A Literature Review of AI Education for K-12

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Abstract: The rapidly evolving artificial intelligence (AI) technology has a significant impact on how humans work and live. As a result, it is critical and timely for educators to guide students in reflecting on how AI may impact people's lives and to equip them with the ability to responsibly maximize benefits while mitigating potential harms. However, there is a lack of educational research on how to teach K-12 students about AI technology and AI ethics to prepare them to deal with these issues as future citizens. In this context, my colleagues and I are developing curricula for K-12 students that incorporate AI technology and AI ethics. As part of our research, this literature review investigates the evolution of AI education for grades K-12. It provides context for AI educational research by us and other researchers in related fields.

Keywords: Artificial intelligence education, AI ethics, curriculum, K-12 education

Introduction

Artificial Intelligence (AI) was defined by McCarthy (2007) in 1956 as "the science and engineering of making intelligent machines" (p. 2). The rapidly evolving AI technology has a significant impact on how we work and live, raising ethical concerns about the use of AI. (Dimock, 2020; Maclure & Russell, 2021; Maouche, 2019). This raises an important question regarding how education can prepare people to become wise consumers and responsible builders of AI technology. However, there is a lack of educational research on curriculum design and testing that enables K-12 students to learn about AI technology and its ethics effectively (Hagendorff, 2020; Johnson, 2017). In this context, my colleagues and I have been conducting research on AI curriculum design with the goal of embedding critical reflections on AI ethics within AI technical knowledge through hands-on activities for K-12 students. As part of our research, this literature review investigates the evolution of AI education for grades K-12, providing context for our study and paving the way for our current curriculum development in preparation for fieldwork. Our research questions are:

1. What programs are available for K-12 students to learn about AI?
2. What is taught in these programs and how?

Development of AI Education

AI education can be divided into two distinct categories: AI education for professionals (mostly for those working in higher education) and AI education for the general public (including K-12 students). The literature on the history of AI education provides context for our research.

AI Education: From Tertiary Level to K-12 Level

Our research focuses on AI curriculum design for K-12 students. However, it is necessary to examine the evolution of AI education for K-12 students to identify gaps in the research. AI education research begins at the tertiary level, with the goal of teaching AI technical knowledge to university undergraduate and graduate students to cultivate future AI experts. Research has been conducted on how to teach AI to students in higher education. Early examples include: Dodds et al.'s (2008) study on fun and inspiring ways to engage undergraduate students in various aspects of AI learning; McGovern et al.'s (2011) research on teaching introductory AI through Java-based simulations; and Torrey's (2012) research about teaching strategies for undergraduate courses about algorithms and AI. More recently, Keating and Nourbakhsh (2018) conducted an experimental study with first-year undergraduate students in Carnegie Mellon University's human-machine interactions course. In this interdisciplinary course, students were introduced to core themes of AI's historical development and current state of the art, such as power negotiations, political implications of advancing technology, and cultural responses. Students in this study built conceptual maps that made sense of technological advances and their societal implications. At the University of California, an introductory AI course that took a project-centered approach was designed to teach AI concepts using the classic game Pac-Man (DeNero & Klein, 2010). In each of the course's four projects (State-Space Search, Multi-Agent search, Probabilistic Inference, and Reinforcement Learning), students implemented general-purpose AI algorithms and then incorporated domain knowledge about the Pac-Man environment. Kong et al. (2021) investigated how a literacy course helps university students from various disciplines develop a conceptual understanding of AI. Tertiary AI education research reports on

experience that AI education for K-12 could benefit from. K-12 students have become more important stakeholders in the AI industry. As an essential component of education to prepare younger students for the AI era, AI education has begun to "trickle down to the K-12 range" (Wong et al., 2020, p. 23). In recent years, researchers and educators have collaborated to determine what AI education for K-12 students should include by drawing inspiration from tertiary level AI education (De La Higuera, 2019; Kandlhofer et al., 2019; Long et al., 2020). The following sections will introduce the efforts being made to promote AI education to younger students who have no technical background.

National or Regional AI Curriculum Guidelines

Many countries have developed national curriculum guidelines to contextualize AI education for K-12 students. According to the UNESCO (2022) report "K-12 AI curricula — A mapping of government-endorsed AI curricula", eleven UNESCO Member States (i.e., Armenia, Austria, Belgium, China, India, Republic of Korea, Kuwait, Portugal, Qatar, Serbia, and United Arab Emirates) "have developed, endorsed and implemented" a national AI curriculum, and many more are developing a curriculum of their own (p. 19). The Chinese government, for example, has launched a series of AI education development plans. Following the *2017 New Generation of Artificial Intelligence Development Plan* (Chinese State Council, 2017), which clearly stated the intention to establish AI courses in primary and secondary schools, "Artificial Intelligence" was listed as a compulsory course in the *2017 New Curriculum Standard of Ordinary Senior High Schools* (Insights, G. E. T. C., 2019).

Other countries have seen an increase in K-12 AI education programs and curricula, including the United States, Finland, the United Kingdom, Canada, Turkey, and Argentina (Touretzky et al., 2019a). Canada, for example, was the first country in the world to announce a national AI strategy in March 2017 (Canadian Institute for Advanced Research, 2017). The *Ontario Curriculum Grades 1-8: Science and Technology, 2022* (Ontario Ministry of Education, 2022) includes AI in its content with the goal of teaching students about the "the development of artificial intelligence (AI) systems" and "the impact and application of AI in their daily lives" (n.p.). However, teaching resources that will assist schools and communities in providing such learning opportunities to students are still in progress. As a result, there is a critical need for educators, curriculum designers, and education researchers to collaborate on AI curricula that are applicable for Ontario schools and beyond.

Frameworks Developed by Research and Educational Organizations

Among the research and educational organizations that have begun to develop AI learning frameworks for K-12 students are AI4All, MIT Media Lab, and the International Society for Technology in Education (ISTE). According to Touretzky et al. (2019a), the AI4K12 Initiative was launched in 2018 with the goal of developing guidelines for teaching AI at the K–12 level. As a framework for teaching AI to K-12 students, the AI4K12 Working Group published their "five big ideas":

1. Computers perceive the world using sensors.
2. Agents maintain representations of the world and use them for reasoning.
3. Computers can learn from data.
4. Intelligent agents require many kinds of knowledge to interact naturally with humans.
5. AI can impact society in both positive and negative ways. (Touretzky et al., 2019b)

Each of the five big ideas is "unpacked into a set of concepts and subconcepts that are further expanded for each grade band (K–2, 3–5, 6–8, and 9–12) and then summarized in a progression chart" (Touretzky et al., 2019a, p. 89). These initiatives lay "the groundwork for AI education in K12" (Touretzky et al., 2019b, p. 9796) and serve as the foundation for our AI curriculum design for K-12.

Development of Curriculum Resources

With the help of the aforementioned guidelines and frameworks, significant efforts have been made to address the need for curriculum resources for K-12 AI education. The early research by Fok and Ong (1996), Heinze et al. (2010), and Tsukamoto et al. (2015) focused on teaching specific AI subjects at the school level. For example, Australian AI researchers collaborated with K-6 teachers to develop a three-year curriculum covering basic AI concepts, AI

terminology, and AI history through the "Scientist-in-Schools" program (Heinze et al., 2010). However, Burgsteiner et al. (2016) commented on Fok and Ong (1996) and Heinze et al's (2010) work, claiming that they "only deal with some selected aspects of AI (e.g. history, Turing Test, chatbots, neural networks, etc.)" (p.4126). Burgsteiner et al. developed a more comprehensive AI course (dubbed "iRobot") that teaches high school students "major topics of AI/computer science (automatons, agent systems, data structures, search algorithms, graphs, problem solving, planning, machine learning)" (p. 4126). More recently, Han et al. (2018) launched a Chinese AI education program in primary and secondary schools in Qingdao City and proposed an "AI+" (AI plus) curriculum that mainly employs "the method of + knowledge acquisition, + technical training, + immersion experience, + project learning, and + social practise to design and implement" (p. 4137). The MIT RAISE website (raise.mit.edu) contains a variety of K-12 AI education resources, including curricula for various levels developed at MIT. For example, Ali et al. (2019) developed K-8 curricula that help students "understand AI, learn about ethics, [and] think creatively" (p. 1) to prepare them to thrive in the AI era. Williams et al. (2019) created the PopBots Platform and Curriculum, which includes a social robot toolkit, three hands-on AI activities, and associated assessments for young children to learn about AI concepts. Williams et al. (2021) created "How to Train Your Robot, A Middle School AI and Ethics Curriculum" for middle school teachers who plan to introduce AI to their students.

Besides research institutions, private companies such as Google, IBM, Microsoft, and Intel, and others, are contributing to the development and implementation of AI learning resources like curricula and teaching tools. Google, for example, has launched a series of online "AI experiments," including "Teachable Machine" and "QuickDraw" (https://experiments.withgoogle.com/collection/ai). Machine Learning for Kids (https://machinelearningforkids.co.uk/) provides online demos in which students train classifiers using web applications or Scratch extensions. The LearningML (https://learningml.org) project by Rodriguez-Garcia et al. (2020) demonstrates how LearningML, a platform designed to teach and learn about machine learning by doing, can help bring the fundamentals of AI to children and encourage learners to understand AI applications and their impacts on people's lives. These efforts contribute to the relatively new resources for AI education. However, media companies benefit from the use of algorithms and other tools designed to keep users on their platforms and generate revenue (Sartor & Loreggia, 2020). Thus, it is critical for educators to help students become aware of these potential issues when using these tools by considering why these companies are developing educational tools, what the goals of these tools are, and how creating and distributing such tools may benefit the corporations themselves.

Current Educational Practices for Various Learners

In-school and After-school Programs

With the help of curriculum guidelines and resources, education researchers have advocated for designing effective learning experiences that prepare young people to be critical consumers of AI technology while also allowing them to see themselves as future AI builders (Williams et al., 2019). To assist K-12 students in learning AI, various in-school and after-school programs have been developed.

For in-school AI education, using the AI-in-a-Box kit provided by ReadyAI, Williams Middle School of the United States has implemented a three-week pilot AI curriculum which introduces students to potential AI careers, as well as gives them the opportunity to examine everyday technologies and existing ethical considerations of the proliferation of AI (Wong et al., 2020). Sabuncuoglu (2020) introduced their 36-week open-source AI course for middle school students in Norway. According to the findings of this research, "exploring digital content and with the physical tasks promise an interesting design space" (p. 101) in AI education.

Because K-12 AI education is still in its early stages, few schools worldwide have the resources to offer AI courses or integrate AI knowledge into existing school subjects. Efforts to promote AI education for K-12 students are primarily visible outside of school settings. Some researchers have discussed AI literacies for various contexts: Druga et al. (2021) developed a 4As (ask, adapt, author, and analyze) framework of AI literacy to help families develop a critical understanding of smart technologies that are embedded in their lives. Druga et al. (2019) investigated how children aged 7-12 years old in the United States, Germany, Denmark, and Sweden perceive current AI technologies and envision future smart devices and toys through engaging these children in 1.5-2-hour long workshops. Long et al. (2021) investigated how to design museum experiences that communicate key concepts about AI.

AI Ethics Education

Historically, tertiary level AI courses ignored ethics, either by separating it from AI technical knowledge or by isolating it into a separate course (Fiesler et al., 2020). At the K-12 level, however, ethics is at the heart of AI4K12's big ideas in AI (Touretzky, 2019b). According to Leslie (2019), AI ethics is concerned with the "values, principles, and techniques" (p. 4) that guide moral conduct and prescribe necessary obligations in the development and use of AI technologies to produce "ethical, fair, and safe AI applications" (p. 4). Gong et al. (2020) discovered that in Qingdao city of China, K-9 students' "awareness of AI ethics and IP is almost zero" as "the societal impact of AI is seldom discussed in class" (p. 5). In response, academics have become increasingly focused on ethical issues, and have established institutions specifically designed to address ethical concerns regarding AI. For example, the Institute for Ethical AI in Education in the UK endeavors to produce a framework for ethical governance of AI in education, and the Analysis & Policy Observatory has recently published a discussion paper on developing an AI ethics framework for Australia (Olaf et al., 2019). Researchers have already begun to develop programs to teach young students about AI ethics: Payne, a graduate student at the MIT Media Lab developed an AI + ethics curriculum for middle school students to learn the ethics of AI with a focus on algorithmic bias (Ma, 2019). Williams et al. (2022) introduced their AI + ethics curricula for middle school youth, covering topics such as bias, privacy, deepfakes, misinformation, and environmental concerns about AI. Their strategy for teaching ethics in their curricula is to embed ethics into technical lessons "through experimentation, discussion, and real-world examples" (Williams et al., 2022, n.p.). Garrett et al.'s (2020) metaphor of AI education, "if AI education is in the infancy stage of development, then AI ethics education is barely an embryo" (p. 272), can summarize the current state of AI education as being a new research subject with a gap in AI ethics education. Thus, it is important and timely for education researchers to guide students to reflect on how AI might impact their lives and to subsequently prepare them with the abilities to enhance the benefits while mitigating potential harms as responsible AI users and creators. Our AI curriculum was therefore designed to integrate AI technical knowledge with AI ethics, thereby allowing students to learn about how AI works and consider its impact.

Pedagogies for AI Education

Oyelere et al.'s (2022) systematic review of AI education in African schools synthesized the "contextualized resources to teach AI in African schools" (p. 1580) and revealed that participatory learning, design-oriented learning, and collaborative learning are commonly used as teaching methods to introduce AI to K-12 learners in different contexts. Ng et al. (2022) conducted a case study over the course of a three-month digital story writing program in Hong Kong to foster AI literacy among elementary school students. According to Ng et al. (2022), digital story writing is an effective inquiry-based pedagogical approach to improving language and technological abilities across disciplines, as well as to effectively foster students' AI literacy in using and applying AI knowledge to solve real-world problems, which goes far beyond simply knowing and understanding relevant concepts. Zammit et al. (2021) conducted research on digital games as teaching and learning tools to improve AI literacy. This research focuses on ArtBot's game design process, final interface, and gameplay loop, yielding a positive overall result of using digital games as tools for AI education.

Trend of AI education for K-12

There is a debate in the field of AI education about the necessity and feasibility of establishing new AI courses for K-12 students. Researchers like Han et al. (2018) support the idea of establishing new AI courses in schools, which is in line with the Chinese educational policy of establishing AI courses in primary and secondary schools. More educators and researchers, however, believe that AI knowledge can be integrated into existing STEM courses such as math and computer science. Gadanidis (2017), for example, examined the intersection of artificial intelligence, computational thinking, and mathematics education, laying the conceptual groundwork for future research in this field. This study provides new contexts and tools for incorporating AI and other disciplines such as mathematics in classroom practice. Based on this conceptual groundwork, the AI syllabus can be viewed as part of a comprehensive approach to education that incorporates other subjects such as science, art, literacy, and numeracy. According to Heinze et al (2010), a "cross-curricula approach" that incorporates "science in general and AI in particular into other parts of the curricula" to the teaching of AI would benefit students by providing "an entertaining, engaging, sustainable and developmental course that provides content that can support the needs of many students" (p. 1892). The decision to establish new AI courses

or incorporate AI knowledge into existing school subjects is mainly determined by the educational system of a particular country or region.

Conclusion

The advancement of AI technology raises an important question regarding how education can prepare students to become wise consumers and responsible builders of AI, as well as live and work in harmony with this new technology. As important stakeholders in AI technology, both currently and in the future, K-12 students need to acquire knowledge and develop critical thinking skills to interact responsibly with AI. To meet this need, governments have provided curriculum guidelines to direct the development of AI education; research and educational organizations have published frameworks for incorporating AI into K-12 curricula; companies have launched initiatives to develop resources for AI education to younger students; and educators and researchers have investigated what to teach and how to engage young learners in learning about and experiencing AI. However, as Wong et al. (2020) stated, this process is still in its early stages and implicated by major issues that still need to be addressed, such as limited funding, teaching resources, and a lack of AI teachers. Within this context, our research interests are to develop AI curricula that embed critical reflections on AI ethics within AI technical knowledge through hands-on activities for K-12 students to prepare them with the abilities to maximize benefits while mitigating potential harms. Our curricula will employ narrative learning (Bruner, 1991), situated learning (Brown et al., 1989; Lave,1991) and design-based learning (Nelson, 1974, 1982) theories to guide our selection of curriculum contents (e.g., what AI is, what it does, how it works, how it is applied in various fields and its ethical considerations) and design of pedagogical approaches (e.g., storytelling, future problem solving, design-based learning, and activity-based learning), thereby giving students the opportunity to learn about AI technology and design their AI products to solve real world problems and at the same time reflect on the social, cultural, and ethical implications of their products.

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