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Young children's understanding of AI

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Abstract
AI has become integral to daily life. Teaching, learning, and research are no exception. However, most studies on education have approached AI as a technology and focused mostly on learning outcomes rather than understanding student engagement and sense-making of AI as a socio-cultural tool with impact on their daily lives. To address this gap in the knowledge base, we performed a qualitative case study to explore young children's conceptualization of AI not only as a technology but also as a tool utilised in their everyday lives. We collected data through semi-structured group interviews with eighteen children aged 11 to 12 and thematically analyzed the data through a combination of deductive and inductive coding techniques. The findings suggest that: a) children's conceptualizations of AI as a technology are grounded in their personal experiences; b) children have a socio-cultural approach to AI in which they experience and understand AI as first and foremost a supportive tool; and, c) children exhibit a high level of engagement with ethics of AI, showing a keen interest in the socio-cultural implications, particularly about AI applications with which they are familiar. Based on these findings and grounded within existing literature, we offer a set of recommendations for the design of engaging and personally relevant AI education curriculum materials for young children with critical AI literacy at the forefront.

Keywords AI education · AI ethics · AI literacy · Young children

1 Introduction

With the rapid expansion of Artificial intelligence (AI) in industry, education, and everyday life, children are living in and facing an increasingly AI-powered society. In the last decade, researchers have explored AI's potential to address

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educational challenges (e.g. achievement gaps, unequity, high workload) through tools such as intelligent tutoring systems, chatbots, or automated feedback models (Heeg & Avraamidou, 2023). More recently, research efforts have shifted from teaching 'with' AI, to teaching 'about' AI, as contemporary reform documents have widely called for 'AI literacy' as a new set of skills and competencies that future student generations need to responsibly and ethically function in an AI-powered society (OECD, 2021; UNESCO, 2022).

As a response, all around the world, attention is placed on developing AI education for schools (e.g. Casal-Otero et al., 2023; Su et al., 2023a, b; Yue et al., 2022). In China, AI education is part of the mandatory high school curriculum and a series of seven AI textbooks is already available for elementary, middle, and high schools (Chen & Tang, 2018; Xiong et al., 2018). In the rest of the world, no national AI curricula have yet been implemented. However, increasing efforts are put into creating AI literacy frameworks and educational materials that can help teachers introduce AI into their classrooms. For instance, in the United States, the AI4K12 project identified 'Five big ideas in AI' and organized K-12 frameworks around them, to serve as guidelines for AI curricula development (Touretzky et al., 2019). Researchers at the Massachusetts Institute of Technology (MIT) developed a collection of AI lessons and tools to engage middle schoolers with the social and ethical implications of AI (Williams et al., 2022). Similarly in Europe, the Erasmus + project GENERATION AI developed an AI introductory course for primary school children available in various European languages. Germany launched a national initiative that included a 6-module AI course (Micheuz, 2020), and in the Netherlands, which defines the context of this study, a series of 'National courses are available for school teachers, with different themes, such as AI in healthcare and AI in education.

As these projects are a few examples of pioneering the development of educational materials and implementing them is novel, consequently, there exists a gap in the knowledge base regarding students' understanding of AI, particularly as a sociocultural tool with ethical implications. This gap also exists in the context of primary schools, where it is especially relevant because of the wide variety of young children's interests, capabilities, and prior experiences, presenting a unique challenge to curriculum development. To design effective and meaningful AI curricula that resonate with all learners, an in-depth understanding of children's engagement and sense-making of AI is needed to inform future curriculum design initiatives. This is precisely what the purpose of the single case study reported in this paper is about; to explore young children's understanding of AI.

2 Theoretical and empirical underpinnings

2.1 AI literacy

AI literacy is part of the 21st-century skills that can enhance living standards, learning and working effectiveness, employability, and support citizens in becoming critical consumers of this technology (Ng et al., 2022a, b; OECD, 2021). The term "AI literacy" was first coined by Burgsteiner et al. (2016) and Kandlhofer et al. (2016),

who defined it as the ability to understand the techniques and concepts behind AI-driven applications and services, instead of just learning how to use them. A related conceptual framework, inspired by drawing an analogy with classic literacy development, contains four different stages of AI literacy development, where each stage is assigned to an educational level starting with building awareness in primary school to becoming fluent in AI at the university level. As the first conceptual framework of AI literacy, the work started a conversation on what AI literacy is and what students need to learn. Since then, other conceptual frameworks have been conceptualized. What follows is a brief overview of three AI literacy frameworks, with each its focus, advantages, and challenges.

A more holistic approach to AI is taken by Kong and Zhang (2021), by shedding light on both the technical and socio-cultural dimensions of AI. The authors propose a conceptual framework for AI literacy to empower citizens by promoting AI literacy and the ethical use of AI. The framework involves three dimensions. First, the cognitive dimension, which focuses on skills and competencies needed to understand and evaluate AI. Second, the affective dimension promotes AI self-efficacy and AI perceptions to empower citizens by making them feel AI is personally meaningful to them. The final dimension is the socio-cultural dimension, promoting the ethical use of AI. Expanding the framework beyond the technical dimension of AI is modern and AI attitudes and AI self-efficacy constructs to empower citizens receive increasing attention in the literature (e.g. Schepman & Rodway, 2023; Wang et al., 2023). However, Kong and Zhang do not offer a set of concrete competencies that can be used to design AI literacy instructions or explore or assess their three dimensions of AI literacy.

Focusing more on cognitive development, Ng et al. (2021) conceptualized AI by building on the classic educational model of Bloom's taxonomy. Through an explorative review, they reviewed how 30 studies define AI literacy and synthesized these different AI literacy definitions into different levels of cognitive processes in AI learning, each associated with a different taxonomy level. These levels require a higher level of complexity and ordered thinking from students, and are successive so that one level must be mastered before the next level can be reached. From the bottom upwards, Ng et al. determined the levels to be 'Know and Understand AI', 'Use and Apply AI', and the highest level'Evaluate and Create AI'. Moreover, they conclude emphasis on the ethical use of AI is needed. With this framework, Ng et al. are the first to bring classic educational models to AI literacy. Bloom's taxonomy was initially created in the 1950s, and originally it endured popularity because it provides a structured framework for educators to design learning objectives and assessments. However, some critics argue that the hierarchical structure of the model is too rigid and that learning is more complex and dynamic, and individuals may engage in higher-order thinking without mastering lower-level skills first.

A more contemporary and widely used framework of AI literature has been developed by Long and Magerko (2020). Following a scoping study of existing research to synthesize what AI professionals believe all citizens should know and common perceptions and misconceptions among learners, the researchers conceptualize AI literacy through five overarching competencies: what is AI, what can AI do, how does AI work, how should it be used, and how is it perceived. Additionally, Long

and Magerko formulated 17 competencies that should be acquired to be AI literate (Table 1). For educators, the conceptual framework comes with 16 design considerations to support the design of AI education.

Although this conceptual framework offers concrete design guidelines and competencies for educators, it is predominantly focused on the technical dimension of AI, as evidenced by the fact that 16 out of 17 competencies focus on technology. Little attention is given to the socio-cultural dimension of AI.

In the pursuit of understanding primary school students' conceptualization of AI, this exploratory study adopts a comprehensive approach by drawing on these various conceptual frameworks and framing them within socio-cultural theories of learning emphasizing social interaction. This approach is deemed appropriate for an exploratory study, given that our purpose is not to test a predetermined hypothesis but to generate insights that inform the design of personally relevant and meaningful AI education materials for primary schools.

2.2 Children's understanding of AI

An examination of the literature shows that before any AI education, young children start conceptualizing AI through exposure to media representations of AI or experiences with AI-enabled devices at home (Druga et al., 2017; Szczuka et al., 2022; Williams et al., 2019). Some children frequently engage with voice assistants such as Hey Google or Siri. Moreover, their interactions extend to popular digital platforms like TikTok and YouTube, where algorithms dynamically tailor online content to align with their individual preferences. Additionally, children actively explore the functionalities of generative AI models, such as ChatGPT or DALL-E, leveraging these technologies to compose text and generate images. Collectively, these interactions contribute to the development of their AI understanding and shape their attitudes toward the technology (Ottenbreit-Leftwich et al., 2022) and hence AI conceptions, before starting AI education, can therefore vary as children can have different experiences (Druga et al., 2017) or unequal access to such experiences (UNICEF, 2021). To ensure effective teaching instructions for all children AI educational materials must tie into these varying prior experiences of children.

Empirical evidence shows that children's existing understanding of AI is that it is not a binary concept that can be determined to be right or wrong, as it encompasses a range of perceptions. For example, in a study with 195 Finnish students aged 12 to 13, Mertala et al. (2022) showed that students' initial conceptions of AI are varied and often uninformed. Data were collected through an online qualitative survey, asking children to describe what AI is, what it is used for, how it works, and why they think AI is used. The students described AI as an autonomous system, being able to perform tasks on its own, without the need for human interference. They also conceptualized AI as programmed, acknowledging the human role in AI development. The same students also showed to have less accurate conceptualizations of AI; assigning AI human-like cognitive processes, such as knowing and thinking. These conceptualizations imply an anthropomorphic conception of what AI is. This is in agreement with the findings of a study conducted by Ottenbreit-Leftwich et al.

Table 1 AI literacy competencies adopted by Long and Magerko (2020)

Competency	Description
Theme: What is AI?	
1. Recognizing AI	Distinguish between technological artifacts that use and do not use AI
2. Understanding Intelligence	Critically analyze and discuss features that make an entity "intelligent", including discussing differences between human, animal, and machine intelligence
3. Interdisciplinarity	Recognize that there are many ways to think about and develop "intelligent" machines. Identify a variety of technologies that use AI, including technology spanning cognitive systems, robotics, and ML
4. General vs. Narrow	Distinguish between general and narrow AI
Theme: What can AI do?	
5. AI's Strengths & Weaknesses	Identify problem types that AI excels at and problems that are more challenging for AI. Use this information to determine when it is appropriate to use AI and when to leverage human skills
6. Imagine the Future of AI	Imagine possible future applications of AI and consider the effects of such applications on the world
Theme: How does AI work?	
7. Representations	Understand what a knowledge representation is and describe some examples of knowledge representations
8. Decision-Making	Recognize and describe examples of how computers reason and make decisions
9. Machine Learning Steps	Understand the steps involved in machine learning and the practices and challenges that each step entails
10. Human role in AI	Recognize that humans play an important role in programming, choosing models, and fine-tuning AI systems
11. Data literacy	Understand basic data literacy concepts
12. Learning from Data	Recognize that computers often learn from data (including one's data)
13. Critically Interpreting Data	Understand that data cannot be taken at face value and requires interpretation. Describe how the training examples provided in an initial dataset can affect the results of an algorithm
14. Action & Reaction	Understand that some AI systems have the ability to physically act on the world. This action can be directed by higher-level reasoning (e.g. walking along a planned path) or it can be reactive (e.g. jumping backward to avoid a sensed obstacle)
15. Sensors	Understand what sensors are, recognize that computers perceive the world using sensors, and identify sensors on a variety of devices. Recognize that different sensors support different types of representation and reasoning about the world
Theme: How should AI be used?	
16. Ethics	Identify and describe different perspectives on the key ethical issues surrounding AI (i.e. privacy, employment, misinformation, the singularity, ethical decision-making, diversity, bias, transparency, accountability)
Theme: How do people perceive AI?	
17. Programmability	Understand that agents are programmable

(2022), who explored the existing understanding and interests of young learners about AI in the context of the US. Through one-on-one semi-structured interviews. Ten students, aged 9 to 11, were asked to elaborate on what AI means, and how it works, and to share examples of AI. Nine of the ten described AI to involve coding or programming. Moreover, the researchers noticed that at times, students described AI to be preprogrammed, making it a human-made artifact, while other times, attributing anthropomorphic, life-like characteristics to these devices, using personal pronouns to describe an AI, and thinking it could understand and see them. The idea of AI being preprogrammed illustrates a lack of a deeper understanding of what AI is and how it works. Ottenbreit-Leftwich et al. (2022) observed a few students who understood AI involves training, however, none of the students were able to give a more detailed explanation of how an AI model is trained.

Another set of studies provides evidence that students' awareness of AI applications in their daily lives is nuanced and not easily characterized as entirely correct or incorrect. While young children demonstrate proficiency in identifying numerous AI applications (Mertala et al., 2022; Ottenbreit-Leftwich et al., 2022), such as voice assistants, search engines, recommendation software, and autonomous devices, Kim et al. (2023) observed students tend to over label automated appliances as instances of AI. During an AI summer camp, 14 middle schoolers were observed playing a game called "AI or not AI?". Students were shown an everyday object and then asked to position themselves from 0 (Not AI) to 100 (AI). Once situated, teachers would ask students to share their reasoning for their assessment. Throughout the activity, several students argued that many automated instances were examples of AI such as electronic toll collection on the highway using RFID technology, washing machines controlled by personal mobile phones using IoT, and industrial robots in the factory.

Notably, there exist conflicting findings concerning students' understanding of the ethical dimension of AI. The literature reports students who believe AI could make lives easier, by helping with certain chores. Especially the lives of sick or disabled people, who could benefit from such AI applications (Mertala et al., 2022; Ottenbreit-Leftwich et al., 2022). Regarding ethical risks, few students in the Ottenbreit-Leftwich et al. (2022) study, shared concerns regarding cybersecurity, privacy, and misuse of AI applications. On the contrary, Kim et al. (2023) found students not to worry about AI, believing AI is emotionless and therefore impartial and fair, not recognizing any ethical considerations of AI.

Collectively, the findings of existing studies shed light on the complexity of students' existing understanding of AI that they bring into the classroom. AI understanding is not a binary concept that can be determined to be correct or incorrect. Instead, it encompasses a range of perceptions, as illustrated by the above-described empirical findings. Research also shows cultural upbringing can influence children's perceptions and attitudes toward AI (Long & Magerko, 2020), adding to the complexity of AI literacy development. In recognition of this complexity, in this study, we use a qualitative research approach to explore primary school students' AI literacy in depth.

2.3 AI-based educational practices

Education, governments, and industry leaders have acknowledged the value of promoting AI literacy among young learners in primary and secondary education (Pedro et al., 2019; Touretzky et al., 2019; UNESCO, 2019). There are currently 14 AI curricula endorsed and implemented at primary and secondary school levels by governments in 11 countries (UNESCO, 2022). Additionally, scholars started to design and implement AI learning activities in the form of interventions, workshops, or courses, and empirical studies on how such teaching and learning efforts can support students in fostering AI literacy. For example, Zhang et al. (2022) designed and implemented the "Developing AI Literacy" (DAILy) course that aimed to develop AI literacy among middle school students by covering age-appropriate technical knowledge and skills in AI, creating an understanding of the ethical and societal implications of AI, and finally, by increasing knowledge of AI's impact on jobs. A group of MIT researchers designed and pilot-tested various AI Ethics activities for middle school students (e.g. Ali et al., 2021; DiPaola et al., 2020; Lee et al., 2021; Payne, 2020; Williams et al., 2022). Van Brummelen et al. (2021) used Long and Magerko's (2020) conceptual framework to design an online workshop of five days. Williams et al. (2022) pilot-tested three activities on generative adversarial networks (GANs), deep fakes, coding, and supervised machine learning. The activities were meant to increase students' technical AI knowledge, ability to think critically about the implications of AI, and ability to apply AI knowledge to topics they personally care about. Eguchi et al. (2021) used related MIT-designed AI + ethics curricula and used a culturally responsive approach to teach it by adapting the curricula to the Japanese context. To do this, they changed or added certain AI application examples. For example, YouTube was replaced with the, in Japan wider known, Yahoo. They also added various AI-enhanced devices that are well-known and used in Japan, such as AI-enhanced microwaves, washing machines, and personal service robots. Moreover, various pedagogical approaches such as problem-based learning (Su & Zhong, 2022), role-playing (Henry et al., 2021), and digital story writing (Ng et al., 2022a, b) were introduced to develop young children's AI literacy.

This body of research provides insights into the design of AI literacy education materials, and the pedagogical strategies tools, and resources used to implement these curricula. A critical examination of the knowledge base showcases specific gaps: a) lack of qualitative studies, b) lack of studies in the context of Europe, c) few studies explore learning experiences and processes, and d) few studies approach AI as a socio-cultural tool. Overall, the existing knowledge base offers merely preliminary insights into the impact of specific curricula on children's AI literacy. The effects are often examined by focusing on learning outcomes, using mixed or quantitative methods. Qualitative research methods can mostly be found in conference proceedings, but offer only superficial preliminary findings of pilot tests of curricula. We argue that since only recently AI curricula have been implemented, more attention should be paid to qualitatively understanding children's understanding of AI and learning experiences rather than solely focusing on learning outcomes. This is precisely the purpose of this manuscript.

2.4 Research questions

As stated earlier, there exists a lack of qualitative studies exploring children's understanding of AI that go beyond the technical dimension and address the socio-cultural nature of AI. In attempting to address this gap in the knowledge base, in the study reported in this manuscript we explore young children's understanding of AI as a technology, AI as a tool, and AI as an ethical phenomenon. In doing so, we aim to respond to the following research questions:

RQ1: How do young children understand AI?
RQ2: How do young children understand AI applications in their daily lives?
RQ3: What (if any) ethical risks do young children identify in relation to AI?

In responding to these questions, through this study, we aim to contribute to the gap in existing literature on an in-depth understanding of students' AI conceptualizations. We provide detailed insights into students' engagement with AI that can be used to support the design of effective and engaging AI curricula for primary school children.

3 Methods

3.1 Research design

To explore what AI themes and competencies are appropriate for primary school children we follow a qualitative case study paradigm with the case being defined by a group of young children in a school classroom (Merriam & Tisdell, 2015). Adopting this paradigm allows us to employ a detailed and in-depth exploration of students' understanding of AI. Even though the students in the classroom will be treated as one case, in analyzing the data we apply a constant comparative approach across the students to also gain an understanding of their personal understanding.

3.2 Context and participants

The context of the study was defined by a primary school classroom of 18 children (11–12 years old). The classroom was selected through a purposeful sampling method to ensure: a) the classroom population is representative of the country's student population, and b) the teacher has background knowledge and interest in the use of AI tools in teaching and learning. In terms of demographics, typical of the country's population, the classroom included Caucasian (national) children and a few of those with a migration background, mostly Arabic. There were nine boys and nine girls, all with average to high socio-economic status. We purposefully selected a classroom with a teacher who was knowledgeable enough about AI and was comfortable in implementing an introductory course specially designed for this age group. The study meets the ethical and legal requirements of the university in the

country context where this study is carried out. Approval for the study was received following an application process to the Ethics committee, which included information about data privacy, consent, confidentiality, and data protection.

The teacher has more than five years of experience, he has a strong interest in digital literacy including AI and he has been involved in curriculum design for digital literacy. The teacher implemented a five-week-long AI introductory course, based on an AI curriculum developed and pilot-tested as part of an EU-funded project developed by the researchers. The course includes 5 lessons on AI definition, voice assistants, machine learning, and AI ethics and is centered around the digital learners' competencies formulated by the Digital Competence Framework for Educators (Redecker, 2017).

It is important to note that the course was not used as an intervention but instead as a context for initiating conversations with the students about AI that would help shed light on their existing understanding of AI. This is precisely why the course was not intended to support the construction of new knowledge but to engage students in activities that would support them in making their prior knowledge and thinking visible.

3.3 Data collection and analysis

The main research data for this study were collected through five online group interviews with the children. Conducting online interviews with children, as opposed to in-person interviews, not only fosters a sense of comfort in their familiar digital environment but also serves as a strategic method to mitigate traditional adult–child power dynamics. In the virtual setting, children can feel safe to express themselves. An illustrative example of this dynamic emerged during interviews where children desiring a private exchange, muted themselves for a few seconds to communicate with each other without the direct presence of the interviewer. This instance showcased a self-directed control over the interview space, reflecting a nuanced shift in power dynamics that supports children to communicate freely within the digital context. To address limitations of the online interaction in forming bonds with the children, we started each interview with informal conversations that included presentations of ourselves in regards to personal interests and hobbies. To increase our efforts to make children, especially shy ones, feel at ease during the interviews, we chose group interviews. Each interview lasted between twenty and thirty minutes.

The first author conducted the interviews and acted as a facilitator to create a comfortable atmosphere in which all participants felt free to share their voices. The second author has more than 15 years of experience with qualitative research, both as a researcher as well as an instructor of advanced qualitative methods courses at the doctoral level. The second author provided training to the first author in interviewing techniques to overcome common limitations of group interviews, such as dominant personalities, silent participants, or students getting off-topic. Techniques such as (a) directing questions at less participating students, (b) follow-up questions on non-verbal communication from students (e.g. nodding, facial expressions), and (c) naturally redirecting the conversation.

The interviews were semi-structured, allowing a more natural conversation to take place during which the students played a role in navigating the direction of the interview. The interview protocol that was used, has been used in similar research with young

children in a different context (Avraamidou, 2013; Heeg et al., 2022). It included a combination of closed and open-ended questions such as the following: Can you explain what AI is? What are examples of AI? Is AI always good for us? A complete list of questions can be found in Appendix. The interview questions were developed through using the research question as a basis as well as input from the literature. They were discussed with a research group and pilot tested with a small group of students for validity purposes.

During the interview, the children shared one laptop with a built-in camera to communicate with the interviewer. All students' upper bodies and heads remained visible during the interview, to ensure non-verbal communication could be seen and acted on by the interviewer. All interviews were audio tape-recorded and fully transcribed for the purposes of the analysis.

For the data analysis, we adopted a thematic approach to identify the AI literacy constructs that were more salient. The Atlas software was used to analyze the data. To carry out the analysis, we combined deductive and inductive analytic practices to provide a more comprehensive view (Vanover et al., 2022). For the first round of coding, we applied a deductive approach to organize our data into deductive categories aligned with the conceptual framework of Long and Magerko (2020), in this case, the AI literacy themes (see Table 1). During the second round of coding, we applied an inductive approach, using in vivo, line-by-line coding techniques, to allow codes and patterns to emerge from the data. Based on the patterns, the inductive codes were clustered in categories, for example, 'imagining the future with AI', 'opinions on AI', and 'privacy', which were then grouped under three themes aligned with the three research questions. For an overview of the coding process, including examples of codes, please see Table 2.

3.4 Trustworthiness

In pursuit of establishing trustworthiness, we increased the internal validity of the interviews by incorporating different questions addressing the same issue in the interview protocol. To establish external validity, both authors independently engaged with the data, using the established coding scheme. In comparing the two codings there was an 80% agreement. The authors met multiple times to discuss the coding and interpretations. The authors discussed disagreements until a consensus was reached as a way to enhance the trustworthiness of the findings. However, typical with qualitative research, confirmability and generalizability are not possible. We, however, provide detailed information about both the context and processes of data collection to advance the possibility of transferability of the findings to similar contexts.

4 Findings

The outcomes of the analysis are presented around the final three themes that align with the research questions of this paper: children's understanding of AI, AI in daily life, and ethical risks of AI. All children's quotes were translated into English from their original language.

Table 2 Overview of coding process

Round 1 of deductive coding using the 5 AI literacy themes by Long and Magerko (2020)	Round 2 of coding using in-vivo, line-by-line coding techniques. Example codes:	Clustering codes into categories using and adding to the 17 competencies of Long and Magerko (2020). Example categories:	Grouping categories under three themes aligned with the three research questions
What is AI?	Algorithm, YouTube, AI recommendations	Recognizing AI	AI in students' daily lives
What can AI do?	AI can clean, AI can talk, AI can help	Use of AI	AI in students' daily lives
How does AI work?	AI is programmed, making AI	Human role in AI	Understanding of AI
How should AI be used?	Bias, racism, sexism, profit, privacy	Ethics	Ethical risks of AI
How do people perceive AI?	Opinion	Opinion	AI in students' daily lives

4.1 Children's Understanding of AI

After a brief conversation on whether or not the students enjoyed the AI lessons, the researcher opened the interviews by asking if students could explain what AI is. This question led to some initial discomfort in most groups, manifesting in the form of silences, exchanged glances, or laughter. In some cases, students would even explicitly share that this was a difficult question to answer. However, in the end, most groups provided a collective answer, that all group members contributed to and agreed with. For example, Sascha, Julia, Feline, and Rachel shared:

Researcher: Could you try to explain to me what AI is?
Sascha: Julia can start.
Researcher: There are no right or wrong answers, everything is ok.
Julia: Well, ehm…
[…]
[all group members laugh]
Julia: It is hard to explain
Sascha: Shall I start?
Julia: Yes please. Sascha will start.
Sascha: Well, I will try. AI is actually, well, a device or something, which has been developed by humans but which can actually make its own decisions.
Researcher: okay
Sascha: Something like that…
Researcher: Does anybody want to add something to that? Or, has other ideas about what AI is?
Feline: Maybe that they can decide that, for example, a self-driving car, they can decide where they want to go. Well, not exactly decide, but they can describe the route and then decide which one to take.
Rachel: They choose themselves
Julia: They can think on their own, but they are programmed, so it is not actually by themselves.
Researcher: okay,, so they can think on their own, and decide on their own.
Julia: Yes

As apparent in the extract, after Sascha started answering the question, all other group members felt comfortable adding to the explanation. As can be seen in the extract, the group described AI as a device that is programmed or developed by humans and that can think and decide on its own. This is a typical description that occurred more or less in all group interviews. Some other typical descriptions from the interviews were AI as an 'algorithm', or 'computer system', that is 'smart' or 'intelligent' because it can 'learn', 'think', or 'do things' on its own. For example, when Bobby was asked why he called AI 'smart', he answered:

Bobby: Well, it can do a lot of things. AI can do things by itself. I think that is smart of AI.

In one group, all group members reacted to the researcher's question by turning their heads to Fred who interpreted this non-verbal behavior as inviting him to answer this question. At the beginning of the interview, Fred already positioned himself as an expert on AI and felt comfortable answering this question on his own. His group members agreed with his explanation, but didn't add anything to it:

Researcher: Can you tell me what AI is?
[all group members looked at Fred]
Fred: Well, I think I will take this one if everybody is looking at me. But I don't mind. Artificial Intelligence, also known as AI, is a computer or a computer program that can independently perform certain tasks, independently decide things, or decide how to do them. For example, when you say something to a Google Assistant, like 'Hey Google, turn on the lights', it will turn on the lights.
Researcher: Okay. Lars, do you want to add something to that?
Lars: No, I think he said everything.

Although all children seemed to understand that AI can 'think' or 'learn' by itself, nobody was able to answer follow-up questions such as 'how does it think?' or 'how does it learn?'. Nevertheless, students had some misconceptions about recognizing Artificial Intelligence, as can be seen in the following conversation prompted by the researcher asking if the students have AI at home:

Erica: I have a phone and my sister has a tablet. My father has two phones. One for work and one for at home. And my mum has a phone. I have another one.
Researcher: And, do all mobile phones use AI?
Stella: Yes, I think so.
Erica: yes
Stella: well actually, when you ask it like that, I don't think it has.
[Stella and Erica laugh]
Stella: oh yes, a phone is electric

The extract shows how both Erica and Stella think that all phones use AI, later doubting that. Similarly, in a different group, Fred and Lars suggested automated calendar notifications might also be instances of AI, but weren't sure about this:

Researcher: How do you use AI at home?
Fred: Well for example, ehm…, for example when you cannot remember things very well, then you can look things up. For example, when my birthday is, or a calendar, an online calendar. My grandma does that sometimes.
Lars: Yes, very helpful as a calendar
Researcher: And what do you mean by calendar? What is AI about the calendar?
Lars: For example, a calendar. Well, I am not sure if that is AI.
Lars: When you put something on your calendar, then it will send you a reminder one day in advance of when that will happen. I am not sure if that is AI

As apparent in this dialogue, students tend to label electronic devices or automated functions, such as online calendars and reminders, as instances of artificial intelligence, reflecting a limited understanding of AI.

4.2 AI in daily life

When prompted to share examples of AI, all groups stated the most common AI applications that children in the context of the study can come across in daily life. Examples included recommendation algorithms on social media and Netflix, voice assistants like Alexa and Hey Google, robotic vacuum cleaners and lawnmowers, and self-driving cars. For example, Rachel, Feline, Sascha, and Julia shared:

Researcher: And do you know examples of AI?
Rachel: self-driving cars, Siri, Alexa, Google Assistant, Corta,
Feline: Corta?
Rachel: that's from Windows
Sascha: Netflix
Researcher: And what exactly is AI on Netflix?
Sascha: Well, for example
Julia: Cookies
Sascha: No, but if you have watched a certain series, then it tells you, you may also like this'
Feline: and it says you can watch this, examples of what you can watch, and usually there is something fun in there that you want to watch
Sascha: because you,
Feline: because you already watched certain things, and because you watch things, or you searched for specific things, it suggests things that are kind of similar. Yes.
Julia: Also on TikTok
Feline: TikTok and Snapchat

In all groups, children named Netflix, TikTok, and YouTube as AI. Through follow-up questions, they would specify how such platforms use AI to identify what videos they like to suggest content of a similar nature. For example:

Betty: On TikTok for example, when you watch a certain video, and you like it, that the next few videos will be the exact same videos. Which can be strange as well…
Researcher: Could it also be boring?
Betty, Sarah, Rose: Yes!
Rose: You never get something different
I: And do you have solutions for this? Do you ever use each other's phones to see something else?
Rose: when you press 'not interested' you will see those videos less
Sarah: yes
Researcher: Oh, I didn't know that was possible
Rose: Yes, and you can also, I do this sometimes, when I don't like a video, I would like it, so I would get other types of videos.
Rose: Or, if you scroll over a nice video, or don't watch it until the end
Betty: yes, that's right

In this dialogue, Sarah, Betty, and Rose describe how they interact with AI systems when they watch videos on TikTok. All three shared their scrolling and liking behavior to manipulate the AI in providing other types of TikTok content. In another group, Tom and Erica, shared similar strategies for manipulating the algorithm:

Tom: What I have done is like a video [on TikTok] that I didn't like, because that would give me other types of videos.
Researcher: you mean you are tricking the AI system in giving you other content?
Tom: yes, and for example, immediately scrolling through videos that you like.
Erica: Yes, that is right.
Tom: Or when you watch a video, but don't finish it, or don't watch it for a long time.

This particular use of the AI recommendation software shows a good understanding of how such platforms track their behavior (e.g. likes, scrolling, watching) and use it to provide tailored content. However, children did not explicitly recognize AI recommendation algorithms responsible for this function; rather, they generally attributed this capability to the platforms, such as Netflix and

TikTok. When asked to share what they thought about AI recommendations, children reported mixed feelings: both boring and convenient.

Besides experiences with recommendation software, experiences with voice assistants were shared in all groups, showing examples of how children use voice assistants. For example:

Aron: We had a Hey Google at home
Researcher: And what would you use it for?
Aron: Ehm,... Usually, for example, to change the volume of music. Asking it for jokes is also fun.
Bobby: 'Hey Google, a joke.' And then it will tell you a joke.

As the extract shows, Aron used the voice assistant at his home for both practical tasks and entertainment. In three groups, students also shared how they believe voice assistants can be helpful for sick, disabled, or lazy people. For example, Ruben, Bobby, and Julia all said similar things in different groups:

Ruben: I think AI is convenient for lazy people, or people who are sick, because they can close the curtains with their voice.

Bobby: It can help you with things. For example, with things that some people cannot do on their own. For example, people who have two broken legs, or no legs. Ehm... Yes, it can help them by automatically closing the curtains, or turning on lights.

The most common tasks that the students reported using voice assistants for were related to listening to music, turning on and off the lights, opening and closing windows, or telling jokes.

All groups mentioned robot vacuum cleaners and lawnmowers as an AI example. A few students shared that they had these applications at home, while others mentioned they had seen them at friends' houses. Similar to the voice assistants, students thought such robots could be helpful:

Stan: A robot lawn mower is pretty convenient too. It can save you time.

Julia: I think the same as Sascha. It can be convenient, for example, if you are sick and you cannot vacuum every day, a robot can do it for you. Or a robot lawn mower. But it can also be used in a bad way.

4.3 Ethical risks of AI

During the interviews, students extensively talked about various ethical issues. In the introductory course, one lesson specifically discussed the topic of AI and Ethics. In this lesson, the teacher discussed with the students why platforms such

as YouTube and TikTok use AI recommendation software. During the interviews, it became evident students have a clear understanding and strong opinions on this matter.

Stella: you know that YouTube gets money when we are watching videos. So they make money off my data.
Researcher: You mean they make money when you use YouTube?
Stella: Yes, I think they should share their profits with me. Because it is my data. They have things that are mine, it is about me.
Researcher: so how does it work?
Stella: Well, if you are watching videos that you don't like, you will probably stop watching videos on YouTube. So you will have less screen time, and then YouTube will get less money because of that.
Researcher: and you think it is not fair that they make money through you?
Stella, Erica, and Tom [simultaneously]: Yes!
Stella: The money should come to us, they already have enough money, why don't they share it? It is our money. No, it is our data, and they get the money.
Researcher: ok
Stella: Do you get it? I mean, I don't necessarily have to make money, but that they make money with my data, that's not ok

Stella understands that YouTube used the algorithm to make sure she spends more time on their platform which will eventually make her behavior profitable for YouTube. Stella and her group members believe it is unfair that YouTube uses her data to make a profit, touching upon the ethical issue of ownership. Stella felt very strongly about this, even asking the researcher in the end 'Do you get it?' to make sure her point had come across. Another group had fewer problems with the idea that YouTube makes money by using this algorithm:

Researcher: And why do you think YouTube or TikTok use AI?
Rachel: so you will keep watching videos
Feline: Yes, they make money, so when you watch more videos, they make more money
Sascha: commercials, because of the commercials. You watch more videos and also more commercials, and they earn money with that
Researchers: And what do you think about that? That they earn money.
Sascha: it's a little annoying, but in some way it is convenient
Feline: Yes
Julia: I mean, they have to eat too. I think it is smart. They have to earn money too.
Rachel: I don't mind it. I mean, I am not complaining when my mum is going to work to make money, right?
Feline: I think it is pretty smart. Smart that they came up with this idea. Because we watch more videos so that they can make more money. Very smart of those people.

In this group, all children believed it was YouTube's right to earn money and they didn't feel they needed to be compensated for that.

A second ethical issue they were concerned with is privacy issues, being afraid that personal data might be sold to other parties or used for other purposes than for recommending new videos. For example, Rogier shared:

Rogier: Well, AI is governed by very big companies and you cannot always trust those.
Researcher: And why, what do you mean by 'we cannot trust those'?
Rogier: Well, Facebook, for example, they have a lot of private data, and they use it for commercials, but that data can be easily used for bad things.

Rogier shows a certain distrust of big tech companies, stating that such companies might misuse their private data. Sarah had similar worries:

Sarah: I think it is important that our personal information is not used to make money [by selling it to other companies], but only to recommend new videos, but they [YouTube] cannot misuse our data.
Researcher: And what do you mean with personal data?
Sarah: Ehm.. Like your address and phone number.

Another ethical issue, extensively present in the data is that of AI bias. All the children talked a lot about the issue of AI bias. During the AI and Ethics lesson, the students took part in an exercise where they would search for biases in Google Images. As an example, the teacher googled 'baby', and the students noticed that Google would mostly show Caucasian babies. After this example, children had to search for such biases in Google Images themselves. During the interviews, it became clear that children were unfamiliar with the term AI bias but did remember the concept vividly.

Researcher: I believe you did an exercise where you had to look for images on Google. Your teacher used the example of googling 'baby' and you would only see white babies.
Rose: Ah, yes, we talked about this.
Betty: yes!
Sarah: we did this!
Researcher: Do you remember the lesson? What happened?
Rose: I remember this because I thought this lesson was super interesting. We talked about, for example, if you have face id, it works better on white people than people of color. And for example, if you look for pictures of 'fights', you usually get pictures of people of color instead of white people.
Sarah: And also with 'kidnapping' you …
Rose: yes
Sarah: you will see mostly men, but they could also be women.
Researcher: And do you know why this happens?
Betty: ehm…
Sarah: Because maybe this sounds more logical to them. It is the same in cartoons.

Other groups shared other examples of biased results, for example that searching for 'married' mostly showed heterosexual couples and not 'boy with boy or girl with girl'. Some children explicitly called such biases 'racist' and 'sexist'. For example, Aron shared:

Aron: I think AI is racist, because when you search for 'monkey holding a box' [in Google Images], you will see a baby of color with a box.

All groups disapproved of such biases and believed they needed to be fixed. and that they should be fixed. However, when asked about the origins of such biases or potential solutions, a large majority of students struggled to respond. One exception was Stella, who shared an idea:

Researcher: So how do you think we can change this [biases in Google Images]
Stella: well, that more people from, more foreigners, and people who are attracted to other genders, also just start working on AI. I don't think it's meant to be that way, because there are those white people who work on it and they kind of forget about the other people. So I think that also just a little more foreigners can contribute to the research or whatever happens. I think maybe more foreigners can join. Because look, for example, you don't see Moroccans there on Google when you search for people. You don't see it.

Stella's words 'or whatever happens' indicate that she does not understand how AI algorithms are exactly made, but she realizes that there are people who develop such AI algorithms. More specifically, Stella believes that there are mostly 'white people' who work on such algorithms who unconsciously forget that there are other-looking people, or in Stella her words 'foreigners'. As a solution to AI bias, Stella believes development teams should be more diverse to make sure nobody is overlooked or not represented. In saying this, Stella places the responsibility for such biases on the developers and holds them accountable for this issue. Other ethical topics that were briefly mentioned by children were: fake news, misinformation, AI taking over the world, and people becoming too dependent, and therefore lazy because AI takes over too many tasks.

5 Discussion

This study aimed to explore young children's understanding of AI as both a technology and a socio-cultural tool. Through semi-structured group interviews, children were inquired about what AI is, how they use it, and the risks they see in using it. The findings are presented with accompanying data extracts to provide insights into students' views and are structured around three main themes: AI understanding, AI awareness, and AI ethics.

The findings carry various similarities with recent studies on students' prior AI knowledge and conceptions. The first similarity is that on an abstract level, students conceptualize AI as a computer system that is programmed by humans and is intelligent because it can carry out tasks independently or autonomously engage in decision-making (Henry et al., 2021; Mertala et al., 2022; Ottenbreit-Leftwich et al., 2022; Williams et al., 2022). This abstract conceptualization lacked depth, as evidenced by students' misconception of labeling electrical devices or automated processes as AI (see also Kim et al., 2023; Williams et al., 2022; Zhang et al., 2022) and a lack of understanding of how AI works (see also Mertala et al., 2022; Ottenbreit-Leftwich et al., 2022).

In terms of AI use, the findings reveal a collective awareness among all students regarding common AI applications in their daily lives, such as voice assistants, recommendation algorithms, and robot vacuum cleaners. Students recognized AI's potential in assisting with household chores and physical tasks, while also acknowledging its capacity to help individuals with disabilities or illnesses. These results contribute to existing research, indicating that children perceive AI as a facilitator, streamlining tasks, saving time, and offering support to those less abled (Mertala et al., 2022; Ottenbreit-Leftwich et al., 2022; Zhang et al., 2022).

The findings show high engagement with and nuanced awareness of the ethics of AI. Students expressed concerns about AI bias such as discrimination against people of color. Moreover, students actively shared opinions about issues of privacy and data ownership, drawing on personal experiences with platforms like YouTube and TikTok. Zhang et al., (2022) found similar results among slightly older students (11–14 years). Similarly, Dipaola et al. (2022) found nuanced views on the ethics of AI when it concerns AI technologies that students aged 11 to 14 are familiar with. Another general concern of students regards the increasing reliance on AI, consequently making people lazy (Mertala et al., 2022; Zhang et al., 2022).

A notable difference between our findings from the existing literature is the absence of AI understanding as robots (e.g., Kim et al., 2023; Mertala et al., 2022; Ottenbreit-Leftwich et al., 2022; Williams et al., 2022; Zhang et al., 2022). As a matter of fact, no one used the term "robot" in abstract AI conceptualizations. References to robots were only limited to specific AI examples like robot vacuum cleaners, lawnmowers, or two distinct provided by two individual students: educational toys or companionship robots in the home of a grandmother with dementia. In literature, conceptualizations of AI as robots are often present and assigned to unrealistic AI media portrayals (DiPaola et al., 2022; Kim et al., 2023). This might suggest a more nuanced understanding of Artificial Intelligence.

A possible explanation for the absence of robot-related references may stem from the fact that in socio-cultural context of the study it is uncommon to have interactions with robots, whereas for example in Japan, personal and service robots co-exist with people in Japanese society, where robots work together with people in restaurants and shops (Eguchi et al., 2021). Another possible explanation of this discrepancy might be that children's understanding was dominantly framed within the context of their own experiences and use of AI within their homes, whereas for example in Zhang et al's. (2022) study, students engaged in ways in which careers will be impacted by AI, resulting in kids imagining AI being able to take over dangerous jobs or perform tasks with more efficiency.

Our findings suggest that children develop an understanding of AI through the use of AI technologies in their everyday lives. This is demonstrated in the findings through children's various strategies to manipulate TikTok's recommendation algorithms to curate diverse content, such as intentionally liking videos that they don't enjoy. Although children do not explicitly link these actions to the workings of AI, students' everyday experiences and observations lay the groundwork for a preliminary understanding. This underscores the influential role of personal encounters in shaping students' early perceptions of AI, aligning with the socio-cultural framework proposed by Vygotsky.

Furthermore, our findings indicate that children perceive AI as first and foremost as a tool rather than a technology. Unlike framing AI abilities in terms of its technical capabilities, such as sensing or hearing through sensors, students focused on how AI functions in the context of their homes. Examples included AI abilities to manage lights and curtains, perform cleaning activities, or aid less abled in the context of their homes. This perspective highlights the practical, hands-on role students attribute to AI, emphasizing its utility as a tool within their immediate living environments or those of others.

Finally, the findings indicate that children exhibit a high level of engagement with the ethics of AI, showing a keen interest in the socio-cultural implications,

particularly about AI applications with which they are familiar. Platforms like YouTube and TikTok provide appropriate and relatable contexts to start discussions on crucial topics such as privacy, data ownership, and how AI influences behavior.

6 Conclusions and recommendations

The rapid integration of AI in our daily lives has turned AI literacy into a necessary skill set and kicked off the development of AI education for schools. To inform the design of effective educational resources, we took a qualitative research approach to explore young children's understanding of AI as a technology and a tool with socio-cultural impact. This approach offered a deeper understanding of how students understand AI, its uses, as well as issues related to ethics. The findings suggest that children's understanding of AI is grounded in their personal experiences and habits as part of their everyday lives. Furthermore, we found that children have a socio-cultural approach to AI in which they experience AI as first and foremost a tool that can help, but also influence their behavior. The goal of this exploratory study was not to draw generalizable conclusions but rather to construct an in-depth understanding of young children's sense-making of AI. Based on our findings, and supporting evidence from the growing literature on both students' prior AI conceptions and experiences with AI ethics curricula, we offer a set of recommendations for the design of engaging and personally relevant AI education curriculum materials for primary school students.

First, to tackle the common misconception among students that AI is robots, we recommend focusing on software applications of AI by providing students with alternative, more realistic, and above all recognizable applications derived from their contexts. Such an emphasis not only broadens their understanding of AI beyond robotic portrayals but also grounds the concept in relatable, real-world scenarios.

Secondly, in curriculum design, careful consideration of the socio-cultural context of students is essential. Integrating learning activities that connect with common daily life AI experiences to which students may already have been exposed is crucial. A practical implementation of this recommendation is to use AI recommendation software, such as those found on platforms like TikTok or YouTube, as an accessible entry point for students to grasp what role data has in the working of AI. By contextualizing AI learning within students' everyday life experiences, educators can enhance engagement and foster critical AI literacy.

However, as highlighted by Eguchi et al. (2021) and Druga et al. (2019), prior AI experiences are not universal and can differ based on several factors, such as geographical context, socio-economic status, or family interests. This leads to our third recommendation: to create AI experiences in the classroom, as a collective experience that can be used as an entry point for other learning activities. For example, by placing a Hey Google in the classroom and integrating it into the teaching by using it to set timers during class activities asking it to share a weather report before going outside, or using a robot vacuum cleaner to clean the classroom. This way, instead of assuming individual AI experiences, the teacher can create collective classroom experiences that can be central to the AI lessons.

Lastly, our final recommendation proposes to develop *critical AI literacy* that places justice at the forefront and approaches AI as a socio-cultural tool (Avraamidou, 2024). Although many AI literacy frameworks incorporate an element of AI ethics, the emphasis often centers on AI as a technology (e.g., Long & Magerko, Touretzky et al., 2019). However, both our findings and existing literature illustrate that students' engagement with AI is especially intertwined with ethical considerations and socio-cultural implications. Therefore, adopting a critical AI literacy framework appears to be a promising direction.

Appendix

Semi-structured interview questions:

These questions served as the base for the semi-structured interviews. It's important to note that the order of the questions was adjusted based on the flow of the conversation and the responses of the young children. In many instances, while responding to one question, students often addressed other questions, or multiple questions simultaneously.

AI as a technology

- Can you explain what AI is?
- How does AI work?
- What are examples of AI?
- Where can we find AI?

AI as a tool

- Do you use AI at home?
- What do you use AI for?
- What can AI do?
- Can AI help us?

AI and ethics

- Does AI also affect you?
- Is AI always good for us?
- Can AI make mistakes?
- Can AI be dangerous?

During the interviews, the first two groups eagerly discussed an exercise at school on AI biases. The students spoke about this exercise with such emotion that the researcher decided to ask the other groups about it as well, to further explore the children's engagement with the topic.

- Do you remember the exercise where you had to look for 'baby' in Google Images?

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Data availability The datasets gathered and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare that they have no competing interests.

References

Ali, S., DiPaola, D., Lee, I., Sindato, V., Kim, G., Blumofe, R., & Breazeal, C. (2021). Children as creators, thinkers and citizens in an AI-driven future. *Computers and Education: Artificial Intelligence, 2*, 100040–100051. https://doi.org/10.1016/j.caeai.2021.100040

Avraamidou, L. (2013). Superheroes and supervillains: Reconstructing the mad-scientist stereotype in school science. *Research in Science and Technological Education, 31*(1), 90–115. https://doi.org/10.1080/02635143.2012.761605

Heeg, D. M., Smith, T., & Avraamidou, L. (2022). Children's experiences and self-identification with science in the context of an out-of-school stem program. *EURASIA Journal of Mathematics, Science and Technology Education*, *18*(4), Article em2091. https://doi.org/10.29333/ejmste/11888

Heeg, D. M., & Avraamidou, L. (2023). The use of artificial intelligence in school science: A systematic literature review. *Educational Media International, 60*(2), 125–150. https://doi.org/10.1080/09523987.2023.2264990

Avraamidou, L. (2024). Can we disrupt the momentum of the AI colonization of science education? *Journal of Research in Science Teaching.* Advance online publication. https://doi.org/10.1002/tea.21961

Burgsteiner, H., Kandlhofer, M., & Steinbauer, G. (2016). Irobot: Teaching the basics of artificial intelligence in high schools. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 30, No. 1). https://doi.org/10.1609/aaai.v30i1.9864

Casal-Otero, L., Catala, A., Fernández-Morante, C., Taboada, M., Cebreiro, B., & Barro, S. (2023). AI literacy in K-12: A systematic literature review. *International Journal of STEM Education, 10*(1), 29. https://doi.org/10.1186/s40594-023-00418-7

Chen, Y., & Tang, X. (2018). *Fundamentals of Artificial Intelligence for High Schools*. East China Normal University Press.

DiPaola, D., Payne, B. H., & Breazeal, C. (2020). Decoding design agendas: an ethical design activity for middle school students. *Proceedings of the Interaction Design and Children conference,* (pp. 1–10). https://doi.org/10.1145/3392063.3394396

DiPaola, D., Payne, B. H., & Breazeal, C. (2022). Preparing children to be conscientious consumers and designers of Ai technologies. In S. Kong & H. Abelson (Eds.), *Computational Thinking Education in K-12: Artificial Intelligence Literacy and Physical Computing.* MIT Press.

Druga, S., Williams, R., Breazeal, C., & Resnick, M. (2017). Hey Google is it ok if I eat you? Initial explorations in child-agent interactions. In *Proceedings of the 2017 Conference on Interaction Design and Children,* 595–600. ACM. https://doi.org/10.1145/3078072.3084330

Druga, S., Vu, S. T., Likhith, E., & Qiu, T. (2019). Inclusive AI literacy for kids around the world. In P. Blikstein & N. Holberts (Eds)., *Proceedings of FabLearn 2019 8th Annual Conference on Maker Education* (pp. 104–111). The Association for Computing Machinery. https://doi.org/10.1145/3311890.3311904

Eguchi, A., Okada, H., & Muto, Y. (2021). Contextualizing AI education for K-12 students to enhance their learning of AI literacy through culturally responsive approaches. *KI-Künstliche Intelligenz, 35*(2), 153–161. https://doi.org/10.1007/s13218-021-00737-3

Henry, J., Hernalesteen, A., & Collard, A. S. (2021). Teaching artificial intelligence to K-12 through a role-playing game questioning the intelligence concept. *KI-Künstliche Intelligenz, 35*(2), 171–179. https://doi.org/10.1007/s13218-021-00733-7

Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016). Artificial intelligence and computer science in education: From kindergarten to university. In *2016 IEEE Frontiers in Education Conference (FIE)* (pp. 1–9). IEEE. https://doi.org/10.1109/FIE.2016.7757570

Kim, K., Kwon, K., Ottenbreit-Leftwich, A., Bae, H., & Glazewski, K. (2023). Exploring middle school students' common naive conceptions of artificial intelligence concepts, and the evolution of these ideas. Education and Information Technologies, (20230118). https://doi.org/10.1007/s10639-023-11600-3

Kong, S. C., & Zhang, G. (2021). A Conceptual framework for designing artificial intelligence literacy programmes for educated citizens. In S. C. Kong, Q. Wang, R. Huang, Y. Li, & T. C. Hse (eds)., *Conference Proceedings (English Track) of the 25th Global Chinese Conference on Computers in Education, GCCCE 2021* (pp. 11-15). The Education University of Hong Kong

Lee, I., Ali, S., Zhang, H., DiPaola, D., & Breazeal, C. (2021). Developing middle school students' AI literacy. In Proceedings of the 52nd ACM technical symposium on computer science education (pp. 191–197). https://doi.org/10.1145/3408877.3432513

Long, D., & Magerko, B. (2020). What is AI literacy? Competencies and design considerations. In R. Bernhaupt, F. F. Muller, D. Verweij & J. Andres (Eds)., *Proceedings of the 2020 CHI conference on human factors in computing systems* (pp. 1–16). Association for Computing Machinery. https://doi.org/10.1145/3313831.3376727

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation*. Wiley.

Mertala, P., Fagerlund, J., & Calderon, O. (2022). Finnish 5th and 6th-grade students' pre-instructional conceptions of artificial intelligence (AI) and their implications for AI literacy education. *Computers and Education: Artificial Intelligence,* 100095. https://doi.org/10.1016/j.caeai.2022/100095

Micheuz, P. (2020). Approaches to Artificial Intelligence as a Subject in School Education. In T. Brinda, D. Passey, & T. Keane (Eds), Empowering Teaching for Digital Equity and Agency. OCCE 2020. IFIP Advances in Information and Communication Technology, 595. Springer.

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). Conceptualizing AI literacy an exploratory review. *Computers and Education: Artificial Intelligence, 2*, 100041. https://doi.org/10.1016/j.caeai.2021.100041

Ng, D. T. K., Leung, J. K. L., Su, M. J., Yim, I. H. Y., Qiao, M. S., & Chu, S. K. W. (2022a). AI literacy for All. *AI literacy in K-16 classrooms* (pp. 21–30). Springer International Publishing. https://doi.org/10.1007/978-3-031-18880-0_3

Ng, D. T. K., Leung, J. K. L., Su, M. J., Yim, I. H. Y., Qiao, M. S., & Chu, S. K. W. (2022b). The Landscape of AI Literacy. *AI literacy in K-16 classrooms* (pp. 31–62). Springer International Publishing. https://doi.org/10.1007/978-3-031-18880-0_4

OECD. (2021). *AI and the Future of Skills, Volume 1: Capabilities and Assessments.* Educational Research and Innovation, OECD Publishing, Paris. https://doi.org/10.1787/5ee71f34-en

Ottenbreit-Leftwich, A., Glazewski, K., Jeon, M., Jantaraweragul, K., Hmelo-Silver, C. E., Scrinber, A., Lee, S., Mott, B., & Lester, J. (2022). Lessons Learned for AI Education with Elementary Students and Teachers. *International Journal of Artificial Intelligence in Education,* 1–23. https://doi.org/10.1007/s40593-022-00304-3

Payne, B. H. (2020). *Can my algorithm be my opinion?: An AI + Ethics curriculum for Middle School Students.* Master's thesis, Massachusetts Institute of Technology, Media Lab, Cambridge, MA, USA.

Pedro, F., Subosa, M., Rivas, A., & Valverde, P. (2019) *Artificial intelligence in education: Challenges and opportunities for sustainable development.* Paris: UNESCO . Retrieved January 30, 2023 from https://unesdoc.unesco.org/ark:/48223/pf0000366994

Redecker, C. (2017). *European framework for the digital competence of educators*. Office of the European Union.

Schepman, A., & Rodway, P. (2023). The General Attitudes towards Artificial Intelligence Scale (GAAIS): Confirmatory Validation and Associations with Personality, Corporate Distrust, and General Trust. *International Journal of Human-Computer Interaction, 39*(13), 2724–2741. https://doi.org/10.1080/10447318.2022.2085400

Su, J., Ng, D. T. K., & Chu, S. K. W. (2023a). Artificial intelligence (AI) literacy in early childhood education: The challenges and opportunities. *Computers and Education: Artificial Intelligence*, *4*. https://doi.org/10.1016/j.caeai.2023.100124

Su, J., Guo, K., Chen, X., & Chu, S. K. W. (2023b). Teaching artificial intelligence in K–12 classrooms: a scoping review. *Interactive Learning Environments*, 1–20. https://doi.org/10.1080/10494820.2023.2212706

Szczuka, J. M., Starthmann, C., Szymczyk, N., Mavrina, L. & Krämer, N.C. (2022). How do children acquire knowledge about voice assistants? A longitudinal field study on children's knowledge about how voice assistants store and process data. *International Journal of Child-Computer Interaction*, 33. https://doi.org/10.1016/j.ijcci.2022.100460

Su, J., & Zhong, Y. (2022). Artificial Intelligence (AI) in early childhood education: Curriculum design and future directions. *Computers and Education: Artificial Intelligence*, *3*. https://doi.org/10.1016/j.caeai.2022.100072

Touretzky, D., Gardner-McCune, C., Martin, F., & Seehorn, D. (2019). Envisioning AI for K12: What should every child know about AI? *In Proceedings of the AAAI Conference on Artificial Intelligence., 33*, 9795–9799. https://doi.org/10.1609/aaai.v33i01.33019795

UNESCO. (2019). *Artificial intelligence for sustainable development programme*. Retrieved February 2, 2023, from: https://en.unesco.org/sites/defaults/files/mlw2019-programme.pdf

UNESCO. (2022). *K-12 AI curricula A mapping of government-endorsed AI curricula.* Retrieved January 30, 2023, from https://unesdoc.unesco.org/ark:/48223/pf0000380602

UNICEF. (2021). *Policy guidance on AI for children*. Retrieved February 2, 2023 from: https://www.unicef.org/globalinsight/media/2356/file

Van Brummelen, J., Heng, T., & Tabunshschyk, V. (2021). Teaching tech to talk: K-12 conversational artificial intelligence literacy curriculum and development tools. *Proceedings of the AAAI Conference on Artificial Intelligence, 35*(17), 15655–15663. https://doi.org/10.1609/aaai.v35i17.17844

Vanover, C., Mihas, P., & Johnny, Saldaña (Eds.). (2022). *Analyzing and interpreting qualitative research : after the interview (First)*. SAGE Publications.

Wang, B., Rau, P.-L.P., & Yuan. (2023). Measuring user competence in using artificial intelligence: Validity and reliability of artificial intelligence literacy scale. *Behaviour & Information Technology, 42*(9), 1324–1337. https://doi.org/10.1080/0144929X.2022.2072768

Williams, R., Ali, S., Devasia, N., Dipaola, D., Hong, J., Kaputsos, S. P., Jodan, B., & Breazeal, C. (2022). AI ethics curricula for middle school youth: Lessons learned from three project-based curricula. *International Journal of Artificial Intelligence in Education*, 1–59. https://doi.org/10.1007/s40593-022-00298-y

Williams, R., Park, H. W., Oh, L., & Breazeal, C. (2019). Popbots: Designing an artificial intelligence curriculum for early childhood education. In *33rd AAAI Conference on Artificial Intelligence* (pp. 9829–9736). https://doi.org/10.1609/aaai.v33i01.33019729

Xiong, Y., Wang, J., & Huang, J. (2018). *Textbook Series on Artificial Intelligence for Elementary and Middle Schools*. East China Normal University Press.

Yue, M., Jong, M. S. Y., & Dai, Y. (2022). Pedagogical design of K-12 artificial intelligence education: A systematic review. *Sustainability, 14*(23), 15620. https://doi.org/10.3390/su142315620

Zhang, H., Lee, I., Ali, S., DiPaola, D., Cheng, Y., & Breazeal, C. (2022). Integrating ethics and career futures with technical learning to promote AI literacy for middle school students: An exploratory study. *International Journal of Artificial Intelligence in Education, 33*(2), 290–324. https://doi.org/10.1007/s40593-022-00293-3