, 2022).

Methods

To our knowledge, there has been no existing review conducted to examine AI literacy in early childhood education. As such, the over- arching goal of this review is to evaluate existing literature and identify challenges and opportunities of AI literacy in early childhood education. The review approach is based on Arksey and O'Malley's (2005) five-stage framework, which employs a rigorous transparency process to improve the reliability of the research findings. The five steps of Arksey and O'Malley's framework were used in this review of the literature on early AI literacy: (1) identifying initial research

questions, (2) identifying the relevant

PRISMA Diagram of Included Articles in the Scoping Review

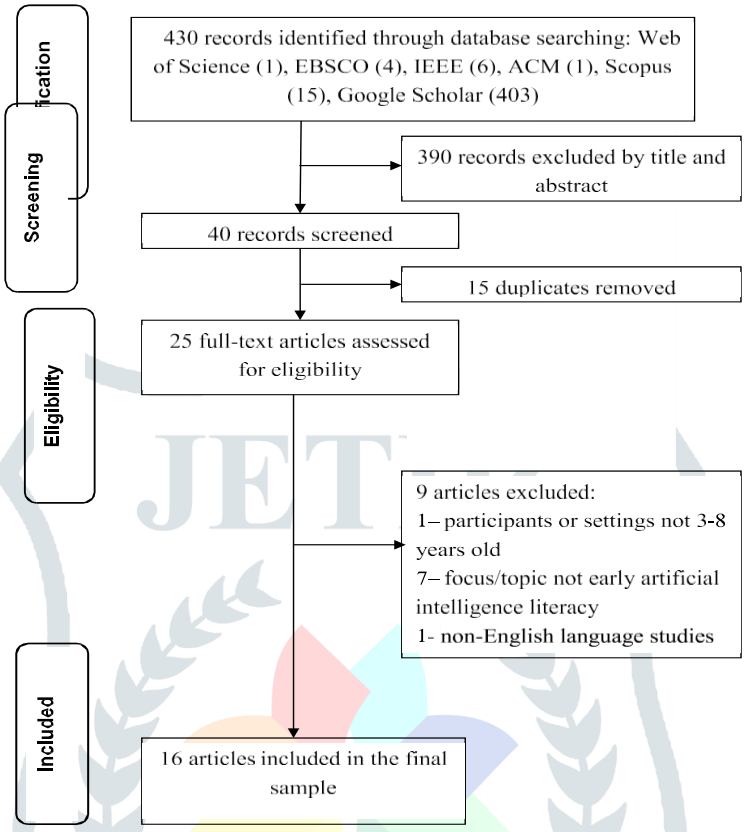

Fig. 1. PRISMA diagram of included articles in the scoping review.

Identify the relevant studies

According to Arksey and O'Malley (2005), a broad definition of keywords for search terms should be used to obtain a 'broad coverage' of existing literature. Keywords and search terms were investigated in existing literature on early AI literacy from international perspectives. The electronic databases used for the literature search included Web of Science, EBSCO, IEEE, ACM, Scopus, and Google Scholar. The search was limited to studies written in English. All articles are accessed in May 2022. To facilitate database search, this study investigated peer-reviewed academic articles published until May 2022. We formulated a search string based on our understanding of and knowledge in the AI in early childhood education domain and also, by referring to related AI education search strings used in other studies such as Su, Yim, et al. (2022). The search string used for the review was: "AI literacy" OR "Artificial intelligence literacy" AND "early childhood" OR "young child*" OR "preschool*" OR "kindergarten*" OR "pre-k*" OR "childcare" OR "child care" OR "day care" OR "children".

Study selection

Using the author key search descriptors, 430 articles were identified. As shown in Fig. 1, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement was followed during the article selection process (Moher et al., 2009). This paper focuses on artificial intelligence literacy in early childhood education. 430 articles were found in the Web of Science, EBSCO, IEEE, ACM, Scopus, and Google Scholar [1 from Web of Science, 4 from EBSCO, 6 from IEEE, 1 from ACM, 15 from Scopus and 403 from Google Scholar (n = 430)]. The following articles were excluded from the study: the first exclusion criteria (E1) was articles that were not related to research title and abstract (n = 390). We excluded 390 results due to their irrelevance to the research topic: (a) whose focus was other topics, such as AI technologies, medical, etc (n = 209); (b) whose focus was primary 3-6, secondary, and colleges/university students (n =

181). The second exclusion criteria (E2) was duplicate studies (*n* = 15). The third exclu- sion criteria (E3) was papers in which the participants or settings were not 3–8 years old (*n* = 1). Furthermore, the fourth exclusion criteria (E4) was papers whose focus/topic was not early artificial intelligence liter- acy (*n* = 7). The last exclusion criteria (E5) was papers that were non- English language studies (*n* = 1).

Data charting and collation

The charting of selected articles is the last step in Arksey and O'Malley's (2005) review framework. The 16 articles that focused on AI literacy in ECE were thoroughly reviewed (2016, 1 article; 2018, article; 2019, 3 articles; 2020, 2 articles; 2021, 4 articles, and 2022, 5 articles).

Research design. The research designs adopted in AI literacy in early childhood education studies are shown in Table 1. Most studies used a quantitative design (6 articles) and qualitative design (6 articles), followed by a mixed-research design (2 articles). The six quantitative studies applied various data collection procedures, such as knowledge and theory of mind skills assessments, questionnaires, and surveys. For example, Lin et al. (2020) used assessments (i.e., knowledge test) to examine children's machine learning knowledge through Zhorai. Results show that children can understand machine learning concepts more easily using the tool. The four qualitative studies used various

Studies	Research Methods	Research Designs
Lin et al. (2020)	Quantitative	Assessments (Pre- and post- assessments)
Kandlhofer et al. (2016	Qualitative	Video data, pictures and observations (field notes)
Williams (2018)	Quantitative	Theory of mind assessment, rock paper scissors assessment performance, supervised learning assessment performance, generative assessment performance, pre- and post-tests of children's perception, attitudes assessment Knowledge assessments
Williams, Park, and Breazeal (2019)	Quantitative	Knowledge assessments
Dwivedi et al. (2021)	Mixed methods	Machine learning metric and training data
Druga and Ko (2021)	Mixed methods	Pre/post perception game responses and observations
Tseng et al. (2021)	Quantitative	Surveys
Kewalramani et al. (2021)	Qualitative	Interviews and observations
Druga et al. (2022)	Qualitative	Video recording: transcribed the videos and noted comments
Williams et al. (2019b)	Quantitative Assessments	Assessments
Vartianinen et al. (2022)	Qualitative	Video recording
Druga et al. (2022)	Qualitative	Interview
Tazume et al. (2020)	Qualitative	Observation

Collection methods through collecting videos, pictures, field notes, comments, interviews, and observations. For example, Kandlhofer et al. (2016) used observation and interview to assess children's AI development. Results show that they were very successful in introducing basic AI/computer science concepts to children in a playful way. The rest of the papers used mixed research methods to collect data through various procedures, such as machine learning metric, training data, pre/post perception game responses, and observations. Two articles (Su & Zhong, 2022; Yang, 2022), only introduced and described their AI curricula in ECE, without implementing them in practice, and thus no data was collected. More details are shown in Appendix 1.

Regions This review shows that all studies were conducted in regions (e.g., Karnataka , Andhra Pradesh, Telangana, TamilNadu, Kerala). As a result, we conclude that this type of article is strong enough to provide effective AI literacy research in ECE fields, representing AI educational articles from various countries.

Classification and taxonomy of AI literacy in ECE settings

According to Ng et al. (2021a, b), AI literacy instructional design can be developed in terms of pedagogy, content

knowledge, tools and assessment methods used. This review examined instructional design, tools, and assessment methods and added learning outcomes that we found in the past studies, as shown in Appendix 1, according to the three research questions. This study first lists the instructional designs that have been used in the past studies, including design-based research (DBR) approach and interaction with AI robots. Then, it summarised the tools used in the AI literacy courses. The second RQ aims to examine the assessment methods such as knowledge/skill-based assessment, questionnaire and observations. The third RQ aims to review how prior studies examine young children's knowledge, concepts, skills and attitudes towards AI literacy. With the coding framework, the selected articles were analyzed in terms of its definitions and technologies used The text segments were

Coding framework Table

Themes	Sub-themes	Explanation	Samples
RQ1: Learning design	learning content	A list of AI knowledge and skills that was suggested to be appropriate for kindergarteners (Kandlhofer et al., 2016).	Kandlhofer et al. (2016); Williams (2018); Lin et al. (2020)
	Tools	AI tools that enable students to visualize AI concepts and interact with physical artifacts through programmable bots with sensors and AI-driven functions.	Williams (2018); Williams et al. (2019a, b)
	Pedagogical design	Different pedagogies used in designing learning activities. The major three approaches are activity-based learning, experiential learning and project-based learning	Druga et al. (2019); Williams et al. (2019a)
RQ2: Assessment methods	Knowledge and skill assessments	To examine the knowledge and skill acquisition of students' AI literacy (Lin et al., 2020).	Williams (2018); Williams et al.(2019a,b)
	Questionnaires	To examine children's perception of robots (Williams, 2018	Williams (2018); Williams et al. (2019a,b); Druga et al. (2019)
RQ3: Learning outcomes	Observations	To document students' interaction in the AI learning experience (Druga & Ko, 2021).	Druga and Ko (2021)
	Knowledge and skills	The learning outcomes of children's AI knowledge and skills. Knowledge: increased AI concepts/knowledge; Skills: increase edinquiry skills (i.e., creative, emotional, and collaborative).	Lin et al. (2020); Williams (2018); Kewalramani et al. (2021)

Extracted and coded under a coding scheme (see Table 2) and re- searchers could discuss any disagreements resolved and reach a final decision. After validating the coding processes and categorization, the findings were then descriptively summarized according to its frequency and identified themes. This paper focuses on the instructional design, tools, assessment methods and learning outcomes which contributes researchers, educators and policy makers to designing and improving the existing AI education practices and curricula to best foster young children's AI literacy. Therefore, this review study adopts the frame- work of AI literacy in ECE studies in terms of learning design, assessment methods, and learning outcomes (Fig. 2).

The first and second authors are coded all included articles filled in a table separately. Information about learning design, assessment methods, and learning outcomes were filled in by researchers. Differ- ences between the first two researchers' responses were then compared and discussed, leading to the revision of tables.

The purpose of the study

This study contributes to a timely review of the current development of the AI literacy education and offers guidance to researchers who are seeking suitable activities to engage kindergarteners (e.g., Su & Yang, 2022; Yang, 2022). The review also provides a reference for policy- makers, who must make critical decisions regarding future development to set the educational standards. The examination of prior research in the field also helps researchers to determine which subjects are of continuing importance. There are few studies in the fields of AI literacy education in ECE settings. In these studies, researchers focus on topics such as pedagogies, content knowledge, and technologies to uncover what, why and how to teach AI literacy for young learners (Yang, 2022). But reviews of research on AI literacy in ECE are less common and this seems to be no review studies summarizing how educators develop young children literacy in terms of age-appropriate instructional design and tools, and what types of assessment methods have been used to examine their AI literacy in the early AI curriculum, as well as its learning outcomes throughout the interventions in ECE settings. To

fill these gaps in the literature, we present a scoping review of the literature on AI literacy in ECE. The present study systematically analyses and discusses existing works from the aspects of instructional design, tools, assessment methods and learning outcomes. Meanwhile, this study concentrates on the challenges and opportunities for AI to assist educators or researchers in locating relevant and important information in ECE.

Our review focused on key aspects of the challenges and opportu- nities of improving AI literacy in early childhood education. The following are three research questions to help guide our search.

Results

RQ1. How do researchers help young children develop AI literacy in terms of instructional design and tools?

This section summarises how researchers design their instruction to develop young children's AI literacy in terms of learning content, tools, length of intervention and pedagogical design.

Learning content. First, it is important to review the learning con- tents in the curriculum design in the studies, which offer a basis for educators to design their curriculum and programs for their students. Although kindergarteners may not understand the working principles behind the AI concepts, young children can attempt to understand these concepts through playful experience such as knowledge-based systems, supervised machine learning, and generative AI (Williams et al., 2019a). What does AI know, teaching AI robots to conduct tasks, experiencing machine learning, and its ethical concerns (Lin et al., 2020). Based on the suggested learning contents, future educators can know what knowledge content is suitable for young children to learn and experience as shown in Table 3.

AI tools. In our review, 14 out of 16 studies engage young children to use AI tools/platforms to learn AI, as shown in Table 4. Among the studies, three of them used PopBots to foster kindergarten children's basic AI understandings and concepts such as knowledge-based systems, supervised machine learning, and generative AI (Williams, 2018; Wil- liams et al., 2019a, b). Other AI tools/platforms reported in the studies include Jibo robot, Anki's Cozmo robot, Amazon's Alexa, Zhorai, Cog- nimates AI platform, Google's Teachable Machine, Cosmo, Blue Bot, Coji by Wowee, Qobo the snail, and vernie-Lego Boost Bot. Furthermore, one

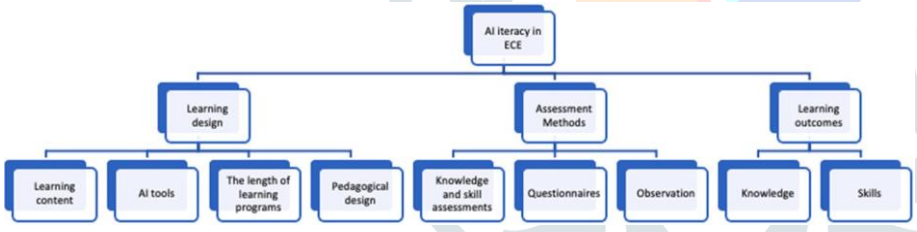

Fig. 2. AI Literacy in early childhood education.

Study found that a conversational platform (Zhorai) can help children to understand machine learning concepts (Lin et al., 2020). Teaching young children AI was not possible in the past. However, with these tools, kindergarten teachers start to explore ways to engage students to experience AI which aims to enhance their technological skills that can facilitate their learning and living. More characteristics of the AI tools, such as categories, information, details.

Length of learning programs. Overall, the learning journey is quite short for students to learn AI as shown in Table 3. Only two of the studies have a longer intervention over weeks (Druga & Ko, 2021; Druga et al., 2022). Six studies engage students in short learning programs within 1–4 h (e.g., Williams et al., 2019a, b; Lin et al., 2020). Future studies are necessary to consider longer interventions to foster students' AI literacy.

Pedagogy design. In terms of the pedagogy design used, studies have used various approaches. The two most commonly used pedagogies are activity-based learning (n = 4) and experiential learning (n = 3).

"The activity-based approach has constructivist aims, and exploits both collaborative interaction and access to information-rich resources" (Macdonald & Twining, 2002, p. 604). Firstly, researchers found that hands-on activities could help students explore AI concepts effectively (e.g., Druga et al., 2019; Williams, 2018, Williams et al., 2019a). Through hands-on experience, students can experience how AI works in robots and toys (i.e., knowledge-based systems, supervised machine learning, generative AI) in order to enhance children's AI literacy (Williams, 2018; Williams et al.,

2019a). Secondly, experiential learning encourages students to learn by doing through hands-on experiences and reflection that connect theories and knowledge learned in the classroom to real-world situations (Morris, 2020). In our review, Kewalramani et al. (2021) designed experiential AI learning activities through engaging 4-5-year-old children in playing with Vernie robots, thereby increasing children's three literacy skills (i.e., create inquiry literacy, emotional inquiry literacy, and collaborative inquiry literacy). Children playing with AI toys can explore their creative thinking and understanding of robots (creative inquiry literacy). Creative inquiry literacy means "throughout their play with AI toys, the children were exposed to many mediums through which they could explore and express their creative thinking and understand-ing of robots" (Kewalramani et al., 2021, p.659). The two pedagogies could enable students to learn and experience AI although it is not necessary for young learners to know and understand the working principles behind AI.

Lastly, only a few researchers (n = 2) in the AI field have designed projects to improve young children's higher-order thinking skills (e.g., communication, collaboration, and computational thinking skills) (Druga et al., 2019; Tseng et al., 2021). For example, Druga et al. (2019) designed play and talk to AI agents (i.e., Alexa home assistant, Jibo and Cozmo robots) activities and children were invited to draw AI agents in the future. It is understandable that young children may not be able to learn much AI concepts and knowledge, but it is important to facilitate young students to use AI to communicate and collaborate with other classmates. To sum up, educators can consider the three pedagogical approaches (i.e., activity-based learning, experiential learning, and hands-on experience) to encourage young children to experience how AI works, know how to use AI tools, communicate and collaborate with others using AI, which facilitate their learning and living in today's digital world. Activity-based learning is based on "the constructivist learning approach, supports children throughout the learning process with activities they do themselves" (Metin, 2020, p. 151). Experiential learning means "knowledge creation resulting from reflection on and during experience, and its acknowledgement of the importance of learning processes and not simply behavioural outcomes" (Kolb, 2014, p. 26). Hands-on learning refers to learning by doing (Niiranen, 2021). Hands-on activities are important in children's learning (Kim, 2020).

RQ2. What were the assessment methods to examine young children's AI literacy in the early AI curriculum?

Regarding the assessment methods used for evaluating young chil- dren's AI knowledge and skills, three data collection techniques, including knowledge and theory of mind assessments (4 articles), questionnaires and observation (3 articles), as shown in Table 5. It should be noted that although there were some overlaps between different assessment methods, this paper quotes the names used in the reviewed papers directly.

Different assessment methods were employed for examining young children's learning effects, such as knowledge and theory of mind skills assessment. Particular knowledge assessments were designed and developed for evaluating young children's AI knowledge (Table 6). For example, a number of studies used knowledge assessments to assess children's AI concepts/knowledge (Lin et al., 2020; Williams, 2018; Williams et al., 2019a, b) (see Table 4). For example, Williams et al. (2019a,b) and Williams (2018) used three activities (i.e., *Rock-- Paper-Scissors*, *Food Classification*, *Music Remix activities*) to evaluate children's different AI knowledge (i.e., knowledge-based systems, su- pervised ML, and generative AI). Results show that AI curriculum helped children improve three concepts, such as knowledge-based systems, supervised ML, and generative AI.

The questionnaires included AI perception questionnaire and perception of robots questionnaire (Table 7). The AI perception ques- tionnaires include several dimensions, including intelligence attribu- tion, truthfulness attribution, and perceived understanding (Druga et al., 2019). Druga et al. (2019) developed an AI perception questionnaire for assessing children's feelings about the agents (i.e., Jibo robot, Anki's Cozmo robot and Amazon's Alexa, home assistant). The researchers found that 68% of children thought the agents understood them the most.

Different observations were employed for examining children's learning effects, such as bservations of learning activities, young chil- dren's and educators' play experiences, and interaction with AI robotics (Table 8). For example, some researchers designed one activity about interacting with an AI robot (RoBoHoN) and used observation to observe children's interaction with RoBonHoN. Results show that children engaged in experiences that promoted the development of non-cognitive abilities" (Tazume et al., 2020, p. 323). "Interactions with AI robots are more similar to human communication than to communication with other media, and this may affect the development of non-cognitive

abilities" (Tazume et al., 2020, p. 328).

RQ3. What were the learning outcomes of AI literacy in ECE settings?

Most studies revealed that the AI curriculum was effective in terms of enhancing young children's knowledge and skills, which facilitate young children to use AI tools for learning and living purposes. This section summarised the learning outcomes in terms of knowledge gain and skill acquisition (see Table 9).

In terms of knowledge gain, AI curricula have significantly improved children's AI concepts, such as knowledge-based systems, supervised ML, and generative AI (Williams, 2018; Williams et al., 2019a,b) and knowledge about machine learning (Lin et al., 2020; Tseng et al., 2021). It was discovered that children can understand three AI concepts, such as rule-based systems, supervised machine learning, and generative AI after basic AI courses. After online workshops, children know the ma- chine learning concepts/knowledge (Tseng et al., 2021). Moreover, young children can improve their skills, such as theory of mind skills (Williams, 2018; Williams et al., 2019a,b) and creative inquiry, emotional inquiry and collaborative inquiry (Kewalramani et al., 2021). For example, Kewalramani et al. (2021) designed interactive learning activities among children to play with robots. Results show that children increased creative inquiry, emotional inquiry and collaborative inquiry after the AI activities. However, none of the research discusses how AI learning programs affect young children's affective learning outcomes such as attitudes, motivation, and confidence of using AI. Future research is necessary to examine how students gain their affective learning outcomes.

Discussion

This paper provides a review of AI literacy studies in early childhood education, focusing on the characteristics and features of AI literacy as well as the effectiveness of interventions. Although there were few empirical studies on AI literacy for ECE, the existing references did provide new insights into various aspects of AI literacy for young children. Our work contributes several new insights into AI literacies in early childhood education by addressing three research questions. Based on the examination of AI curriculum designs in the reviewed studies, several findings were identified. Firstly, most studies used age- appropriate learning tools or platforms to enhance young children's learning AI. Robotic kits, especially PopBots, is the most common tool to enhance children's basic AI concepts (n = 3) Lack of teachers' AI knowledge and skills. Teacher AI knowledge, in particular, was discovered to be one of the challenges encountered by educators who do not have technical background, but need to develop and implement early AI literacy curriculum in their schools. It is a challenge for most teachers. However, universities started to offer a wide range of AI activities for students such as the AI-for-kids curriculum in Hong Kong, and developed professional training for ECE teachers. They can make use of the resources to develop an age-appropriate cur- riculum and activities for their students (Laato et al., 2020). Future studies should explore what types of learning activities and tools are more suitable for early childhood education, and what kind of teacher training is necessary for kindergarteners. Low teachers' confidence. Since most ECE teachers do not have a

Appropriate for "small-scale educational research projects involving collaboration among educators, students, and researchers" (p. 56) to enable teachers to improve their instructional design to best foster stu- dents' AI literacy (Jetnikoff, 2015).

Fourthly, three assessment methods were adopted to assess chil- dren's AI literacy in ECE, including knowledge and theory of mind skills assessments (4 articles), questionnaires (3 articles), and observation (3 articles). We suggest further studies adopt performance-based mea- surements for evaluating children's AI knowledge/skills. Moreover, so far there has been no standard questionnaire, survey or test for assessing young children's AI knowledge/skills.

Finally, the current research on AI literacy in ECE classrooms lacks empirical research from implementation and research methods not very rigorous. More empirical and interventional research designs are ex- pected to be implemented by researchers in future, with clearly defined curriculum and control groups and a variety of data analysis techniques (e.g., t-tests, ANOVA).

Although included studies have discussed the positive cognitive learning gain that these learning programs could offer students, some studies stated several obstacles when students learn AI. For instance, low socioeconomic status (SES) children perform on average worse on AI abilities than children with higher SES backgrounds (Druga et al., 2019). This situation also happens in AI literacy education. A study investi- gating whether SES will impact children's AI perception shows that AI perception could be influenced by parents' social-economical back- ground. The authors also found that "children in low and medium SES schools and centres tend to have stronger collaboration skills compared to high SES children, but had a harder time advancing because they had less experience with coding and interacting with these technologies" (Druga et al., 2019, p. 1).

Technical background and have not yet received related training, they tend to have a low confidence level to understand AI, and a negative attitude to develop related activities and curriculum for their students. Educators reported feeling overwhelmed by the entire process of experimenting with new digital tools (Dickey, 2011; Horton & Horton, 2003) and having little patience for dealing with minor technical issues (Davidson, 2012; Drexler et al., 2008; Perry, 2015). This is worsened by teachers' tight teaching schedule and they do not have any extra time to learn AI knowledge. They may worry excessively since most of the currently available AI tools are children's toys designed for children to explore what AI is (Dyrbye et al., 2009). As such, teachers' unreadiness towards AI teaching is a great barrier for developing appropriate AI materials and activities. However, some university and company may help develop some AI materials (Ng et al., 2023).

Lack of curriculum design. Few articles explain what, why, how, and when children should learn. Less research on early AI education, though, has concentrated on curriculum design (Su & Yang, 2022). Therefore, curriculum design is the second of the challenges encountered by edu- cators when engaging in the development and implementation of early AI literacy.

Lack of teaching guidelines. Experiential exposure and project-based learning is appropriate for children's development of AI concepts (Kandlhofer et al., 2016; Williams, 2018; Williams et al., 2019). Among these activities, most of the studies have identified that children scaffold their understandings through age-appropriate AI tools (e.g., Williams, 2018; Williams et al., 2019)

A framework of the elaborated elements of AI literacy for young children (Ng et al., 2021).

Elements	Descriptions	Examples

AI concepts	Technical and conceptual understanding of the basic functions of AI	Learning about classification, patterns and rules
AI practices	The techniques and strategies used when applying AI	Using tools to facilitate their everyday living and studies
AI perspectives	Attitudes and dispositions adopted while solving problems	Collaboration, communication, problem-solving, curiosity, inquiry

Resources for children. Therefore, governments' support is important to sponsoring schools to equip them with these technologies to enrich students' exposures. Further, some websites (e.g., *Machine learning for kids* https://machinelearningforkids.co.uk/ and *IBM* https://www.ibm. org/activities/machine-learning-for-kids) offer open-source pre- school-oriented AI curriculum using free web-based software such as Teachable Machine for young children to learn AI (Machine learning for kids, n.d.; IBM.org, n.d.).

Opportunities

Developing AI concepts and practices. In the past, it was challenging to foster young children to learn AI concepts and skills due to a lack of suitable tools. With a growing number of developmentally well-designed technologies for young children, young children can explore what AI is through playful experiences. For example, young children can play with AI social robots, toys and services (e.g., Cozmo, PopBots, Quickdraw, Wowee) to learn how to interact with AI tools that make responses based on children's emotions and expressions and stimulate their curiosity to explore AI technologies in their everyday lives (Kewalramani et al., 2021; McStay & Rosner, 2021). The interaction with AI can help stu- dents improve their digital literacy skills and attitudes, preparing them better for their progression in primary schools even though it is acknowledged that young children at this age hardly know and under- stand AI. Parents could use these AI toys and services to create a digital environment for their kids, and this new skill may make them more comfortable with the tool, increasing the likelihood that they will use it in the future as part of their instructional design. For example, paren- t–child interactions through AI toys (i.e., Alpha Mini, Coji, Qobo the snail, LegoBoost Bot) activities to enhance children's social and emotional abilities (Kewalramani et al., 2021).

Developing AI perspectives. AI perspectives refers to attitudes and dispositions adopted while solving problems (Ng et al., 2021). Most studies show that teaching young children early AI concepts and skills significantly enhances their understanding of AI (e.g., Rule-based sys- tems, Supervised machine learning, and generative AI) (Williams, 2018; Williams et al., 2019). However, children may not comprehend the knowledge and concepts behind AI at a young age because AI in ECE is vastly different from AI in primary and secondary schools. For example, AI in ECE mainly focuses on how to use AI tools (i.e., AI toys) to facilitate their daily life and studies, but AI in primary and secondary schools focuses on knowledge and skills acquisition. However, young children can develop their digital skills through play and exploration, enhancing their emotional, collaborative, and inquiry literacy as well as related AI perspectives like social skills (like how to play and interact with other kids), curiosity, and others (Kewalramani et al., 2021). Children use AI devices (e.g., drawing tools, robotic toys, chatbots) on a daily basis to improve communication skills through group activities and stimulate their imagination through digital storytelling and writing (Ng et al., 2022c). Based on the above, it is worth developing AI literacy for chil- dren in ECE. The following demonstrates a summary of AI concepts, practices and perspectives adapted from Ng et al. (2021b), as shown in Table 11.

Suggestions

To address teaching challenges, educators should update their AI knowledge. Early childhood educators can use digital resources to learn AI concepts in their spare time.Researchers should design adaptable AI curriculum approaches, such as holistic approaches. The six important components (i.e., AI knowledge, AI processes, the impact of AI (content and product), student relevance, teacher-student communication, and flexibility (process and praxis) for designing AI curriculum using holistic method (Chiu, 2021).

- Educators should design more interesting AI activities for young children, which could change their existing attitudes towards AI.
- A technological, pedagogical, and content knowledge (TPACK) framework should be taken into consideration to provide a roadmap for understanding how to effectively integrate AI literacy into classrooms in order to aid educators in teaching more effectively (Ng et al., 2022b).
- Future researchers and educators will develop quantitative and qualitative assessments to assess children's learning outcome through pre and post-knowledge tests, surveys, and observations.

Pedagogical implications

In order to help young children develop AI literacy skills at an ECE level, this paper first introduces various teaching content, tools, and pedagogy that are appropriate for this age group. This can aid in the development of age-appropriate AI curriculum, games, and toys for kids by researchers and educators (Ng & Chu, 2021). This article synthesises the evidence that shows the effectiveness of the AI curriculum in ECE. Most studies have shown that the AI curricula have significantly improved children's AI or machine learning concepts (Williams et al., 2019a,b; Ng et al., 2022a) and theory of mind skills and several inquiries (i.e., creative inquiry, emotional inquiry and collaborative inquiry). One study designed AI activities to enhance kindergarten children's creative inquiry, emotional inquiry and collaborative inquiry (Kewalramani et al., 2021). Moreover, teachers were able to effectively implement the AI curricula in order to promote children's learning and gains. For example, researchers could design interesting AI activities (e.g., interact with AI robots) for children to enhance children's AI perceptions (Tazume et al., 2020). Furthermore, by presenting the various assess- ment methods used, the research findings in this paper advance AI education in ECE research. Three frequent assessment tools were most used, including knowledge and skill assessments, observation, and questionnaires. For example, Williams (2018) used knowledge assessments to examine children's AI knowledge and skills. Results show that the AI curriculum for ECE has significantly improved children's perceived AI knowledge. Therefore, there is a need to promote quality AI education in the early years at the fronts of pedagogical. This paper also outlines the challenges and opportunities of AI literacy in early childhood education for researchers and educators as a reference. The challenges of AI literacy in ECE, including lack of teachers' AI knowledge and skills, low teachers' confidence, lack of curriculum design, and lack of teaching guidelines. On the other hand, we identified some opportunities for AI literacy in ECE, including developing AI concepts and practices and AI perspectives. This paper provides some suggestions for researchers and educators. For example, future educators could design some engaging AI activities for young children's learning about AI, such as interacting with AI robots, etc. Our discussion provides a good starting point for scholars to further investigate the effectiveness of early AI literacy and for various stakeholders to develop stimulating and engaging AI courses in educational fields.

Conclusion

This review contributes to mapping the research design, tools, research methods, intervention programs, and research findings ascribed to the existing studies on early AI curriculum. It also explains the challenges and opportunities of AI literacy in early childhood edu- cation. The results of this literature survey can inform future research in terms of advancing tools, pedagogical methods, research design, research methods, intervention, and assessment for early AI curricula and provide researchers and practitioners a guide for the design, implementation, and evaluation of age-appropriate AI curricula for young children. This review would provide valuable directions for early AI education and serve as a reference for future ECE research in the digital society.

Two limitations in this study. Firstly, most of the studies selected in this review only are of their beginning stage and their research methods were preliminary, descriptive and exploratory in nature. More re- searchers are anticipated to join the conversation, contributing more rigorous research techniques, as well as successful instructional and

research designs for AI in ECE settings. Secondly, The research's scope was constrained by the paucity of literature on AI literacy for early childhood education, making it impossible to quantify generalizations. However, according to the available literature, early AI literacy is a worthwhile investigation and a highly valuable emerging research direction for future researchers.

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