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Lessons Learned for AI Education with Elementary Students and Teachers

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Abstract

With accelerating advances in artificial intelligence, it is clear that introducing K-12 students to AI is essential for preparation to interact with and potentially develop AI technologies. To succeed as the workers, creators, and innovators of the future, we argue students should encounter core concepts of AI as early as elementary school. However, building a curriculum that introduces AI content to K-12 students presents significant challenges, such as connecting to prior knowledge, developing curricula that are meaningful for students, and creating content that teachers feel confident to teach. To lay the groundwork for elementary AI education, we investigated the everyday experiences and ideas of students in grades 4 and 5 (ages 9 to 11) about AI to inform possible entry points for learning. This yielded themes around student conceptions, examples, and ethics of AI. For each theme, we juxtapose the student ideas with the teachers' reflections on those ideas as frames of reference to consider in co-designing curricular approaches.

Keywords K-12 AI education · AI Ethics · Elementary Education · Teacher co-design

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Introduction

There is increasingly widespread acknowledgement of the prevalence of AI in our lives, which is likely to continue to expand (Touretzky et al., 2020). However, the applications and considerations around AI will likely be some of the more complicated concepts that these future citizens will need to grapple with, and CS education will need to be reframed to prepare students for these considerations (Tissenbaum & Ottenbreit-Leftwich, 2020). Successfully doing so places increased demands on teachers and students, who are being introduced to a completely new content area, AI, and its complex concepts, practices, and perspectives. A critical first step is to enable teachers and students to define the key entry points for learning AI.

Due to the increased ubiquity of AI, Wong et al., (2020) argued that K-12 students need to understand three dimensions of AI literacy: AI concepts, AI applications, and AI ethics/safety. Several national governments have acknowledged the importance of including AI in the K-12 curriculum. The Chinese education ministry has integrated AI into the mandatory high school curriculum, including a pilot textbook to teach students about fundamental AI technologies such as machine learning and pattern recognition (Liu, 2020). China also piloted AI courses in some elementary and middle schools in one city, with the aim to spread AI education to all curricula (Caixiong, 2019). The Commonwealth of Australia (2017) has also emphasized the importance of preparing their students to use and understand AI in their innovation vision statement: "education [is] the foundation stone of an innovation system because the capability of systems is determined by the ability of the people in them" (p. 22).

However, such broad calls and national strategies call into question the viability of accelerating classroom AI initiatives before attaining a deeper understanding of feasibility and adaptability within preexisting systems of knowledge and practice. As with any new and unfamiliar classroom initiative, teachers require substantial resources and support (e.g., Davis et al., 2009). For example, when teachers were first required to integrate technology into their classrooms in the 1980 and 1990 s, numerous studies found that teachers required considerable support in the form of resources, training, and coaching (e.g., Sandholtz, 1997). For successful integration, teachers had to overcome steep learning curves with new subject matters and required substantial support from coaches and curriculum specialists. This has also been true for the inclusion of K-12 computer science, especially at the elementary levels (e.g., Israel & Lash, 2020). Studies have shown that elementary teachers describe the potential struggles students face with learning computational thinking (Rich et al., 2020). Therefore, to build a developmentally appropriate AI curriculum that teachers are capable of implementing, we need to understand teachers' and students' current conceptions of AI as we continue to develop efforts for K-12 AI education.

Background

Current Efforts in K-12 AI Education

Education and industry leaders have acknowledged the pervasiveness of AI in our lives and the importance of educating our students on how AI technologies function (Kandlhofer et al., 2016; Pedro et al., 2019; Touretzky, 2020) suggested that students need to know about AI for four primary reasons: (1) AI will power the next technology revolution, (2) citizens need to be knowledgeable about issues related to AI, (3) given how AI is integrated into our lives, students need to understand basics of how it works, and (4) students need to be encouraged to think about how to use AI for future careers. Researchers have identified 17 primary competencies in AI literacy for non-technical learners including ethics, decision-making, representation, learning from data, and sensors (Long & Magerko, 2020). However, Zhou et al., (2020) pointed out that while these competencies are helpful to identify key ideas, K-12 education needs more specific frameworks and standards to help identify learning trajectories and curriculum design considerations (e.g., Duncan & Rivet 2013; National Research Council, 2007). A working group on K-12 AI education, AI4K12, has identified 5 big ideas in AI that all students need to understand: (1) perception (computers perceive the world using sensors), (2) representation and reasoning (agents maintain representation of the world and use them for reasoning), (3) learning (computers can learn from data), (4) natural interaction (intelligent agents require many kinds of knowledge to interact naturally with humans), and (5) societal impact (AI can impact society in both positive and negative ways) (Touretzky et al., 2019). However, although the frameworks are helpful to designing K-12 AI education, the field is currently missing a description of learning trajectories and guiding standards for younger students.

There are few examples of curriculum and studies that have focused on AI education at the younger grades. In fact, in Zhou et al.'s (2020) review of 49 K-12 AI education programs, only eleven of these included students at the primary level. Of those eleven programs, the most common topics focused on decision making (9), machine learning (8), humans' role in AI (8), learning from data (7), and programmability (7). One curriculum was constructed using previous college-level AI textbooks to identify the critical AI competencies around AI knowledge, AI skill, and AI attitude (Kim et al., 2021). Early versions of elementary computer science curriculum were designed using similar frameworks and standards, drawing on content covered at the higher education levels (e.g., CS Framework, 2016; Oda et al., 2021). Although guiding frameworks can offer insight regarding *what* to consider, researchers are only just beginning to chart pathways that will inform *how* we can engage K-12 learners, and especially young learners, with ideas about AI. Furthermore, we need to focus more on whether or not concepts are developmentally appropriate for young learners, as well as defined learning trajectories. Therefore, the question around AI education needs to consider what students are developmentally ready and able to learn about AI, and how their learning needs to be structured to yield the best learning outcomes for students.

Learning in Complex Systems

One of the challenges associated with teaching AI originates from the complexity of the domain. Not only are ideas about AI complex, but the algorithmic details of AI can be hidden and abstract. However, as Yoon et al., (2018) noted, learning about complex systems is foundational to the types of societal and environmental problems students learn to confront within the Next Generation Science Standards (NGSS) (National Research Council, 2012). Moreover, learning about dynamic and complex systems, such as AI, requires students to locate both underlying properties as well as emergent, nonlinear ones (Yoon et al., 2018). For example, to formulate an AI plan, learners must understand and articulate that there are defining states, possible actions, and goals. However, execution of the AI plan is dynamic, nonlinear, and responsive to a multitude of triggers in the environment. Thus, the inherently dynamic nature of the system further adds to the complexity and underscores essential difficulties of supporting learners as they negotiate complex and emergent phenomena toward comprehensive conceptual change.

To support this conceptual understanding, diSessa (2014) argued that a critical starting point is the recognition that new ideas build on existing knowledge, which leads to an essential understanding that conceptual change is required rather than acquisition or new ideas or corrections of false ideas. In other words, learning of complex, dynamic systems cannot be framed as "acquisition" or "correction," and conceptual change models account for naive knowledge students might enter with, the contexts in which students learn, and the ways in which students develop comprehensive understanding of relationships (diSessa, 2014; Svila & Linn, 2012). As Smith et al. (1994) pointed out, students' existing knowledge on a topic has "roots in productive and effective knowledge. The key is context - where and how those conceptions are used" (p. 124–125). Therefore, one of the critical elements of building successful learning trajectories around AI needs to first examine students' existing knowledge around AI.

Existing Knowledge as Entry Points for Learning

Presently, there is an increase in research about where children are with respect to their understanding and readiness to learn about AI. Williams, Breazeal, and Resnick (2017) found that most younger students were aware of intelligent agents (e.g., Google Home, Alexa) and described them as friendly and trustworthy. Their study of 26 students between the ages of four and ten found that the students were able to adapt their questions so that intelligent agents could respond appropriately, and they attempted to test the limits of the program by asking playful questions ("Is it OK if I eat you?"). However, even though students as young as preschoolers and kindergarteners may be aware of some AI concepts, they often are unable to recognize AI, and are unable to explain how it works (Williams et al., 2019).

There is also evidence from studies that have shown that younger students have the capacity to explore and understand ideas around AI. For example, Vartiainen et al., (2020) examined six primary students and their experiences with Google's Teachable Machine (machine learning). Using their own examples, the students focused on

teaching the computer things they were familiar with (such as emotions). In another curricular example with primary students, Kandlhofer et al., (2016) had primary students explore AI and computer science concepts through different robotics tools (Bee-Bots, LEGO Mindstorms, and Cubelets). These ideas included graphs and data structures, sorting algorithms, and problem solving by search. Wong et al., (2020) recommended that the upper elementary AI curriculum will need students to already have certain computational thinking skills to understand AI ideas (i.e., basic algorithmic understanding, and creating programs with control structures like sequences and conditionals). However, building on children's capacity for learning AI requires a more detailed understanding of their existing understanding in order to support reaching competencies and proficiencies in AI.

While Long & Magerko (2020) mapped competencies that align with goals for AI literacy, they note the need for more research into how children perceive and critically examine AI. More specifically, they highlight the importance of surfacing children's alternative conceptions about AI as a crucial aspect toward building widespread AI literacies. One key step toward building conceptual understanding in AI education with young learners is to elicit how children are considering AI concepts, practices, and perspectives (Jung & Won, 2018). Because many young learners experience AI-enabled devices and media representations beginning early in life, their reasoning about AI is likely to reflect differing experiences, ideas, and conceptual understanding that can vary widely with age and type of exposure (Williams et al., 2019). At the same time, we do not have a clear sense of learning progressions that can inform how young learners reason about and gain facility with AI ideas and practices.

Thus, we argue for the need to capture existing understanding and interests of young learners about AI to offer teachers and designers key insights into entry points for learning and building conceptual understanding. Teaching for conceptual change is inextricably linked to the ideas students enter with as well as the expertise of teachers to surface naive ideas and create conditions for learners to develop more sophisticated understanding (Duschl et al., 2007; Leary et al., 2014; Männikkö & Husu, 2019). We argue that this requires teams of researchers, experts, and teachers to co-design classroom experiences that will foster meaningful conceptual change about these complex ideas.

Participatory Co-Design

One of the limitations of many previously constructed primary-level AI education curriculum have been the lack of K-12 educators in the design process (e.g., Kim et al., 2021). To arrive at the curricular approaches in upper elementary grades, we need to engage teachers in this process, both to identify developmentally appropriate pedagogical processes, as well as identify how to best support teachers in the implementation of any curriculum. Participatory co-design can help guide this process, by leveraging contributions and expertise of each group member and presenting opportunities for teacher professional development. By drawing on the expertise of each person, the group can benefit from initially building shared understanding prior to collaborative curricular construction during the design process.

In Yoon, Liu, and Goh (2009), teachers participated in a summer professional development workshop on constructing and delivering STEM units of instruction before implementation of their designs within a classroom setting. Study findings suggest that during the professional development workshops, the most successful groups were ones that demonstrated distributed expertise where each member of the group and their contributions were equally valued and incorporated into the overall designs generated (Yoon et al., 2009). Shared professional development experiences not only orient all members to the research to be conducted and any background knowledge needed to complete the research (Roschelle et al., 2006), but it also provides researchers and teachers an opportunity to connect and bond together as a group. Building relationships within this context enables improved communication and the possibility of deeper collegial discourse or collaborative perspective taking (Gomoll et al., 2022; Ko, Hall, & Goldman 2022) during the research process. The process of professional development illustrates the importance of shared knowledge by having participants participate in the process of collaborative knowledge building, which is the construction of new knowledge that benefits a societal group (Scardamalia & Bereiter, 2006).

Leveraging Entry Points to AI Learning

As we have argued, supporting learning of AI concepts, practices, and perspectives among elementary children requires a dual emphasis: (1) capturing a detailed understanding of students' existing knowledge and (2) engaging teacher's capacities for supporting learning in complex systems via participatory co-design. As part of our co-design process, we aimed to establish these dual purposes as a first step toward AI education in upper elementary grades. As such, we first sought to capture students' everyday knowledge and experiences around AI, and, subsequently, engage teacher reflection about their students' knowledge. More specifically, we conducted interviews with students to capture their existing knowledge about AI. We then conducted interviews with teachers to discuss students' knowledge, as well as gather information about teachers' experiences with AI, and how to teach AI. In this study we investigated two questions:

1. What existing ideas do upper elementary school students have about AI?
2. How do elementary school teachers reflect on students' existing knowledge about AI and what are the implications for teaching their students about AI?

Method

Research Design

We used a two-phased qualitative research design method (Creswell,, 2012). First, we interviewed ten fourth grade students to examine their existing knowledge around AI. After analyzing students' data, we summarized the data and presented the themes to the teachers. Then, we interviewed three upper elementary grade teachers to

Table 1 Overview of classrooms

	Grade	Student Diversity	Free/Reduced Lunch Rates	Environment
Teacher A*	4th	55% Black, 25% Hispanic, 15% White	76%	Urban
Teacher B*	4th	94% White	43%	Rural
Teacher C	5th	92% White, 5% Multi-racial	32%	Suburban

*NOTE: students from these classrooms were selected for interviews

explore how they would teach AI to these students based on their students' existing knowledge.

Research Context and Participants

The study involved three teachers and students from two of the teachers' classes (see Table 1). The decision to select students from only two of the classrooms was based partially on the need to ensure contrast in experiences and diverse perspectives, and partially on scheduling constraints. Thus, we selected two fourth grade classrooms as this targeted the average grade level of prospective students. The teachers were asked to each select five students that represented a range of abilities and genders: Teacher A selected three boys and two girls, and Teacher B selected two boys and three girls.

Data Sources

We first interviewed ten 4th grade students (five female, five male) to identify how they currently conceptualize artificial intelligence. Once we gathered students' ideas, teachers were asked to review students' ideas and describe how this should guide our curriculum development efforts.

Student interviews. One researcher conducted all 10 one-on-one interviews with the students in person. The semi-structured interviews included five main questions and lasted between seven and 20 min. Interview questions focused on students' understandings and experiences with AI (e.g., What does AI mean to you? Can you think of any examples of AI? How do you think the example of AI you mentioned works?). The interviews were recorded and transcribed. We used emergent thematic coding to "categorize coded data based on thematic or conceptual similarity" (Saldaña, 2016, p. 235). After reviewing the full data set, a team of three researchers independently annotated and listed potential codes. In some cases, codes were reworked. For example, initially ideas of AI were divided into correct conceptions and misconceptions. However, after discussion with the research team and utilizing the framework of focusing on students' existing knowledge, this resulted in reframing our codes to reflect students' general conceptions. The team then met to clarify codes by creating a definition guide for each code with definitions and example quotes. With this codebook, the researchers then independently coded all the data from the interviews. The researchers then reviewed the codes together, and where disagreements occurred, discussed these until they achieved consensus (Harry et al., 2005). Although this process takes longer than individually coding, the process enabled the research team

to interrogate each theme and thoroughly examine each students' and teachers' meaning within the interviews. The codes were then grouped into themes with definitions for each sub-theme, as well as example quotes, to outline the key elements of each idea (Saldaña, 2016). The student themes were organized into three main themes: (1) conceptions of AI, (2) examples of AI, and (3) AI ethics (see Table 2 for selected examples of sub-themes).

Teacher Interviews. Each of the three teachers were interviewed separately for 25–35 min. First, teachers were asked how they would define AI. Next, we provided teachers with a summary of the students' existing knowledge responses grouped into three main themes: (1) conceptions of AI (including knowledge gaps), (2) examples of AI, and (3) AI ethics. The teachers were asked to review the summarized student responses that represented their existing ideas about AI, and were asked to describe how we should build curriculum around these ideas. Next, teachers were asked to review the summarized student examples of AI and discuss how they might incorporate these into an AI curriculum. Finally, teachers were asked to reflect on the critical topics they thought should be covered related to AI ethics, to review students' descriptions of ethical AI situations, and explore how ethics could be incorporated into the curriculum. Teachers were also asked to reflect on whether or not AI should be taught; teachers' responses are presented at the end of the results section.

Results

A crucial step in developing curricula that meets learning needs of children originates with their everyday experiences and ideas as contexts for teacher interpretation, designs, and enactment (Rich et al., 2019; Rivet & Krajcik, 2008). Because our goal was to have the teachers use the student ideas as an important foundation for their later design efforts, we use an unconventional format to present the results. For each theme, we juxtapose the student ideas with the teachers' reflections on those ideas with respect to designing curriculum. Furthermore, as many elementary teachers lack experience engaging and planning for approaches for AI education, we present these results as a means for surfacing entry points for AI education at the intersection of the teacher, student, and AI-encounter.

Students' Conceptions of AI

Based on the students' interviews, nine of the ten students described AI as involving programming or coding. Many students specifically used the words code or programming: "She's [Siri] programmed to know specific answers" (Student A5), and "well [AI] uses code. And like the way you program it helps it decide what it's gonna do and how it's gonna help us" (Student B1). Some of the students provided additional descriptions of AI, which specifically included discussions around having to teach the computer to implement particular tasks. For example, Student A3 specifically mentioned that a person needs to program the AI or robot: "You need a person to program the robot. It can't do things unless you program it and train it on what to do." Some students specifically mentioned that they believed AI required the use

Table 2 Examples of emergent AI themes for elementary teachers and students

Theme	Description	Example Quotes
Conceptions of AI: AI Means Programming	Students believe that AI needs to be programmed and that AI must be told what to do.	"you need a person to program the robot. It can't do things unless you program it…You need a person to program it. The robot can't do things unless you program it and tell it what to do." (A3)
Conceptions of AI: AI encompasses teaching the computer	*AI/computer needs to be taught how to perform certain tasks or the computer is learning. This can involve trial-and-error, needing to go back and fix any problems you encounter. It can also be data driven. Students may not specifically know HOW to teach the computer (misconceptions around showing it pictures), but they know it needs to be taught to perform a particular task.*	*"If you program something enough like, it will learn how to do the things that you programmed it to do." (A1)*
Conceptions of AI: Personification	Some students thought there were people operating the AI in a different location. Assigning human characteristics to the AI.	*"I think it's controlled by somebody." (B5)* *"Because she probably understands me and the person I am." (A2)*
Conceptions AI: Sensors/ Representation/ Visualization	Students were confused by how computers gather and process data/ information to make representations and reasoning.	*"There might be one (camera) on the robot (Roomba) … because the camera, it would look at it and sense it and say don't go into it would turn the other way." (B3)* *We can use like a clips of me like doing like what I want the robot to do and we could try to install some data on it, so it could do it." (A3)*
Conceptions of AI: Unclear on how AI plans or makes decisions	*Students understand AI outcomes, but don't understand how the AI works.*	*"[AI] is robots that can do things that humans can do. I don't really know how to say it. I don't know how to word it." (B4)*
Conceptions of AI: People control AI	*Students recognized that AI was related to programming, but suggested that a live person was controlling the device.*	*"I feel like there's somebody controlling [Alexa]. And speaking to you, and they're just like citing all that information." (B5)*
Example of AI: Recommendation Systems	Students recognized that recommendation systems were able to identify what they wanted to find and this related to how it was programmed.	*"If you want information about certain things or topics it will recommend for you. Like YouTube. It recommends stuff for you to watch." (A5)*
Example of AI: Siri/Alexa	This was the most prevalent code for examples. Students all recognized that Siri/Alexa were examples of digital voice assistants.	*"Sometimes I ask her [Siri], how to spell something, and one time there was this one animal but I didn't know what it was. So I asked her to show me photos and it showed me what it was" (B2)*
Example of AI: Roomba	*Students described seeing or hearing about robotic vacuums.*	*"Like maybe a robotic vacuum. I've heard of auto robots but I've never really seen a lot. I think I've heard of one of them. I don't know if this counts as a robot but like the Tesla, I believe, it has a feature where you it can navigate by itself without a human doing it." (A4).*

Table 2 (continued)

Theme	Description	Example Quotes
Example of AI: Self-Driving Cars	*Students described seeing or hearing about self-driving cars.*	*"Now sometimes there are cars that can drive by themselves and you have to teach it whether to stop or not." (A3).*
Example of AI: Google Search Engine	*Students recognized that Google Search Engines were able to identify what they wanted to find and this related to how it was programmed.*	*"When I go on Google and search some stuff up, they usually have the right information for me because it was programmed to" (A3)*
AI Ethics: Positive	Students recognized that AI is improving our lives and has potential positive implications in the future.	*"It can help, in a lot of ways. But I think if you know how to use it and you can use it right it's very powerful." (B1)* *"It can also help like people with disabilities, if they need help." (B3)*
AI Ethics: Negative	*Students recognized that AI has potential negative consequences and this often depended on who coded it or how it was used.*	*"I feel like it would take up more people's jobs." (B2)* *"maybe if they're controlled wrong or something messes up or somebody's trying to do that and it can do something bad. If they control it wrong or they're trying to make it do bad." (B3)*

of trial-and-error: "I think a lot of technology and a lot of trial and error goes into it" (Student B4). A few students also mentioned that this iterative teaching process required data: "they take multiple clips of people walking across just like jaywalking and clips like that, of people that they're not doing what they're supposed to be doing" (Student A3). Although these students seemed to recognize that AI involves programming and training, most were unable to describe what this meant or how AI software implements particular tasks. For example, when Student A2 was asked how AI learned, they responded with the following: "Probably teach it. Just keep practicing. Like on little models… And maybe if you practice, you have to do a bunch of tries to make it…so you can always try again. But I don't know how you would actually do it." This lack of understanding will be explained further in the section around misconceptions.

Teacher Reflections on Students' Conceptions of AI

Teachers had similar definitions of AI as their students. For example, Teacher A defined AI as "Initially, my understanding was Siri, and Alexa. Now I have the understanding that it's much broader in so many things that we do, and it's unseen. So it's not just the things like a personal assistant to make my life easier. But it's [AI] pervasive in lots of things that we do online, without even knowing it."

Teachers described that they read students' explanations of AI as being correct, focusing on the coding or programming aspects: "I feel like they seemed to know about most of it. Just the fact they knew that you actually are programming it was impressive." However, teachers also mentioned that students needed to move beyond AI as just coding. For example, Teacher A described that we would need to "show them the next step, like we can code it and tell it what to do, but now it can also take information that then to make other decisions. I think that's probably where we would

go next." Teacher A emphasized that students need to understand how AI makes its own decisions that were not predetermined by coding: "…An area that we need to grow in, I think, is it's not just coding a robot. Coding a robot doesn't necessarily use artificial intelligence. Artificial Intelligence can be used as robots, but I think what I'm thinking of is like machine learning…students would need to understand that it's not necessarily just programming."

Teachers noted that the student theme of teaching the computer was an important concept to build on in future curriculum for all students: "That was impressive that they knew about showing the different pictures" (Teacher B). Though the teachers identified that it was critical to teach students about AI, they expressed hesitation in how to teach these complicated concepts: "it [AI] works better than our brain in the fact that it has so many different combinations, and we have to kind of teach it to do that. I don't necessarily know how you teach it. I've learned that through pictures we can teach the machine to identify things. We feed it information so that it can figure things out." This showcases that teachers may still need additional professional development to better understand AI so they can be more confident in teaching these concepts.

Teacher A also mentioned that she felt strongly about describing the role of humans in developing and engaging with AI. She indicated that it was important to have students understand the range of AI, and how humans might be involved at different levels: "The programs can learn with the help of people to make decisions and do things that humans necessarily wouldn't be able to do in that amount of time that a machine could. I think certain things can feel more human than the other, but… humans still play the same initial role in programming and collecting data and—and writing code" (Teacher A).

Students' Knowledge Gaps Around AI

Students had several ideas about AI that revealed knowledge gaps. One of the salient areas that students lacked understanding was related to how AI plans or makes decisions. As noted above, students defined AI technologies in their own words, but when asked to illustrate how it worked, the students were not confident or described it in a less accurate way. When students were asked how they thought the AI worked, they commonly responded that they did not know: "because it was programmed to. I really don't know" (Student A3). In other words, for students, AI remains a black box, despite ideas about it being programmed.

A common student conception was that humans did all of the coding, which was then loaded onto a device. This explanation does not account for the role of machine learning. For instance, Student B1 described how Alexa worked: "They'll answer almost any question you have and that's all powered by the people who coded those and copied that code and put it in every single robot and sent it off." Student B5 also described that humans had programmed every possible response for Siri and put that on to the device's hard drive: "I think she knows, just because I think [about] how that device was made. It was made because the person who made it put all the things in it that people would ask."

Another common student idea was that they tended to anthropomorphize AI systems such as home assistants. This was demonstrated as they often used personal pronouns when describing an example of AI, and sometimes assigned human characteristics to the AI embedded software or device. For example, Student A2 stated that "…she [Google Home] probably understands me and the person I am, and by showing pictures, it can see so maybe if I just show her." Other students also described that there were people operating the AI in a different location: "I feel like there's somebody controlling it and speaking to you, and they're just like citing all that information in" (Student B5). These statements suggest that student ideas are not uniformly held, at times reflecting notions about human-made artifacts and other times attributing anthropomorphic, life-like characteristics to these devices.

Teacher Reflections on Students' Knowledge Gaps Around AI

After reading the summary of students' conceptions around AI, the teachers recognized that students were still struggling with AI concepts and examples: "I think they have a good starting place for understanding CS. But I think we need to refine" (Teacher A). Although teachers described that we need to correct students' misconceptions, none of the teachers were able to provide suggestions about how to address them: "I think you'd have to get rid of some of those misconceptions. And kind of like you explained it to me, it's not concrete. I think that's what makes it so hard to explain. Kids want to [describe AI] just like it's a robot. It's not. So I think that's what we would have to do is kind of get rid of that misconception that it's not just a robot, it's more" (Teacher B).

This struggle is likely due, in part, to the teachers' own lack of AI knowledge. Teachers described that they still struggled with their own conceptions of AI and expressed concerns about their lack of understanding: "I feel my definition isn't any better than a student's" (Teacher C). She expressed her concerns of her lack of understanding about AI and frustrations about teaching AI: "there's lots of things that [the professor] says but I really have no idea. When teachers go to teach this, will we have background information? How will I have the knowledge to teach the kids? How do I get that knowledge before I teach this?" (Teacher C). The teachers all expressed a need for more guidance in what and how to teach AI: "what do you want us to teach the kids about artificial intelligence? I guess as a teacher I like somebody who tells me this is what you need to teach, and then I will figure out" (Teacher B).

Students' Examples of AI

During the students' interviews, students' existing knowledge included a range of different AI examples. Examples included the Google search engine, recommendation systems built into YouTube and Netflix, Roomba vacuum cleaners, self-driving cars like Tesla, and digital voice assistants like Siri or Alexa.

Search Engines. Three students suggested that the Google search engine was a representation of AI. They described how as they typed keywords into Google, the search engine was able to identify what they wanted. They suggested that someone had programmed the search engine to be able to do this: "I'm going to this party this

summer. And I have to find the dress. I search for the dresses, to find one. It has been easier because, like I can just find it online instead of the store so it's easier to communicate" (Student A2). Student A3 also mentioned that the Google search engine was an example of AI: "When I go on Google and search some stuff up, they usually have the right information for me." Student A4 described that Google was helpful as it suggested words: "Google helped me because I didn't know how to spell it and stuff and pronounce it." When the researcher followed-up and asked how they thought that worked, Student A4 responded that the search engine was designed to anticipate but could not describe how that was happening: "Maybe it was designed to understand what you are typing."

Other students mentioned additional Google applications such as Google Maps: "Google makes like maps and so it helps you know where you're going" (Student B1). When asked about how that worked, the student described how they thought that Google had cars take pictures and humans would code the information once the car returned to Google:

> I saw something where they used cars and they go around the whole United States and places. And they'll have a camera on top that takes videos of everything. And then they get back and they code it to put those images on the where it's supposed to be. And sometimes like they'll get a picture of a human, and they'll just be there until they update it next.

Recommendation Systems. When asked if they could provide AI examples, only one student described a content recommendation system like would be commonly found in YouTube. Student A5 described how YouTube identifies similar videos or shows based on their watch history: "If you want information about certain things or topics it will recommend for you. Like YouTube. It recommends stuff for you to watch." When Student A5 was asked how recommendation systems work, they were able to describe how the system collects data to make these recommendations: "Because it takes in everything that you watch and it looks at it, and if you watch something similar to that all the time it will take in information about that and put it into its files and then put it out."

Robotic Vacuum Cleaner. When asked if they knew of any examples of robots in their daily lives, six students mentioned that they either knew about or owned a robotic vacuum cleaner: "I've seen [Roomba] on TV before and at stores" (Student A1). When asked how they thought it worked, Student A1 described how they thought it used motion sensors: "I think it's just a regular vacuum but it has motion sensors around it and it is programmed to suction everything up…I think it feels if it has something touching it. I think it can tell if it's an animal or a wall or if it's touching something. It probably has like cameras or something. And it can probably tell if it's the wall or not" (Student A1).

Self-Driving Cars. A few students mentioned knowing about or having seen self-driving cars before. Student B4 specifically mentioned Tesla cars and described how these cars can navigate without a human driving: "I've heard of auto robots but I've never really seen a lot. I don't know if this counts but like the Tesla, I believe, it has a feature where you it can navigate by itself without a human doing it."

When asked more about how they thought self-driving cars worked, Student B4 described the significant amount of trial-and-error required to design this type of AI:

> "I think they have to have a lot of cameras to be able to make sure that they're not going to run into anything that could damage that robot or whatever. I think a lot of technology and a lot of trial and error goes into it. I don't know how long that process can take because obviously they have to figure, and make it where it can be almost anywhere. There's definitely gonna be a lot of trial and error and mistakes made" (Student B4).

Digital Voice Assistants. Seven students identified digital voice assistants like Siri and Alexa as the most common example of AI in their daily lives. Some students described being playful with their digital voice assistant requests, while others were productivity oriented: "my brother told me to tell her to beat box" (Student A1), "Sometimes I ask her to remind me stuff like wake up like for school and put a timer for a certain time" (Student A2), "what the weather is and asking if she can change light colors. Sometimes she tells jokes and plays songs" (Student A5), and "Sometimes I ask her [Siri], how to spell something, and one time there was this one animal but I didn't know what it was. So I asked her to show me photos and it showed me what it was" (Student B2).

Students were then asked to describe how they thought Siri or Alexa worked. Some indicated that they thought humans had programmed them with all the possible responses: "The people who made the iPhone who made Siri would tell her to do different things, and maybe if someone said something and she didn't know it yet, maybe they would like fix that and then when they came out with a new phone maybe they would add that" (Student A1). Others had indicated that they thought there might be a person at another location answering your questions, suggesting again that there is a person directly controlling AI technologies.

Teachers' Reflections on Students' Examples of AI

Teachers expressed the importance of including relevant examples from their students' existing knowledge of AI. Through the use of relevant examples, teachers indicated that this could spark students' interest in the topic and build on students' existing knowledge:

> "There's so many cool, neat little things that we've talked about that I don't even think they realize that takes place, like with Alexa. I feel like kids are getting harder and harder to engage in class. So, if this is something that...I can bring into my classroom and... tie in literature...math. They're going to learn it better than just me teaching out of the book" (Teacher B).

Teacher C described how she had used one of the videos we introduced during our professional development in her class last year, and it prompted a rich discussion amongst her students: "we watched it in my fifth grade classroom and…had great discussions about self-driving cars and…how the computer can beat the person play-

ing a game." Teacher A indicated that she was impressed with the students' range of examples, and recognized that they have a broader capacity than she originally thought which will likely impact her curriculum planning:

> "I'm really impressed with their ability to think of examples from Siri and Alexa to self-driving cars and vacuums. I have kind of expected just robot talk, but this makes me think that they may have a deeper understanding than I thought at first. I was particularly impressed with the recommendations from YouTube, because that's not concrete at all. I feel like with my students, those more abstract examples are much more difficult for them to grab. So the question is, how do we use this to start our teaching?"

All three teachers felt that beginning with what students knew or have been exposed to in their daily lives was an important place to start teaching students about AI. Teacher C indicated the importance of starting with AI examples could help students connect to more abstract ideas by "starting with what they know, and kind of expanding on it, and then transferring that idea to less concrete examples." Teacher B also described starting with relevant examples as important, but then showcasing more complex examples that "build on this so that they understand there's a lot bigger uses of artificial intelligence than these basic every day [examples]. There's obviously a lot bigger uses in society…".

Students' Identification of AI Ethics

During the interviews, students were asked whether they thought AI was helpful or not. While students did not specifically mention AI ethics by name, they did identify both positive and negative impacts around the use of AI. All ten students mentioned both the positive uses of AI while eight also mentioned that AI had negative consequences. Three students identified potential positive applications of AI such as helping with chores: "It can probably help us like if someone needs help with like vacuuming or something or if they have a lot of chores to do, or something and they can probably like if it was like something hard to do for like old people or something. It can be like motion sensored and stuff," (Student A1). Two students specifically mentioned that AI could help people with greater needs (like older people or people with disabilities): "It can also help like people with disabilities, if they need help or dogs can do that too but, like, sometimes if they need something they can have the robot go get it for them if they can't do it or something like that, they can just help them" (Student B3).

Students also described their existing knowledge as including negative aspects of AI, specifically citing an example of the dangers self-driving cars can pose: "…if you accidentally programmed the wrong thing in a self-driving car, it can get messed up…Our science computer teacher was talking about a self-driving car and how was programmed to like stop out lights and stuff, but it ran over someone because it had something wrong on his program" (Student A1). Students also identified other negative aspects of AI such as cyberhacking, Siri answering homework questions which means you are not learning, and Siri always listening.

Teachers' Reflection on Students' Identification of AI Ethics

Teachers spent the most time during their interview discussing the ethical implications of AI and how to teach these concepts as it related to students' existing knowledge and the teachers' own knowledge of how to design curriculum. All the teachers specifically discussed using self-driving cars as a good discussion point. Teacher A described that the self-driving car example stood out to her because it connected to ethics and important education ideas beyond AI:

> "I was really interested about the one with the ethical self-driving discussion because it's more than just an example. They remember it because it had an emotional or humanity aspect to it. We're not just talking about robots but we're talking about actual education and possible issues. I felt like students have maybe processed it more than just recalling content." (Teacher A).

Teacher C described a different aspect of self-driving cars, by examining the economic impact of this technology on the trucking industry: "In the movie, there was a truck driver who had no idea there were self-driving semis. They talked about the little money that they had as it is. The kids were really affected by that. The fact that people would lose their jobs." In both of these examples, teachers expressed the importance of connecting the examples to something that requires an emotional connection to the material.

In a slightly different view, all the teachers also mentioned the importance of students understanding the ethics associated with AI use of their data. Teacher C described that students need to know that "In today's technological world…personal information is being collected on everything we search for or everything we look up or TikTok, or Instagram. They need to be aware that information is being collected on them." Teacher B mentioned that it was important for students to realize that AI can be used to try and change your mind/beliefs: "Whether it's for really the good of a cause or if it's money or just to sway you in a different direction in politics. They try to sway your views. I think these things need to be covered because kids and adults can be very swayed by some of these things that are taking place, on their phones, on Facebook."

Teacher A identified a connection to teach character education through discussions around AI ethics. She described how schools typically teach character development by talking about negative and positive behaviors and the consequences for both of those: "We're intentionally or not intentionally encouraging students to make decisions that we feel are good and morally right and ethical." She continued to elaborate on this analogy by having students conceptualize the type of person they want to become and what kinds of choices will lead to that type of person: "What kind of person do I want to be, how can I be that person in my life at school, my life online, and the work that I choose to do." She also posed several questions that could scaffold students' ideas around AI: "What is the data that's being collected? Do you really want these people having our data? What's the problem with these companies and entities, having our personal data and what could possibly go wrong with that? They

need to have an understanding of the potential issues that come with AI beyond malfunctioning machines."

Teachers' Motivations for AI Education

When teachers were asked to reflect on whether AI should be taught, they suggested three different rationales: (1) compliance with new required state standards, (2) prepare students to be functioning members of future society, and (3) showcase how AI is already embedded in the world around them. When teachers were asked why they volunteered for this collaborative project to teach AI, Teacher A described the increased focus on CS ideas within the state: "Within the last couple years, there is a big push for CS, especially because they're now included in the Indiana standards. One of our special area classes became CS." Teacher C also described the increased focus on STEM and technology in her school: "In recent years, there's been a big push, and we were told we might be a STEM school. So anytime there's anything that has to do with science or technology I sign up to learn more, so that I can be a better teacher."

All three teachers also identified that AI will likely be a large part of future society and students will need to understand AI to fully participate: "I strongly feel like this is the way of the world for our future, for our kids' future and so we need it to be a part of their lives" (Teacher C). Teacher A also provided some specific examples to show students how AI could change the future: "The opportunity to start using data with AI to achieve things that we haven't ever achieved before…they have amazing potential to learn about it, explore with it and grow with it as they grow."

Teachers also reflected on the need for students to realize that AI is already present in their daily lives. Teacher A described the importance of students understanding the pervasiveness of data collection, and how that is utilized by AI:

> "But [AI] is pervasive in lots of things that we do online, without even knowing it. I'm much more conscious of when I click the Accept terms. Before, it didn't really matter to me, because I didn't really have an understanding of what the data was used for. But now I do. And I understand how data kind of allows AI to do what it does. So I think I'm just much more conscious about the pervasiveness in my everyday life, even though I wouldn't necessarily see the outcome... And so what I think I would want my students to know, is one, kind of on the skeptic side, being aware of your data and what it represents and what it can be used for. And that's very important for students to know..." (Teacher A).

Discussion

In general, we found that students' conceptions of AI tended to focus on programming and robotics. Students had vague and basic existing knowledge of AI. All students described AI as coding or programming, and many described that AI involved teaching the computer, often through trial-and-error. Students also described some

areas of confusion around AI such as students' personification errors that were likely related to their misunderstandings around how computers gather and process data to make representations and reasoning. Students' existing knowledge also contained examples of AI such as robotic vacuums, Siri/Alexa, YouTube, and search engines. Finally, students expressed existing knowledge around different ethical implications of AI, focusing on both positive and negative aspects of AI that could help or harm people.

This study informs a deeper understanding of elementary students' existing ideas and the corresponding teachers' perceptions of how to leverage students' everyday experiences and ideas to teach them about AI. This understanding can fuel the decisions necessary to establish relevant AI education initiatives that are meaningful and relevant within preexisting systems of knowledge and practice. The student interviews revealed that, not surprisingly, children have ideas about AI. What is particularly interesting across both the general questions about AI and in the specific examples, they show some consistent patterns in their thinking and that these patterns bear some resemblances to novice ideas about complex systems more broadly (Yoon, 2018). In particular, children assume that there is some kind of central control– whether that control is a person or some causal linear sequence of interactions (i.e. the program code). To help students develop a more sophisticated understanding of AI, we need to provide them with opportunities to open up the black box of AI. As in this study, it is helpful to prepare the teachers for co-design activities by increasing their awareness of their students' ideas and helping researchers understand teacher perspectives.

Capturing teacher perspectives on their students' ideas lends specific insight into the teachers' frames of reference and motivations as they reflect on those ideas. Teachers were generally surprised with the range of students' existing knowledge. They also described being impressed with the level of detail in the students' descriptions of their knowledge. In reflecting on the students' conceptions of AI, the teachers generally found it meaningful to consider that while students did not have clear understandings of how to define AI, they understood how deeply prevalent and relevant AI was to their lives and to society. Finally, with regards to AI ethics, teachers suggested it would be important to build on students' ideas about positive or negative impacts of AI, but also promote more specific nuanced discussions regarding ethical uses of AI in society. As such, the teachers' perspectives serve as a critical insight into our co-design practice as we move forward with designs for AI education at the elementary school level.

Elementary AI Education: Implications for Co-Design Practice

AI education in the elementary grades represents a particular range of challenges given that approaches are relatively emergent. The community of researchers in this area have yet to define and map learning trajectories for children. Moreover, neither children nor their teachers have substantive knowledge foundations for AI education. Thus, we have leveraged approaches for co-design with teachers, which can both support teacher understanding in new areas of knowledge as well as representing an ideal context for developing new approaches to classroom instruction (Penuel et al., 2022). In other words, co-design processes afford the opportunity for a reason-

able starting point based on everyday knowledge of children that, in partnership with teachers, we can build on, particularly focusing on the human role in AI and how AI uses data to make decisions.

Defining points of entry for teachers. It is no surprise that teachers mentioned compliance with new state standards as a primary motivator, though they further described being motivated to teach about AI because they wanted to prepare students to be functioning members of future society, and explain how AI is already embedded in the world around them. Teachers' motivations for teaching AI seemed to align with Touretzky's (2020) rationales related to the pervasiveness of AI into our daily lives and the need for students to have knowledge of AI issues and potential career opportunities. Therefore, as we attempt to expand opportunities for elementary AI education, we should focus on using these rationales to convince teachers about the importance of teaching AI. Teachers especially are motivated by the ideas of preparing their students to be ready for their futures (Lauermann et al., 2017).

At the same time, we critically need to address teachers' apprehensions about their lack of knowledge in AI. The teachers in our study were apprehensive about the conceptions of AI and how it works due to their own lack of experience with and knowledge of AI. This is a common tension for teachers. In general, when teachers encounter a concept that is new or challenging for them to understand, this impedes their ability to teach the concept (Harlen & Holroyd, 1997; Hill et al., 2005). In computer science education, this can reflect a common tension. Previous studies have reported numerous barriers to elementary teachers' implementation of computing education and strategies, including their students and their own limited knowledge of computer science (Ozturk et al., 2018; Rich et al., 2019; Yadav et al., 2017). Teachers have described challenges with teaching computer science and computational thinking due to their lack of content knowledge in these areas. Teachers have often reported receiving a lack of training in these areas at the elementary level (e.g., Ozturk et al., 2018), and they often indicate feeling underprepared and unable to incorporate these ideas into existing curriculum (Ottenbreit-Leftwich & Biggers, 2017).

What to feature and where to start? We argue that AI ethics can represent a potential starting point for teachers to teach AI and CS concepts. Teachers demonstrated more confidence in discussing AI ethics with their students. In the case of Teacher C, she described her enjoyment in showing students a video about AI that discussed semi-truck drivers and the impact of automation. Several of the students shared they had family members that were truck drivers and an impassioned discussion occurred as a result. This topic led to an engaged discussion where students responded to one another with empathy and economic explanations. It seemed that through the use of the relevant, authentic discussions around automated truck driving, the teachers expressed more excitement to teach about AI issues.

We suggest the appeal of AI ethics may be due, in part, to teachers' preferences in teaching material that they have mastered. Other studies have shown that when teachers are uncomfortable with certain content knowledge, they can tend to avoid or skim over that material (Arzi & White, 2008). Guiding moral and ethical decisions are part of elementary teachers' daily tasks. One of the teachers related AI ethics to character education: "We're intentionally or not intentionally encouraging students to make decisions that we feel are good and morally right and ethical." Therefore, we suggest

that if AI curriculum was situated around an ethics problem, this may make teachers feel more confident in teaching the material. Teachers may feel more comfortable teaching AI from this vantage point.

Conclusions

K-12 computer science education must "deeply consider what kinds of citizens we are trying to develop" (Tissenbaum & Ottenbreit-Leftwich, 2020, p. 42). We are examining how to best teach elementary AI education because AI will be highly integrated into our daily lives as well as society writ large, and it is necessary for all citizens to understand how it is and can be used (both for good and bad purposes). However, building a curriculum that covers content new to K-12 students and teachers can present challenges, such as connecting to students' existing knowledge and developing curriculum that is meaningful for students and possible for teachers to teach. Therefore, we suggest that those creating elementary curricula to teach AI should engage in co-design with teachers and target four design features that will likely increase teachers' use. To address teacher apprehension about unfamiliar content, we have engaged a participatory co-design structure that surfaces teacher ideas and needs for future professional development. The teachers, while unfamiliar with much of the technical content related to AI education, considered AI ethics a familiar entry point. This is due in part to the familiarity they have in incorporating ethical decision making into their instruction and in part to the complex, interesting nature of AI applications in society.

AI is becoming ubiquitous in our everyday lives. For students and their teachers to become AI-literate citizens who can make informed decisions about these technologies and how they are used, they need opportunities for meaningful learning about AI. Such learning does not happen in a vacuum. As we have learned in our co-design process, we need to continue to attend to meeting the teachers and students where they are as we develop approaches for AI education in the upper elementary grades. We look forward to illuminating the continuing co-design process with teachers as well as how we can best support teachers and upper elementary students in learning about the complex ideas that underpin AI.

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Declarations

Ethics Approval The work presented in this paper was approved by Indiana University's Internal Review Board number 2001835213.

Consent to Participate and Publish All student participants signed an assent form to participate in the interviews. Written consent from their parents was obtained prior to the interviews. Students were told they could withdraw at any time during the interviews. All teachers provided consent to participate in the interviews and were told that they could withdraw at the beginning of the interview if they preferred.

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