“It Would Be Cool to Get Stampeded by Dinosaurs”: Analyzing Children’s Conceptual Model of AR Headsets Through Co-Design

Julia Woodward
Department of CISE, University of Florida, Gainesville, Florida, USA
julia.woodward@ufl.edu

Feben Alemu
Department of Geography, University of Washington, Seattle, Washington
feben.alemu@outlook.com

Natalia E. López Adames
University of Puerto Rico, Mayagüez, Puerto Rico
natalia.lopez17@upr.edu

Lisa Anthony
Department of CISE, University of Florida, Gainesville, Florida, USA
lanthony@cise.ufl.edu

Jason C. Yip
Information School, University of Washington, Seattle, Washington
jcyip@uw.edu

Jaime Ruiz
Department of CISE, University of Florida, Gainesville, Florida, USA
jaime.ruiz@ufl.edu

ABSTRACT

Children are being presented with augmented reality (AR) in different contexts, such as education and gaming. However, little is known about how children conceptualize AR, especially AR headsets. Prior work has shown that children’s interaction behaviors and expectations of technological devices can be quite different from adults’. It is important to understand children’s mental models of AR headsets to design more effective experiences for them. To elicit children’s perceptions, we conducted four participatory design sessions with ten children on designing content for imaginary AR headsets. We found that children expect AR systems to be highly intelligent and to recognize and virtually transform surroundings to create immersive environments. Also, children are in favor of using these devices for difficult tasks but prefer to work on their own for easy tasks. Our work contributes new understanding on how children comprehend AR headsets and provides recommendations for designing future headsets for children.

CCS CONCEPTS

• **Human-centered computing**; • **Human-computer interaction (HCI)**; • **HCI theory, concepts and models**;

KEYWORDS

Augmented reality, children, co-design, participatory design, conceptual model

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1 INTRODUCTION

Augmented reality (AR) supplements the real world through combining virtual objects with the natural environment [42]. Past studies have examined using AR with children of all ages in different contexts, such as education [11, 32–34, 61, 63] and gaming [3, 40], and as an aid for children with autism and disabilities [26, 39, 64, 67]. For example, AR has been shown to increase student engagement and knowledge retention in elementary, middle, and high school [11, 24, 60]. However, little is known about how children conceptualize AR and how to design AR for children, especially for AR headsets. Compared to hand-held AR platforms (e.g., smartphone, tablet), headsets provide mobility and hands-free capabilities, which allow for more user freedom and immersion. AR headsets are starting to enter the industrial and consumer markets [84, 90], and children are using them in a variety of applications. For example, AR headsets are being used as educational tools for children (e.g., games, virtual field trips) [40, 70], as communication and emotion recognition aids for children with autism [30, 67], and to help children relax during medical procedures [13]. As children are starting to utilize these devices, it is important to understand their mental models and expectations because this can affect their perceptions of the system and usability. According to the Expectation-Confirmation Model for information systems, users are more satisfied with a system when they view it as useful and when their expectations are met [10]. Mismatches in expectations between users and designers can cause usability issues [59].

Children’s interaction behaviors and expectations have been shown to be different than adults’ across multiple devices and platforms (e.g., [4, 48, 49, 77]). It is important to examine AR headsets with children, since their interactions, perceptions, and expectations might be different. To create a conceptual model [37] about children’s understanding of AR headsets, we conducted four remote online participatory design (PD) sessions with an established intergenerational co-design group of ten children (ages 7 to 12). PD helps elicit rich design ideas from children (e.g., [7, 18]) and can be used to construct children’s mental models [79]. Modeling children’s thought processes is important to capture how children perceive things and has been used to develop children's learning instruction and technology (e.g., [21, 73]). We completed online remote PD sessions over Zoom [91] due to the COVID-19 pandemic. Online PD sessions have been shown to be equivalent to in-person sessions in collecting rich data, as well as allowing for a wider range of children to participate [44, 74]. Since the study was remote, the children did not interact with AR headsets while designing. None of the children had any prior experience with AR headsets, which enabled us to observe their initial perceptions and expectations. In the design activities, we focused on designing content for AR headsets with an emphasis on using them for tasks. Task completion is a common application for AR headsets, such as in maintenance, healthcare, and education (e.g., [39, 47, 83]). We defined "tasks" to the children as a job, chore, or project. We are interested in the tasks children would be interested in for AR headsets, and how they would want the devices to help them.

After completing the PD sessions, we created an affinity diagram [9] of the children's utterances from the video recordings of the sessions and then constructed a conceptual model. We found that children expect highly intelligent AR systems that can recognize and virtually transform surroundings, provide guidance and suggestions, and create immersive environments. In addition, children are in favor of using the headsets for games and difficult tasks but would prefer not to use it when they are trying to be creative and when completing easy tasks. Children often want to accomplish things on their own [51] and this translates to AR headsets. We also learned more about resolving challenges of conducting PD sessions online that involve a device not available for participants to interact with while designing. The contributions of our work include: (1) a conceptual model of how children comprehend and perceive AR headsets, and (2) new design recommendations for designing AR headset content and experiences for children. Our findings inform future designs of AR headsets for children.

2 RELATED WORK

We focus our related work on four major categories: (1) examining children's technological interaction behaviors and expectations, (2) using augmented reality (AR) headsets with children, (3) applying participatory design methods, and (4) conducting participatory design sessions with children on AR.

2.1 Children's Interactions and Expectations

Previous work has examined children's interaction behaviors and expectations with technological devices, such as touchscreens [4, 53, 77, 78], tabletop computers [65, 80], and voice input systems [48, 49]. Anthony et al. [4] examined touch and gesture interactions by children (ages 7 to 16) and adults on a smartphone. The authors found that children had increased holdover touches (i.e., when the location of touch is in vicinity of the previous target) and higher miss rates than adults. Prior work has also shown that children require a different pointing performance model for finger input on touchscreens than adults, most likely due to children's variability in touch performance [78]. Lovato and Piper [49] explored how children (ages 7 and under) use voice input systems by analyzing YouTube videos of children using Siri. The authors identified three ways children use voice input systems: exploration, information seeking, and function. Also, the authors observed low recognition accuracy due to the devices having a harder time understanding children's speech. Woodward et al. [79] also found that children expect different error detection and correction techniques for intelligent user interfaces than adults. For instance, children wanted IUIs to admit when it does not understand and seek clarification instead of using common techniques, such as auto-correcting or suggesting alternatives. These studies highlight both how children's interaction behaviors are different than adults and how children may have more difficulty using devices; therefore, it is important to examine AR headsets with children since their interaction behaviors and expectations might be different than adults.

2.2 Using AR Headsets with Children

Although previous AR studies with children have mainly focused on hand-held platforms (tablets, smartphones) (e.g., [26, 32, 63]), headsets are increasing in popularity due to being more immersive and interactive. For instance, Juan et al. [40] created an AR headset game focused on learning about endangered animals. In the game, children (ages 7 to 12) interacted with tangible cubes that had reference codes that the headset would recognize and overlay with virtual graphics and videos. The hands-free capability of the headset allowed the children to interact with the physical cubes and see the virtual content at the same time, which made the experience more immersive. In the non-AR condition, pictures and information were pasted directly onto the cubes and the children would watch videos on a separate computer monitor. The children enjoyed the AR game more, although they found it harder to use than the non-AR condition. Andersen et al. [3] designed Battle-Board 3D, an AR headset based game. During the game, one child would wear a headset, which showed augmented characters overlaid onto physical board game pieces, while the other child saw the characters on a monitor. The children wearing the headset found the game more entertaining and immersive, but they sometimes had difficulty navigating the physical space and interacting with their opponent. Even though Juan et al. [40] and Andersen et al. [3] found that children enjoyed using AR headsets, both studies identified device usability issues. Prior work has started to examine different interaction methods in AR headsets with children [57, 58]. Munsinger and Quarles [57] analyzed three interaction methods (voice, gesture, controller) for a Fitts' Law task in an AR headset with children (ages 9 to 11). In the study, the controller resulted in significantly faster time, less fatigue, and higher usability compared to voice and gesture.

Importantly, Southgate et al. [71] explored the ethics of designing AR experiences for children. The authors remarked that there has been little research on the physical, cognitive, emotional, and social effects of highly immersive experiences on children. Children (under age 13) have a harder time separating the real from unreal [46, 62] and can become so immersed that they lose track of their environment in an unsafe manner [6, 23]. The authors emphasized considering the developmental stage of the children when designing and to include researchers with expertise with children when conducting studies. Although studies have examined using AR headsets with children, it is still unclear how children conceptualize these devices and what their expectations are, both of which are critical to understand for children's design. Knowing and matching users' expectations is important for users' satisfaction and to avoid usability issues [10, 59]. Therefore, we aimed to understand how children conceptualize interaction with AR headsets.

2.3 Participatory Design Methods

For our study, we utilized participatory design (PD), which is a method of design that brings users and designers together to create new technologies [41]. Specifically, we used a PD method called Cooperative Inquiry that emphasizes close partnerships with children [19, 20, 82]. Prior studies in child-computer interaction have used PD methods such as Cooperative Inquiry to create technology tailored towards children [7, 14, 18, 20, 45, 68, 76, 79, 82]. PD can elicit rich ideas from children, more so than interviews [7, 18, 79]. Woodward et al. [79] used PD to understand how children conceptualize intelligent user interfaces. The authors conducted four synchronous in-person PD sessions with children (ages 7 to 12) to create a conceptual model of children's understanding of intelligent interfaces. They reported that asking children specific questions about the technology in the warm-up discussions did not produce as insightful results as the design activities, since the activities allowed the children to express abstract ideas.

Prior work on PD with children has mainly focused on synchronously designing together in-person. However, due to the COVID-19 pandemic, our design sessions had to become remote. Remote PD has been used in the past to increase access to participation for children who may have transportation, location, or other limitations [44, 74]. Other advantages of conducting online PD sessions exist, such as: (1) separating small groups into breakout rooms for more defined partnerships, (2) allowing children to design in a familiar environment (e.g., their home), and (3) incorporating digital materials more seamlessly into activities. Lee et al. [44] conducted and examined ten online remote PD sessions with a co-design group consisting of both children (ages 7-11) and adults. The authors provided guidance for how to modify existing PD techniques to an online format. We used Lee et al.'s [44] technique adaptations as a base for our design sessions, which we explain in the Methods section.

2.4 Participatory Design Sessions on AR

Previous studies have also used PD methods with children to examine AR [1, 14, 68]. Alhumaidan et al. [1] conducted PD sessions with a group of children (ages 8-10) and adults to design an AR textbook for a tablet. The co-design sessions focused on creating low-tech prototypes out of craft materials, as well as critiquing an existing AR textbook. Based on the children's designs, the authors presented design features for an AR textbook (e.g., being able to interact with the virtual elements using the tablet touchscreen). In addition to tablets, prior work has also used PD methods with children for AR headsets [14, 68]. Cassidy et al. [14] utilized PD design methods to gain insight into what augmentations children find engaging in play contexts. The children (ages 7 and 8) were instructed to create designs for a "super pair of glasses" that would help them play. In small groups, the children drew on a clear acetate sheet over three static photograph images (i.e., Legos, fake food pieces, and a coloring book) to simulate AR display technology. The most common elements the children added were item information and instructions. Similarly, Sim et al. [68] used PD methods to examine how children would design AR experiences, except for a museum context. The children (ages 7 to 9) were presented with a storyboard of going to a museum, putting on smart glasses, and looking at an exhibit of a Roman soldier. The children were instructed to draw augmented content onto three images: walking into the museum for training, the soldier exhibit, and then a sign with text describing a museum artifact. The authors found that the children were able to grasp the idea of AR and designed virtual content, some in which was interactive (e.g., fighting the soldier). Although these two prior studies utilized PD methods to examine children designing for AR headsets, they only conducted one design session and constrained the context of the children's designs by providing the children with specific static images. For our study, we conducted four open-ended design activities, instead of constraining the context. These two studies investigated whether children could understand the concept of AR headsets but did not analyze how the children conceptualize the technology itself, what their ideas for its use might be, and what their expectations for the technology are. We concentrated on understanding how children conceptualize AR headsets and their overall expectations.

3 METHODS

For our study, we conducted four remote synchronous participatory design (PD) sessions with an existing intergenerational co-design group. The sessions focused on designing content for AR headsets, with an emphasis on utilizing the devices for completing tasks (i.e., jobs, chores, projects). Our design activities were open-ended; we did not constrain the children to specific tasks. We conducted four 80-minute design sessions across two weeks over Zoom [91], with two sessions a week. Our protocol was approved by our institutional review board, and we collected both parental consent and child assent. The four sessions included:

- Design Session 1: Design an AR headset game.
- Design Session 2: Design elements in an AR headset that would be helpful while using Legos.
- Design Session 3: Create a story of using an AR headset for doing a task.
- Design Session 4: Finish a story of using an AR headset for one of the tasks from Design Session 3.

3.1 Participants

We conducted the study with an intergenerational co-design group, consisting of both adult design researchers and child participants, called *KidsTeam UW* [44, 81, 82]. The group includes ten children ages 7 to 12 [M = 9.3, SD = 1.9]. The age group of the children is consistent with existing Cooperative Inquiry studies (e.g., [75, 79, 82]), as well as prior work on using AR headsets with children [40, 58]. None of the children had used AR headsets before. All names presented in the paper are pseudonyms, and the children's demographics were parent-reported (Table 1).

3.2 Design Sessions

Each design session was conducted remotely over Zoom and was broken down into four parts: *social time* (10 minutes), *introduction*

Table 1: Child participant demographics. All names are pseudonyms.

Child Pseudonyms	Age	Gender	Ethnicity
Anne	7	Female	Asian/Black
Akira	7	Male	Asian/White
Elsie	8	Female	Asian/White
David	8	Male	Hispanic
Marcus	8	Male	Asian/White
Kotaro	10	Male	Asian/White
Mike	10	Male	White
Katie	11	Female	Asian/White
Billy	12	Male	Asian
Henry	12	Male	Hispanic

(10 minutes), *design activity* (40 minutes), and *discussion* (20 minutes). *Social time* allowed time for the children and adults to arrive and get settled. In the *introduction*, we asked a "question of the day" and presented the design activity for that session. We used the question of the day to prompt the children about what we would be designing and to get insights into their mental models. During each day's *design activity*, the main group broke into smaller intergenerational groups in Zoom breakout rooms to complete the activity. In each group, the adult design researchers acted as partners by designing with the children and facilitating discussions. After the design activity, all the groups came back together to discuss their finished designs during the *discussion*. Each design activity was chosen for its potential to explore different aspects of the design space of children's conceptual model of AR headsets. When using PD to build mental models, Woodward et al. [79] recommends starting with designs sessions that allow participants to become familiar with the context before structuring the later sessions to focus on more complex topics. Therefore, we organized the activities to scaffold the children's thought process on AR headsets, by first introducing the concept of AR headsets and then delving into using it for task performance. The design sessions were video recorded through Zoom.

3.2.1 DS 1: AR Headset Game. On the first day, we focused on introducing the concept of AR headsets. During the *introduction*, we asked the question, *"Does anyone know anything about augmented reality (AR)?"*, to try to establish the scope of the children's pre-existing mental models of AR. Since the children did not interact with headsets during the design sessions and none of the children had any prior experience with headset AR, we first discussed AR as a group before the design activity. Similar to prior work [68], we explained AR within the context of *Pokémon G*O [92] and showed videos of the functionality of AR headsets [16, 55] before starting the activity. The videos depict people seeing and interacting with virtual content while wearing AR headsets in both first- and third-person perspectives. We then explained the *design activity*, which was to design an AR headset game. The only design constraint was that it had to be for a headset (i.e., not tablet, etc.). For the activity, we used two existing PD techniques: *Bags of Stuff* [19, 76] and *Big Paper* [29, 76]. *Bags of Stuff* is a low-tech prototyping technique, in which large bags are filled with craft materials and each group uses the materials to create a low-fidelity prototype. *Big Paper* is a form of paper prototyping, in which each design group has a large piece of paper to collaborate and draw. Due to the remote nature of our sessions, we shipped the children a box of craft materials for them to use to create their own prototype, including a child-size face shield they could use to simulate an AR display (Figure 1 left). The children could draw on the face shield and physically put it on to test out their designs. For *Big Paper*, we had each small design group collaborate using Google Slides. Overall, the session included: craft materials, face shield, and Google Slides.

3.2.2 DS 2: Lego Activity. For the second design session, we asked the question, *"What information would you always want to know throughout your day that would be helpful to you?"* We asked this question to elicit children's ideas about information they would like to have access to in an AR headset. The *design activity* was to design elements to appear in an AR headset while using Legos and depict how the elements should be displayed in the headset (Figure 1 right). The children could make anything with the Legos; it just had to connect with what they designed in the headset. We chose to use Legos as the activity because we wanted to shift the design activities towards using AR headsets for tasks. Building with Legos has similar characteristics to working on tasks, such as being step-based and having an end goal (i.e., completion), and Legos are still familiar to the children. We utilized the same PD techniques as DS 1 (i.e., *Bags of Stuff*, *Big Paper*); we also shipped the children Legos. Altogether, the session included: craft materials, face shield, Legos, and Google Slides.

3.2.3 DS 3: AR Headsets for Tasks Part 1. We designed the third session to introduce the concept of using AR headsets for task performance. The focus was to have the children think about and identify what tasks they would want to use the headsets for. During the *introduction*, we asked the children, *"What would you want to use AR headsets for throughout your day?"*, to get the children thinking about using headsets for specific purposes. The *design activity* was to create a story of using an AR headset for doing a task. We clarified "tasks" to the children, as a job, chore, or project. We used *Comicboarding* [76], an existing PD technique in which children come up with a story about a technology they are designing while an adult artist is drawing their story. Since our sessions were remote, we utilized Lee et al.'s [44] modified online *Comicboarding* technique of having the groups create a story together using Google

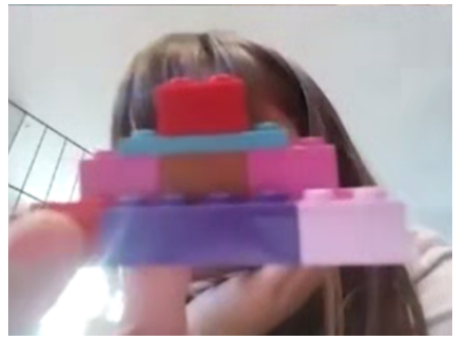

Figure 1: Child participant's AR game using a face shield [DS 1] (left) and child participant's design using Legos [DS 2] (right).

Slides and the children direct the adults on finding visuals online. For the story the groups had three boxes to fill out with a prompt in each one: what is the task, what will you see, and how will it help. The three prompts helped the children identify tasks, as well as consider visual elements presented in the headset.

3.2.4 DS 4: AR Headsets for Tasks Part 2. The last design session was a continuation of DS 3. The goal was to further explore using AR headsets for task performance, specifically focusing on functionality. For our last question, we asked the children, *"How would you explain augmented reality (AR) to someone?"* The purpose of the question was to examine how the children's concept of AR may have shifted during the sessions. The *design activity* was to finish a story of using an AR headset for one of the tasks from DS 3. We chose three of the tasks the children designed in DS 3 and assigned each small group one of them: helping with homework, teaching how to cook, or assisting in a fire (e.g., leading people to safety). We utilized Lee et al.'s [44] remote *Comicboarding* and had the groups fill out three boxes using Google Slides with the prompts: create a character of who would use it for that task, how would they use it (when and where), and what happens when they use it. We also used the PD technique *Layered Elaboration* [75, 76], in which transparent material is added to paper-based prototypes to enable iterative design. For our remote sessions, we modified the technique to have the children elaborate on one of the tasks from D3. The small groups could look back to the Google Slides from DS 3 to see the previous design and expand upon it. For both DS 3 and DS 4, the sessions included Google Slides, in which the children could annotate and draw on.

3.3 Data Analysis

After completing the four design sessions, the first and third authors transcribed the Zoom recordings. The recordings included 16 videos, consisting of approximately 554 minutes of video data (not including *social time*). The transcriptions resulted in 512 utterances used for analysis (i.e., excluding utterances not pertaining to the design activities). Out of the 512 utterances, 372 were made by the children (72.7%); the rest were made by the adult design partners or researchers. Similar to prior work [79], we analyzed the utterances through affinity diagramming, which is a method to organize large-scale qualitative data through a bottom-up inductive approach [9]. We did not compute inter-rater reliability as it is not recommended when the research goal is to determine concepts and themes [52]. To create the affinity diagram, the first three authors iteratively grouped the individual utterances into themes over the course of ten meetings (approximately 20 hours) using *Miro* [93], an online whiteboard tool for remote collaboration. We initially identified 12 central themes, which we further combined into 7 main groups. We iteratively grouped the themes until we had a clear distinction between groups. The entire research team then met over two 1-hour meetings to discuss the themes and determine the links between the groups to create our conceptual model [37] (Figure 2).

4 FINDINGS

We identified 7 main groups: *User Feeling*, *User Input*, *System Output*, *Context of Use*, *System Ability*, *System Immersion*, and *System Intelligence*. When determining the 7 groups we were inspired by the groupings from Woodward et al.'s conceptual model on intelligent user interfaces (IUIs) [79]; however, we found differences between our results and the model on IUIs which we elaborate on in the Discussion section of the paper. We provide an overview of the conceptual model before discussing each main group and themes.

4.1 Conceptual Model Overview

In our study, the children talked about their distrust towards the AR headset and only wanting to use it in certain situations (*User Feeling*). Their feelings influenced how they used and interacted with the device. When designing for interaction, the children added a wide range of input modalities (e.g., voice, body movement) (*User Input*). The children expected diverse system outputs (e.g., color, voice, virtual elements) *(System Output*). Both user input and system output illustrate the required high level of system intelligence (*System Intelligence*). In addition, the children expected certain contexts of use, as well as certain headset abilities and content (e.g., virtual characters, social connection) (*Context of Use*, *System Ability*). The intelligence and output of the system then impacted the children's feelings of immersion and connection, which in turn influenced their feelings towards the system (*System Immersion, User Feeling*). Overall, the children designed highly intelligent AR headsets that accepted a wide range of input modalities to create immersive environments for the user (Figure 2).

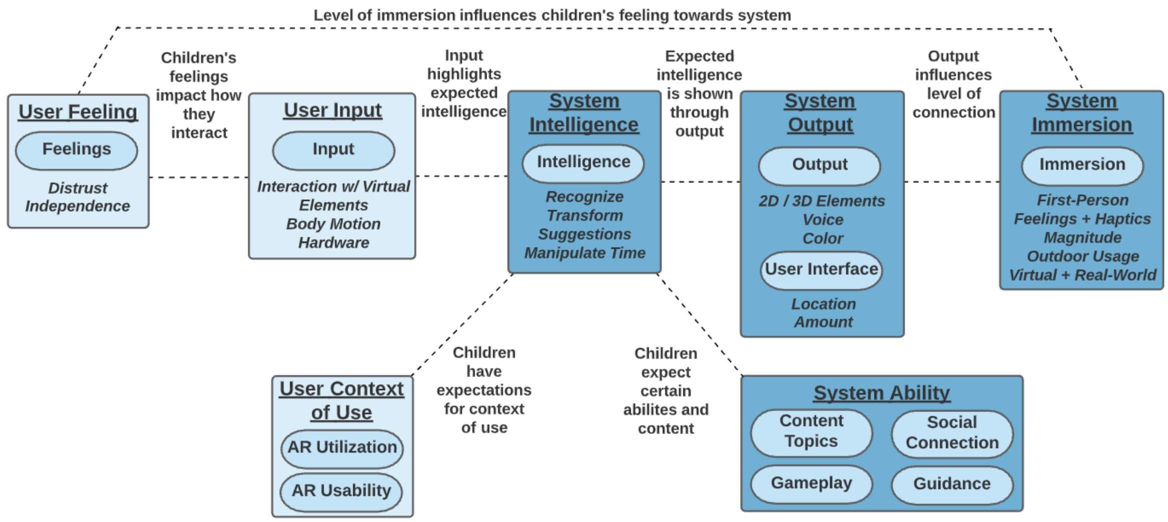

Figure 2: A conceptual model of children's understanding of augmented reality (AR) headsets.

4.2 Main Groups and Themes

We will now discuss each of the 7 main groups and the subthemes, with specific examples from our design sessions. Although some of the children's designs are not feasible (e.g., using AR headsets to see the future), we take inspiration from these ideas and provide design recommendations in the Discussion that can be applied to real-world AR headsets.

4.2.1 User Feeling. Throughout all four design sessions, the children remarked on their *Feelings*, which included: *Distrust* and *Independence.* The children frequently commented on their lack of trust in the headset. When designing AR headsets for cooking, Kotaro stated, *"I wouldn't trust it because like, obviously AI can do weird stuff. Maybe it might like mess up when it's like, I don't know when the stove is on and then it catches the entire house on fire."* [DS 4]. The children were concerned the headset could make faulty decisions. Children's experience with the limitations of smart technologies (e.g., voice assistants not understanding them [8, 49]) made them wary of trusting a new device to make decisions and help them accomplish things.

For *Independence*, the children did not always want to use the headset, rather wanting to accomplish certain things on their own: *"If people get along easily without it, why do we need it?"* [Marcus, DS 4]. When designing using an AR headset for homework, Mike preferred to use the headset for step-based problems instead of creative writing. Also, the children would sometimes prefer a human connection and a break from technology: *"I'd rather be with humans than robots."* [Kotaro, DS 3] and *"I wouldn't wear it a lot, I already do a lot of screens."* [Akira, DS 3]. One interesting thing to note is Kotaro equated AR headsets with robots. This may be due to the increasing pervasiveness of robots (e.g., [31, 66, 86]), as well as children's perceptions. Children view robots as intelligent, comfortable, social, and helpful [56]. Therefore, Kotaro may view a headset as comparable to a robot due to having similar characteristics. While discussing independence, the children talked about wanting to use the AR headset for certain circumstances. For example, during DS 2 the children discussed not wanting to use a headset for free building Legos. They preferred using the headset for Lego sets that require instructions. The children's distrust and desire for independence influenced their feelings towards AR headsets and how they want to interact with it.

4.2.2 User Input. The children considered a wide range of input modalities for *User Input*, which included three themes: *Interaction with Virtual Elements*, *Body Motion*, and *Additional Hardware.* In their designs for AR headsets, the children incorporated how to interact with the virtual elements, such as through natural interaction, direct manipulation (e.g., button clicks), and voice. For natural interaction, the children talked about interacting with the elements as they would in the real-world. During DS 1, Mike created a prison escape room game, in which the user had to interact with virtual elements similarly to how one would interact with real-world elements to find clues (e.g., grabbing a virtual wrench). When asked how it would look like when someone is using a headset to cook, David said, *"It will probably look normal except the AR headset would be on the person's head."* [DS 4]. In the children's mental models, a person would not need to change their interactions to suit the AR headset, they could act normally to complete the task. We found that the children added voice interaction, especially with tasks: *"I think it [voice input] would be easiest to do like, um, on short notice. Um, because like, you don't have to take time to like touch something."* [Mike, DS4].

The children utilized *Body Motion* as a method of input in their designs. During DS 1, the children frequently created AR games which required whole-body movement. For example, Henry created a game in which the user must avoid virtual cars coming towards them by physically moving and dodging, and Mike used head movement to move a virtual character. The children also added *Additional Hardware* into their designs, such as joysticks, physical buttons, and even physical mechanical arms attached to the headset. The

Figure 3: Designs for an AR headset field-of-view for cooking [DS 3] (left) and locating a fire [DS 4] (right).

children added hardware to increase the functionality of the headset and to expand interaction options (e.g., combination of voice and physical buttons).

4.2.3 System Output. The children considered the System Output and User Interface, which contained six themes: 2D Virtual Elements, 3D Virtual Elements, Voice, Use of Color, Location in Field-of-View, and Amount of Information. While we saw a mix of both 2D and 3D virtual elements throughout all four sessions, the children mostly incorporated 3D elements into games (DS 1) and 2D elements for task-based designs (DS 3 and 4). For the 3D elements, the children designed both realistic and fantasy elements (e.g., cars, dragons), as well as 3D text instructions. For the 2D virtual elements, the children included text, images, mini-maps, and symbols/shapes. When designing AR headsets to help pinpoint a fire, Mike said, "A circle would be good. And then you could like, put a random number on it, like 150 degrees Fahrenheit." [DS 4] (Figure 3 right). In terms of Voice and Use of Color, the children mostly included these features in task-based designs. For example, Akira designed the headset to give a tsunami warning: "Someone would yell in your ear and say, 'get out of here! warning! There's a tsunami!"' [DS 3]. For cooking, Katie used color to show food that the user is allergic to or that has gone bad: "Red. Just like tint it red. You get red, give it an X, just give it a big X. Like a gone bad stamp." [DS 3] (Figure 3 left).

We observed the children consider the *User Interface*, by determining where elements should be located in the field-of-view and the amount and type of information to be displayed. The children frequently designed elements to be on the right-hand side of the field-of-view. For example, when discussing where to place a game menu, Akira said, "*Maybe a little corner at the top,*" and David responded by saying, "*Well, it's usually on the right top corner.*" [DS 1]. The children's expectation of elements being located on the right side of the field-of-view might be based on prior experience with video games. For instance, both *Mario Kart 8* [85] and *Fortnite* [94] include mini-maps on the right-hand side. The children considered the amount of information to be displayed, because they did not want the information to be too distracting or difficult to understand.

4.2.4 Context of Use. During the design sessions, the children thought of a wide range of contexts that AR headsets could aid in (*AR Utilization*) and considered how the headset differs from traditional interaction methods (*AR Usability*). The children designed headsets to help in contexts such as homework, video games, cooking, recording and playing events, and safety. The children thought of situations in which augmented information and elements could be entertaining (e.g., games), as well as beneficial to the user. For instance, the children thought AR could aid in instructional-based activities (e.g., cooking, homework) and in emergency situations. David suggested that in a fire, a large virtual character, such as Nintendo's Mario, could lead users to safety. Also, virtual arrows could appear on the ground to show the user which direction to go [DS 3]. Although the children did think of different contexts, it is important to note that the children did not perceive AR headsets as pervasive; rather, viewing the device as a tool for specific situations.

Throughout the sessions, the children compared the usability of AR headsets to traditional methods. For instance, Elsie compared playing games on the headset to the Nintendo Switch: *"I would probably want to play it like kinda like in a headset, so you put it on and you can see everything like up close and you don't have to like lean into your switch screen."* [DS 1]. Also, the children thought the headset would be more useful than paper instructions: *"I think I prefer it [headset] over the book because having the book it always splits closed or like twists the next page or whatever."* [Katie, DS 2].

4.2.5 System Ability. We noticed the children incorporated certain abilities and content for the AR headset that included: *Content Topics, Gameplay*, *Social Connection*, and *Guidance.* In all four design sessions, the children considered content as a base of their design. The children commonly focused on fantasy and science fiction topics and added characters and elements from existing entertainment (e.g., *Mario Kart*, *Minecraft*, *Sesame Street*). For example, in DS 4 David wanted a virtual Cookie Monster to show him how to cook in the headset. The children also included certain game elements, such as different game modes, customization, and the ability for game progression (e.g., different levels). For example, Akira and David created a *Star Wars* game, in which a user can battle other players, visit different planets, and build ships [DS 1]. Through using AR headsets, children can build objects that are impossible in the real-world (e.g., life-size *Star Wars* ships) and view how those objects relate to the natural environment.

During the sessions, we observed that the children frequently included a *Social Connection*, through interacting with virtual characters and adding human collaboration. The children created a wide range of virtual characters, from fantasy creatures to humans. During DS 3, Mike said, *"Like if I had a couch it [headset] could add, like somebody sitting on the couch I have in my room."* The children also added aspects of human collaboration, such as multi-player options and allowing people to view what the user is doing. For example, Anne included the ability to share experiences with other people: *"But if someone else is wearing the headset too, then they can see it."* [DS 3]. In the children's mental models, they also view AR headsets as a system to provide *Guidance*. The children incorporated elements, such as instructions, explanations, and reminders/warnings throughout all four sessions. For instance, Mike wanted the headset to help with his homework [DS 3]. In the children's designs, the headset would recognize what the user is doing in real-time and provide guidance through overlaid visual elements and voice.

4.2.6 System Immersion. The children designed the AR headset experiences to be *Immersive*, as represented through five themes: *First-Person*, *Feeling and Haptics*, *Physical Magnitude*, *Outdoor Usage*, and *Interaction Between Virtual and Real-World*. Most of the children's designs focused on a first-person perspective. For instance, Billy created a game in which life-size dinosaurs walk around and the user can battle or dodge the dinosaurs. In his game, Billy also incorporated the idea of *Feeling and Haptics* through being able to interact with the dinosaurs as if in the real-world: *"I think it would be cool to get stampeded by dinosaurs."* [DS 1]. We also saw this concept of haptics in other children's designs, such as Henry's game with virtual cars in which the user must *"[. . .] avoid traffic or get run over."* [DS 1, utterance posted in Zoom chat]. Additionally, the children designed AR experiences that included virtual elements with *Physical Magnitude* (e.g., dinosaurs, spaceships, cars) and that occurred in different environments, such as *Outdoors*. For example, Henry talked about playing his game with virtual cars on sidewalks, racetracks, and on hiking trails.

One main immersive concept that appeared in the children's designs was the idea of *Interaction Between Virtual and Real-World*, in which virtual elements can influence the real-world environment. In existing headsets, users can interact with virtual elements; however, the virtual elements do not in turn impact the users' environment. We observed the children consider how virtual elements could affect and change their environment. For instance, in Akira's and David's *Star Wars* game, David was worried that the virtual characters with lightsabers would affect the real-world: *"Actually it wouldn't be good if AR could sense the things that were around you, because if it could sense the things around you the characters are going to be cutting in half all the cars around you."* [DS 1]. While it is not feasible for virtual elements in AR headsets to physically interact with and change the real-world (e.g., cutting cars in half), the devices could include more interactivity with the real-world. For instance, a virtual character's actions (e.g., dialogue, movement) could refer to elements in the user's actual physical environment.

4.2.7 System Intelligence. The children expected a high level of *System Intelligence*, such as the ability to *Recognize Surroundings and Objects*, *Transform Surroundings*, provide *Suggestions*, and *Manipulate Time*. In the children's mental models, the headset must be able to recognize objects, locations, danger (e.g., a fire), other people, and the status of objects and people. For instance, Mike and Katie discussed using the headset to determine people's ages and level of danger during a fire: *"Like, uh, put the people in like green dots and then people who are in danger red dots."* [Katie, DS 4]. The children thought the headset should discern people's ages in a fire because *"[. . .] the kids need to be rescued first, then the old people then the middle-aged slash adults."* [Mike, DS 4]. Like Katie's "gone bad" food stamp discussed in the System Output section (Figure 3 left), Billy also designed the headset to go beyond recognition in having the headset decide the status of food: *"Um, and it [headset] can also show you like if your food has gone rotten, and so you can throw that away."* [DS 3].

In addition to recognition, the children expected the AR headset to be able to virtually transform their surroundings. For the *Star Wars* game, David discussed transforming his surroundings to a spaceship workshop. When talking about adding virtual elements to the environment, Anne said, *"And then, and then like basically the whole room, it turns, it looks, it turns into real life and it looks real, but no one else can see it except me because I'm wearing the headset."* [DS 3]. Other levels of intelligence the children included were providing suggestions and manipulating time. For example, Anne thought of using the headset to change the future and past. While this level of intelligence is not possible, the headset could show how things may have looked in the past or will look in the future (e.g., a finished building that is under construction). Overall, the children incorporated a high level of system intelligence into their design concepts.

5 DISCUSSION

We focus our discussion on (a) summarizing the key points of our conceptual model of children's understanding of AR headsets, (b) comparing our conceptual model to existing models of children's understanding of technology, (c) discussing new insights on conducting remote online PD sessions with children about a device they do not have access to while designing, and (d) suggesting new design recommendations for AR headset experiences for children.

5.1 Our Conceptual Model

Based on our findings, children perceive AR headsets as a type of intelligent system that can go beyond recognizing objects to also determine important status details about those objects (e.g., people's ages, expired food). Children also envision headsets should be able to transform users' surroundings to create immersive environments, in which virtual elements can interact with and affect the real world. Children imagine interacting with AR headsets through voice, natural interaction, and body movement, and expect the system to intelligently respond using 2D and 3D virtual elements and voice. Children's perceptions of AR headsets go further than just a visual augmentation tool, rather considering an all-encompassing system. In addition, children have specific ideas of what they want to use headsets for, as well as expect certain abilities and content (e.g., existing characters). For example, David designed a virtual Mario to lead users to safety during a fire. When discussing the size of the character, David said, *"It would be kind of creepy if it was little, more little than me. He's 25 years old."* [DS 3]. Yip et al. [81] found that qualities such as an ominous physical appearance (e.g., overly tall), mimicry, and unpredictability can lead to children viewing technology as "creepy". In David's mind, a virtual

Mario in the headset should realistically represent the character's characteristics, such as age. Although children are interested in using AR headsets, they still value their independence away from the headset to be creative and interact with people without digital screens. Prior research has found that children still enjoy performing non-digital activities (e.g., outdoor play) away from technology [38]. Also, children often want to accomplish things on their own without help from their parents [51], and children (ages 7 to 11) are learning to be competent and productive individually [25]. We observed that children's desire to do things on their own translated to AR headsets in our sessions.

Through conducting PD sessions, we were able to elicit rich ideas from the children and extract their complex perceptions of AR headsets. In our study, not having the children interact with existing headsets allowed us to view their original mental models and engender new design ideas. For example, the children were not limited in their designs by the field-of-view of existing headsets; Mike discussed having an *"[. . .] endless circle of a face shield."* [DS 1]. Overall, we were able to create a cohesive conceptual model of children's understanding of AR headsets, which can be used to design headsets that match children's expectations.

5.2 Our Model vs. Existing Models

We used a top-down deductive approach to compare our conceptual model to existing models of children's understanding of technology. Jarvis and Rennie [36] created a five-stage model of the development of how children (ages 5-11) understand technology. The authors generated their model based on children's drawings of what the term "technology" means to them and one-on-one interviews. In the model, the five stages are: (1) No Model, (2) Embryonic Ideas (unestablished ideas), (3) Single Explanation (consistent idea), (4) Multiple Explanations (inconsistently applied), and (5) Development of a Generalized Concept. Lachapelle et al. [43] examined children's (ages 8-11) conceptions of technology through responses to open-ended questions and picture analysis (i.e., determining if a picture of an object can be classified as technology). The authors found that children conceptualize "technology" primarily as artifacts powered by electrical energy. In our conceptual model of children's understanding of AR, the children go beyond a simple explanation of being powered by electrical energy and their design concepts displayed evidence that they have a generalized concept. The children's generalized concept was also evident through their responses to the question of the day for DS 4: *"How would you explain augmented reality (AR) to someone?"* For example, David answered, *"You put [it] on your head, then you can see things and interact with [it],"* and Billy said, *"So in the headset, you can see like virtual objects on top of the real world."*

As mentioned, Woodward et al. [79] created a conceptual model of children's understanding of intelligent interfaces (IUIs). The authors defined IUIs as interfaces that try to interpret the user's intent, such as smartphones and speech agents. In comparing our conceptual model of AR headsets to Woodward et al.'s model [79], there are similarities in children's expectations. For example, children expect a wide range of input modalities and system outputs (e.g., voice, visual elements), social connections, and high system intelligence. In both models, children presume high accuracy and recognition, as well as that the system will be able to make decisions (i.e., suggestions). Although we see similarities, there are clear differences between the models. For instance, with AR headsets children expected more mobility, such as the ability to use whole-body movement as user input (e.g., fighting). The immersive and hands-free capabilities of the devices allow for whole-body motion as an input method. Furthermore, we noticed that children view AR headsets as a tool to provide guidance (e.g., learning how to cook), instead of users teaching and commanding the system as in Woodward et al.'s model of IUIs [79]. Other differences between the models include our finding of user feeling compared to user behavior and our theme of system immersion. In our study, we observed the children discussing their feelings toward using AR headsets, instead of mainly focusing on their desired input behaviors as with the model of IUIs. This difference could be a result of the novelty of AR headsets and the children not having any prior experience, compared to IUIs (e.g., smartphones). The emphasis on user feelings was also present in our theme of system immersion, which was not part of children's mental models of IUIs. For AR headsets, children considered what the user would experience and feel. Also, children viewed headsets as able to affect and influence the physical environment. According to children, it is important to consider users' perceptions and immersion when designing interactions with AR headsets. In general, our findings along with Woodward et al.'s model [79] illustrate that children think about technology in complex unexpected ways. It is important to understand children's perceptions and expectations of technology to effectively design for them, especially as children continue to use technological devices in different contexts.

5.3 Remote PD Sessions with Children

In part due to our PD sessions being remote, the children did not interact with AR headsets while designing, as sending individual devices to each child as part of the design sessions was out of scope for our project. Since the children did not have access to an existing AR headset, we tried to simulate a headset through a low-tech commonplace item: a face shield. We chose a face shield because it shares similarities with a headset: (1) a person physically wears it on their head, (2) there is a transparent screen, and (3) it is hands-free. By using the face shield, the children were able to create and test out their designs as if they were wearing a headset. For example, when Elsie put on her face shield when creating an AR headset baking game, she immediately said, *"I drew it too low!"* [DS 1]. Low-tech prototyping is a long-established PD technique for in-person sessions (e.g., [19, 76]). We found that this is still a valid PD technique when conducting online PD sessions with children involving a device that is not available. Researchers can utilize commonplace items that have similar characteristics with the unavailable device for online PD sessions. Our work corroborates Lee et al.'s [44] finding on the importance of improvisation in conducting remote PD sessions with children. For instance, Billy never received the package with the craft materials and face shield. Therefore, we had to improvise; instead, Billy used plastic wrap that was in his kitchen, since it still shared enough similar characteristics to an AR headset (e.g., transparent screen).

In our study, we noticed the children had different ways of communicating that were unique to an online format. In addition to speech, the children sent responses and images in the Zoom chat and annotation on the Zoom screen. The distinct methods of communication allowed the children to express themselves in a way they felt most comfortable. Designing through images and annotation enabled the children to clearly articulate their visual ideas. When transcribing the data, we had to be mindful of the different ways the children communicated to capture their designs. In analyzing the data, we observed that DS 2 (i.e., Lego activity) had fewer utterances and design ideas than the other design sessions (i.e., 70 utterances out of 512). Compared to the first design session that focused on designing an AR headset game with a face shield, DS 2 required the children to focus on two external items: (1) Legos, and (2) a face shield. The children frequently remarked that they were confused: "I *don't understand what we're supposed to do with it.*" [Katie, DS 2]. Also, the groups were able to collaborate on Google Slides during DS 2; however, the children mainly focused on the two individual components (i.e., Legos and face shield). In comparison, the groups in DS 1, 3, and 4 actively collaborated using Google Slides. For conducting remote PD sessions with children, we recommend researchers actively incorporate an online collaboration component (e.g., Google Slides) into the design activity. For instance, for the online *Comicboarding* technique, groups can create a story together using Google Slides [44].

5.4 Design Recommendations

Based on our model, we suggest recommendations for designing AR headset content and experiences for children. In each subsection, we connect the recommendation to our conceptual model. We also highlight which recommendations are currently applicable and which require future research directions. Existing and future designers of AR headset experiences for children can utilize our model to examine if their designs match children's expectations.

5.4.1 Location of Content in AR Headset [Current]. Prior work has found that people exhibit a leftward visual and spatial bias, known as *pseudoneglect* [12, 72]. Pseudoneglect leads to advantages in the left visual field, such as faster motion processing, greater detection accuracy, and higher contrast sensitivity [15, 50, 72]. Furthermore, prior research has shown that pseudoneglect extends to elements located on the left-hand side of a computer screen [50]. However, based on the themes *System Output* and *User Interface* in our conceptual model, the children expect elements to be on the right-hand side of the AR headset field-of-view. The children's expectation of virtual elements being on the right side of the field-of-view is most likely do to their prior experience with video games, where mini-maps and other elements are often located on the right (e.g., *Mario Kart 8* [85]). We suggest that current designers consider a trade-off between noticeability and usability when designing where to place content in AR headsets for children. For instance, Jones et al. [39] investigated using monocular AR headsets to help facilitate sign language in learning environments. Deaf or hard-of hearing students receive instruction visually and usually must split attention between signed narration and visual aids. Therefore, Jones et al. examined how displaying sign language in an AR headset could help with receiving instruction. The authors allowed the students to choose where to place the sign language in the headset, and the majority chose the top-right. The students struggled to split attention between the real world and signed narration in the headset. Based on our findings, while the top-right aligns with their mental model, in the context of education the information may be better suited to be displayed on the left-hand side to lead to higher detection and contrast. One thing to note is, while pseudoneglect has been shown to occur in both right-handed and left-handed people, it is not prominent in cultural groups that read right-to-left [69]. Therefore, designers should also consider users' cultural groups when designing where to place the elements in headsets.

5.4.2 Consider Context [Current]. Prior work has examined the applicability of using AR headsets in an array of contexts (e.g., healthcare, military, navigation, education) and how headsets compare to traditional display methods [27, 28, 40, 47]. However, based on the *User Feelings* theme in our model, designers should pause and consider when to design AR experiences for children; certain contexts do not match children's mental models. In contrast to other wearable technology (e.g., smartwatch), children do not view AR headsets as pervasive technology to wear throughout the day. We observed the children want *Independence*, as they did not want to use AR headsets for situations that were not difficult for them. For instance, Marcus said, *"I do my homework in 15 minutes, why do I need the AR, or I easily read cookbooks, I don't need someone telling me."* [DS 4]. Children have a desire to accomplish things on their own [51], and the children in our study exhibited this behavior with AR headsets. Besides not wanting to use the headsets for tasks they did not need help with, the children did not want to use it when being creative (e.g., free building Legos, writing). Therefore, our findings show that, while AR headsets are being applied in educational contexts for children [11, 40], not every topic might be relevant. For instance, although the children considered using the devices to help with homework, it was only for certain subjects (e.g., math) and for things they found difficult to work on themselves. Prior work in intelligent tutoring systems has focused on providing appropriate scaffolding based on learners' cognitive and affective states (e.g., [17, 22]). Designers can apply scaffolding and intervention techniques from intelligent tutoring systems research to design for AR headsets to recognize and present help when children are having difficulty. Overall, we recommend that designers consider children's desires to accomplish things on their own and only deliver support in headsets when children are having trouble with a task.

5.4.3 Avoid Specific Gesture Commands [Current & Future]. Because one of the main benefits children seemed to conceptualize for AR headsets was the ability to use them hands-free, we found that children rarely thought of interacting with the devices using specific gestures. Instead, in the *User Input* theme in our model, we saw the children focus on natural interaction, direct manipulation (i.e., button click), and voice. In our study, the children often used voice interaction for tasks. For example, in the context of using AR headsets for cooking, David said, "*Well I wouldn't want to clap or something, if I had soap on my hands or something then it would all go flying, so maybe voice.*" [DS 4]. Based on the children's mental model, we recommend avoiding interactive hand gesture commands in AR headsets with children. For example, the *Microsoft*

HoloLens AR headset utilizes a "Bloom" gesture, which symbolizes a flower blossom, to invoke the start menu [87]. This gesture does not necessarily fit with children's mental models and expectations of how they would interact with a headset. For the HoloLens 2, the "Bloom" gesture was replaced with a virtual wrist button, which is more aligned with children's mental models as we saw them. However, in our study, the children focused on direct manipulation with physical buttons and virtual buttons in their main field-of-view (e.g., not on their wrist). Based on our findings, designers should avoid using interactive hand gesture commands when designing AR headset experiences for children. Although current designers should avoid using gesture commands, a broad-spectrum of modalities (e.g., voice, natural interaction, body motion) will have to continue to be improved for children. Prior work has shown that voice assistants have trouble recognizing children [8, 49] and motion recognition systems are not tailored to children's motions [2, 35]. Therefore, future designers should focus on increasing accuracy in these areas to meet children's mental models and expectations.

5.4.4 Allow for Mobility [Future]. In our study, the children designed a wide range of mobility for AR headsets, such as being compatible with different environments (e.g., indoors, outdoors). The children designed outdoor AR headset experiences, which is captured in the themes of *System Immersion* and *Outdoor Usage* in our model. For example, David suggested, *"Um, maybe while taking a hike and it could tell you what species of animal or plant or thing it was."* [DS 4]. While the idea of using these devices outdoors is not novel (e.g., using headsets for military operations [5]), our findings highlight children's expectations. Also, Microsoft recommends only using the HoloLens indoors to avoid natural sunlight [88]; therefore, current headsets are not yet optimized to support the use cases in which children want to use AR headsets. In addition, in the theme *User Input*, the children incorporated whole-body movement as an input method in their designs (e.g., fighting, running). For instance, in Billy's dinosaur game, the user can fight the dinosaurs by utilizing their whole body, such as dodging and throwing punches. As of right now, AR headsets focus on hand-tracking, eye-tracking, and voice interaction [89]; existing headsets do not yet track or recognize whole body motions. Furthermore, current headsets are limited in their mobility by either being tethered to a computer (e.g., [54]) or having restricted usage. For instance, the HoloLens 2 has a battery life of 2-3 hours [89], which restrains the user's experience. We recommend that AR headsets for children allow for extensive mobility and recognize whole-body input.

6 LIMITATIONS AND FUTURE WORK

There are limitations to the scope of our work. Since we could not provide headsets to all the children, the children did not interact with any existing AR headsets while designing. This allowed us to get children's initial expectations; however, there are disadvantages, such as not being able to get the children's impressions of existing headsets (i.e., likes, dislikes). Future work should explore children's perceptions of the usability of existing commercial AR headsets. In addition, ten children participated in our PD sessions. Although the number may seem small, it is consistent with prior PD sessions with children (e.g., [7, 44, 79, 81]). Another limitation is that the children were recruited from Seattle, Washington, USA, and the surrounding area; therefore, the children's economic, social, and cultural backgrounds might be similar to each other. For future work, researchers should explicitly recruit children from geographically distributed areas; this is especially feasible when conducting remote PD sessions.

7 CONCLUSION

As augmented reality (AR) headset use among children continues to grow, it is important to understand how they conceptualize these devices to design content and experiences that match their mental models. To examine children's expectations and perceptions, we conducted four remote PD sessions with a group of ten children. In the design sessions, we focused on designing content for AR headsets with an emphasis on using headsets for tasks. We found that children expect highly intelligent systems that can recognize and virtually transform surroundings, provide suggestions, and create immersive environments. Children want to use headsets for games and difficult tasks but would prefer not to use it when being creative and when accomplishing easy tasks. Based on our findings, we created a conceptual model of children's perceptions of AR headsets. We present new recommendations for designing AR headsets for children that are aligned with their conceptual models, such as avoiding hand gesture commands. Our findings inform the design of content and experiences for AR headsets for children.

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