Play-Based Design: Giving 3- to 4-Year-Old Children a Voice in the Design Process

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ABSTRACT
There has been a dramatic growth in interactive technology use by children under the age of 5 during the past decade. Despite this growth, children under the age of 5 typically participate only as users or testers in the design process in the overwhelming majority of projects targeting this population presented in key child-computer interaction venues. In this paper we introduce play-based design, an age-appropriate design method to give 3-4-year-old children a voice in the design process. More specifically, we contribute a thorough analysis of the use of existing methods to design technologies for children under the age of 5, a summary of the process that resulted in the development of play-based design, a detailed description of play-based design, a qualitative analysis of our experience implementing play-based design with two groups of children, and a discussion of play-based design's place among other methods, its advantages, and limitations.

Author Keywords
Children; preschool; design methods; play.

CCS Concepts
•Human-centered computing → Human computer interaction (HCI); •Social and professional topics → Children;

INTRODUCTION
Children under the age of 5 have steadily increased their use of interactive digital technologies over the past decade mainly due to the advent of mobile touchscreen devices. A 2017 survey by Common Sense Media in the United States [52] found that 95% of 0-8-year-old children had access to a smartphone in the home (up from 41% in 2011), with 43% of 2-4-year-old children owning a tablet and spending an average of 58 minutes a day on mobile media. Researchers have identified similar trends in other countries (e.g., [42, 1]). If we assume that these use trends will continue and we want positive outcomes out of them, we are faced with the challenge of designing interactive technologies for children under the age of 5 that benefit their development. This challenge highlights three significant gaps in research: 1) developing design methods to use with this age group; 2) identifying common and critical skill deficits for children under the age of 5 that may be addressed through interactive technologies; and 3) identifying age-appropriate technologies that are sustainable and able to have a broad impact on these skill deficits.

Our focus in this paper is on the first gap, targeting 3-4-year-old children. While there is a wealth of design methods to enable the participation of children aged 5 and older in the design process [35, 69, 32], there have been few attempts to use these methods with younger children, and these attempts have often not been successful (e.g., [34, 14]). We value including children's voices in the design process in order to make it more likely that technologies designed for them consider their needs, abilities, and preferences, and because similar approaches with older children have resulted in novel ideas that adults are unlikely to develop on their own [32]. In this paper, we present a novel design method for use with 3-4-year-old children we call play-based design.

We developed the insights that led to play-based design as we analyzed and reflected on the process of designing interactive technologies to support make-believe play for 3-4-year-old children. Through this analysis, we noticed that make-believe play activities enabled children to contribute ideas through acting and making requests. We then realized the technology developed through this process to support make-believe play could be re-purposed to support design sessions. Play-based design sessions start with an interactive story. We use these stories to enable children to gain a common understanding of a context intended to motivate children to develop ideas for a particular type of technology. Then, we prompt children to plan their role in make-believe play by selecting a character from the story they experienced through an interactive app. Finally, children play, pretending to be a character in the context presented to them, using generic physical props to stand for objects, including technology. During make-believe play, children act out the experiences they want within the context set up by the interactive story. As children play, they interact

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with other children, adult facilitators, and a tangible voice agent controlled by adult facilitators that scaffolds play.

The contributions of this paper include: a thorough analysis of the use of existing methods to design technologies for children under the age of 5, a summary of the process that resulted in the development of play-based design, a detailed description of play-based design, a qualitative analysis of our experience implementing play-based design with two groups of children to develop ideas for smart home technologies, and a discussion of play-based design's place among other methods, its advantages, and limitations.

WHY GIVE 3-4-YEAR-OLD CHILDREN A VOICE?

Proponents of the use of design methods that include children's voices and ideas point at their participation enabling a deeper understanding of children's needs, abilities, and preferences, as well as the development of different kinds of design ideas [32]. There is also an ethical component to giving users of technology (in this case children) a voice in its design, empowering them to shape the technologies they will use [41]. A significant portion of the child-computer interaction community has endorsed these arguments as evidenced in the wide adoption of participatory design methods for children aged 5 and older, with a recent book citing more than 40 examples of various methods while drawing primarily from the CHI and IDC conferences [35]. However, similar experiences with children under the age of 5 are few and limited, and novel methods are necessary due to developmental differences between children younger than 5 and older children.

IDEAL CHARACTERISTICS OF DESIGN ACTIVITIES WITH 3-4-YEAR-OLD CHILDREN

Child development is a dramatic, highly-complex process that we are only beginning to understand [65]. Ages 3 and 4 are a crucial time for development, in particular for building the foundations of executive function skills (e.g., selective attention, planning, cognitive flexibility) through self-regulation [43]. They are also a time for the development of curiosity, creativity, imagination, social play, cooperation, language and communication, and storytelling [19].

When considering what types of activities to conduct with children of a particular age, developmental milestones can be a useful resource in better understanding children's abilities at that age. Milestones for 3-year-old children provide a baseline for what most children should be able to do in our age group of interest. By the time they turn 3, typically developing children should be able to copy the behavior of adults or friends, take turns, show a wide range of emotions, follow 2-3 step instructions, name familiar things and friends, participate in make-believe play, copy a circle, and understand the concept of "two" [19]. Milestones for 4-year-old children give us a sense for what some 3-4-year-old children may be able to do. They include enjoying doing new things, being more creative with make-believe play, preferring to play with others rather than alone, expressing likes and interests, cooperating with others, telling and remembering stories, and counting [19].

These milestones can be useful to inform the type of design activities in which 3-4-year-old children may be able to participate. For example, activities that require the use of abstract concepts, or even sketching user interfaces could be quite challenging [34, 14]. On the other hand, children should be able to express emotions with respect to technologies and may be able to act out an experience they would like to pursue, based on their ability to participate in creative, make-believe play.

Researchers should also consider what type of design activities are likely to be beneficial to children. For example, activities that expose children to appropriate academic material [20], social activities [70, 22], or creative endeavors [5, 9, 23, 59, 58] are likely to be beneficial to 3-4 year-old children [20]. Other human-computer interaction researchers have cited similar types of activities, although in the context of what technologies should support (e.g., [73]).

A final, but important consideration, is to make children's design activities enjoyable for participating children. A primary reason is that 3-4-year-old children may have difficulty understanding the process involved in the design of interactive technologies and are likely unable to give proper consent for participation (consent should be obtained from parents). Therefore, given the power imbalance between adults and young children, we suggest it is important not only to stop children's participation when there are signs of distress (a standard requirement in ethics protocols), but also to set up activities that the children can enjoy and in which they want to participate.

DESIGN METHODS FOR CHILDREN UNDER 5

In order to better understand the current landscape of design methods for children under the age of 5, we conducted an extensive literature review in five key venues relevant to child-computer interaction. These venues were the Interaction Design and Children (IDC) conference, the Human Factors in Computing Systems (CHI) conference, the International Journal of Child-Computer Interaction (IJCCI), the International Conference of the Learning Sciences (ICLS), and the International Conference on Computer-Supported Collaborative Learning (CSCL). We searched for the terms "young children", "very young children", and "preschool children" in publications that appeared between the years 2000 and 2017.

The criteria we used for selecting publications followed two major guidelines. First, the publication had to report on children under the age of 5 (some papers use the term "preschool" but only include children 5 and older) either using technology or participating in some role in the design process to develop a technology. Second, the publication had to provide clear information on how the researchers designed, evaluated, or established requirements for the technology. Therefore, we excluded publications where the details provided would be insufficient for the analysis, such as Work in Progress or Demo papers.

The search terms yielded a total of 877 results, from which we selected 99 articles according to the inclusion criteria. We classified the 99 selected publications using Druin's taxonomy for the four design roles children may play in the technology design process [26]. We categorized children's participation as described in the publications as users, testers, or informants. We could not identify any publication that included children under 5 as design partners, which would require meetings on a regular basis and a higher level of involvement from the beginning of the design process through the end [32]. In case a publication self-identified children's role in the design process (e.g., informants), we classified the publication according to the role identified by the authors. In case a publication involved children in multiple roles throughout the design process, we considered the most advanced role in the spectrum in our classification. One researcher classified all papers and consulted with two other researchers on publications where the classification was unclear.

Most of the publications (49 of 99) involved children under the age of 5 as testers of some kind of technology, followed by 45 publications that involved them as users, and only five publications that involved them as informants. The age range of the participants across all 99 publications varied from 0 to 17-years-old. In total, there were 38 publications that included only children under the age of 6, and 15 publications that included solely children under 5. In addition, we analyzed the number of children participating in the studies (there were seven cases excluded where the information could not be found in the publication) and the number of sessions conducted, even though in many cases this information was not clearly stated (there were 48 cases excluded). The minimum number of participants was two and the maximum was 840. The number of sessions varied between zero, which includes publications that conducted analysis of YouTube videos, and 16. We provide a full list of the 99 publications and their classifications in the supplementary materials.

Of the five publications describing children's participation as informants the majority were short papers, with three short [72, 64, 4] and one full paper from IDC [49], and one short paper from CHI [34]. Since the majority of the publications in this category were short papers, in many cases the authors did not elaborate much on the details of their design experiences with young children and reported on no more than three design sessions. We identified four additional publications from other venues that also fit the criteria of children participating as informants [63, 48, 14, 50]. The activities in these nine publications included requests of ideas based on exposure to prototypes [4, 72, 48, 49, 64] including the use of Wizard of Oz activities to gather requirements for gestures [49], creating art to be incorporated into technologies [63], and asking children to develop ideas from scratch through sketching, the use of art materials, and comicboarding [14, 34, 50]. While there appeared to be some success in the limited reports of obtaining feedback from prototypes [4, 72, 48, 49, 64], the attempts to involve children earlier in the design process did not work well for children under the age of 5 [14, 34, 50] even when incorporating methods such as Mixing Ideas [31]. Two additional articles published since 2018 self-report engaging children under the age of 5 as design partners. Abbas et al. [2] described obtaining feedback from 3-5-year-old children on character preferences, as well as requesting background art to situate the preferred characters in a particular environment, while Korte [44] focused on how parents collaborated with four 4-year-old Deaf children in using expressive art materials (e.g., Play-Doh) when prompted for design ideas.

The current set of experiences in the literature all made useful contributions toward understanding design methods that involve children under the age of 5. At the same time, they highlight why more researchers have not engaged with children of this age as informants or design partners: we still have much to learn about how to conduct design activities with them. There is certainly room for improving and adapting methods, developing new ones, and analyzing design sessions in order to learn from experiences. The challenge is to develop age-appropriate methods, and to validate their usefulness through extensive experiences, ideally across different groups of children, research goals, research teams, and cultures. The work presented in this paper begins to address this gap.

PRELIMINARY RESEARCH LEADING TO PLAY-BASED DESIGN

The preliminary research we conducted that led to the development of play-based design involved the analysis of design sessions of interactive technology to provide support for 3-4-year-old children participating in make-believe play in the style of the *Tools of the Mind* preschool curriculum. There is significant empirical evidence that this style of play helps children develop self-regulation and executive function skills [5, 6, 23, 24, 54], which in turn lead to improvements in mathematical ability [3, 7, 17, 21, 27, 51], reading, emergent literacy and vocabulary [3, 7, 51], theory of mind [18], and creativity [55]. *Tools of the Mind* style play involves groups of children engaged in pretend play that includes common goals for play, planning, role-play, interactive social dialogue and negotiation, improvisation, and the use of generic physical props as opposed to realistic toys [9, 10, 13, 8, 12, 11, 46]. However, adoption of *Tools of the Mind* requires significant investments, with a recent study including five days of teacher training in addition to in-class coaching sessions every other week [5]. Pantoja et al. designed *StoryCarnival* [57, 36, 37] to lower barriers to and support make-believe play in the style of the *Tools of the Mind* curriculum [9, 10, 13, 8, 12, 11, 46].

These researchers designed and developed *StoryCarnival* through 15 sessions with a group of five (three boys and two girls) 3-4-year-old children at a preschool in a city with a population of about 100,000 in the United States. They conducted all research activities in rooms at the children's preschool. During design sessions, two to four research team members and one teacher were always present in the room in addition to the children. Two of the research team members had parenting experience with children of a similar age, and another had extensive experience working at schools. They video recorded every session. After completing a session, the adult members of the design team met, wrote a summary of the session, and noted any design requirements that arose out of the session.

The researchers used the first four sessions to get a better sense for how children interacted with and related to devices already familiar to them by asking them to use educational software from organizations with a long track record on educational media (*PBS Kids* and *CBeebies*) on a variety of mobile devices (*Samsung Galaxy Tab 4*, *Kindle Fire 7" 4th generation*, *Microsoft Surface Pro 4*, and *Apple iPad 4th generation*). The remaining 11 sessions typically included the introduction of a story theme involving a setting and characters, planning play, and supporting the children during play, which included the use of generic physical props and role-play, giving children the freedom to act out the experiences they wanted. In these design sessions, the adults in the research team steered children toward the make-believe activities the researchers wanted to support, while children steered the researchers toward the experiences that were fun and meaningful for them. This was enabled by the structured, yet open-ended nature of the sessions. As the sessions went by, the researchers replaced some of the facilitation by adults with support through interactive technology while integrating children's preferences.

The final version of *StoryCarnival* consists of an app with interactive stories to introduce children to characters of equal importance and story settings on which to base play, and a play planning tool (see Figure 1) that enables children to select the character they will play and be reminded of the character's role [57]. These components helped children have a common context for play that resolved problems with a lack of stories all children knew, as well as presenting multiple meaningful characters and a way to plan play that was concrete and clarified children's roles [57]. Children typically experienced an interactive story and planned play for about five minutes using a tablet app, and then played for another 15 minutes using generic physical props (e.g., foam shapes) (see Figure 2) without any screen-based technology.

The notes the researchers took after each design session identified the requirements for *StoryCarnival*. Examples of requirements included incorporating storytelling as a foundation for play and supporting the merging of story themes. Starting from these requirements, two researchers in our team went back to the video recordings of every session to identify the events that led to each requirement. They identified two ways in which children contributed during the design process. In some cases, they concluded that the research team could have arrived at the same requirements by asking the children to conduct a specific task, as if the children were participating as testers. In situations like these, researchers observed children's behaviors they wanted to avoid or encourage and identified what triggered those behaviors. For the remaining requirements, the children went beyond what would have typically been expected of testers by explicitly providing ideas or suggestions through verbal communication or through actions, often as part of exchanges with adult members of the design team. Out of 17 design requirements identified, the two researchers agreed on coding eight as originating solely through observation, four through a combination of observation and children's suggestions or actions, and five solely through children's suggestions or actions. See Table 10 in the supplementary materials for a detailed list of design requirements. The analysis of how the design requirements originated in design sessions gave us insight into how make-believe play activities could enable children to contribute ideas to the design process.

Figure 1. *StoryCarnival* play planner enables children to select the character they will play and reminds them of the character's role.

Figure 2. Example of generic props used during make-believe play.

The next set of design sessions we analyzed was intended to design voice agents to better support make-believe play activities [56]. In these sessions, the same researchers from the *StoryCarnival* sessions worked at the same preschool with a different group of 3-4-year-old children. In this case, the group consisted of eight children (four female, four male). Researchers conducted 24 sessions in total that led to various insights on voice agents following the same approach pursued during the last 11 *StoryCarnival* sessions. Through these sessions, the research team learned that tangible voice agents controlled by researchers promoted social interactions, could redirect children's behavior to keep them socially engaged in play, were incorporated by children into their play activities (e.g., putting them inside prop constructions), and provided an alternative way for adult facilitators to communicate with children [56]. As with the *StoryCarnival* sessions, two researchers coded design requirements and their origin based on after-session notes and reviewing session videos. Examples of requirements included designing voice agents so they could be picked up by children and prompting children by their role-play character names. For this set of 24 sessions, out of 21 design requirements, 10 arose from observations only, eight from a combination of observations and children's suggestions or actions, and three from children's suggestions or actions only (see Table 11 in the supplementary materials).

These findings consolidated our ideas about the good fit of make-believe play as a type of activity that could be used to give 3-4-year-old children a voice in the design process. More specifically, we thought that make-believe play supported by *StoryCarnival* and voice agents provided a setup that could be used to enable 3-4-year-old children to contribute design ideas for a wide variety of technologies.

DESCRIPTION OF PLAY-BASED DESIGN

Play-based design is a novel design method inspired by the two distinct explorations of technology to support make-believe play with 3-4-year-old children described above. It re-purposes the technology-supported make-believe play activities described earlier to facilitate design sessions. Play-based design sessions have three basic steps (see Figure 3), two technological components, and two adults running a session with one facilitating the activity and the other controlling a voice agent.

First, an adult facilitator sets the context for design using an interactive story presented in *StoryCarnival*. These stories need to be engaging and open enough to lead to make-believe play. They also need to effectively set a reasonable context for useful design ideas to emerge. Preferably, these stories should have no more than four characters with different skills that collaborate with each other in a given context, as well as a voice agent character in a support role. Stories could also be authored or experienced in another environment. *StoryCarnival* stories are similar to an electronic book, with pages presenting visual story scenes, but with added interactivity, enabling, for example, the reinforcement of story components by asking children questions and prompting them to select from visual answers. The stories include narration and character speech generated using the Amazon Polly speech synthesizer, which can enable easy story variations that are automatically produced (e.g., changing characters or settings) as well as a perfect match between the voices of characters in the story and the voices of tangible voice agents used during play. Character speech is further supported by speech bubbles as recommended by best practices [71]. If children have experienced a story a few times, it is possible to ask children questions about the story to ensure comprehension rather than having them experience the story again.

Second, children split into groups of no more than four, with two adults in each group. At this point, one of the adults uses the *StoryCarnival* planner to support children negotiating the selection of specific roles based on the characters from the story they experienced. The adult facilitator should hold the mobile device and prompt children to take turns while they select their roles. If a child decides they want to be in the same role as another peer, the adult can facilitate negotiation which could involve selecting another role and switching roles later during play. It is also possible to let more than one child play the same role if it makes sense for the given design session.

Third, children play, pretending to be the character they selected, in the context presented to them in the story, using generic physical props to stand for objects. An adult facilitator controls the speech of a tangible voice agent by typing in text, which is synthesized using Amazon Polly matching the voice of the same character in the story. The voice agent can be used to help children remain socially engaged in play and can provide suggestions on areas of the story (and the design space) to explore next. During make-believe play, children will interact with their peers, with the voice agent, and with the adult facilitator who is not controlling the voice agent, who might participate in play, give suggestions, or repeat what the voice agent said to prompt children to remain engaged in play.

Adult facilitators should meet immediately after each design session to discuss and record any design ideas they observed during the session. In addition, we recommend that sessions be video recorded so that they can later be reviewed to possibly extract additional lessons learned.

The most time-consuming and critical aspect of a successful play-based design session is the authoring of the story used to set up play. Making the story relevant and interesting to children while enabling the development of useful ideas from sessions can be challenging. The output of the method is design requirements that must be extracted from children's verbal suggestions and acting during make-believe play as they interact with adult facilitators and voice agents.

APPLICATION OF PLAY-BASED DESIGN

To obtain evidence that play-based design could be used to obtain design ideas from 3-4-year-old children, we decided to conduct play-based design sessions with two separate groups of children. The goal of the design sessions was to develop design ideas for smart home technologies. Smart home technologies were a good candidate for play-based design as these technologies are typically experienced across physical spaces and may have social components. They are also a complex type of technology that currently does not have many child-oriented applications. Our specific research objective was to learn whether we could effectively use play-based design to enable 3-4-year-old children to contribute ideas for smart home technologies.

Research Setup

Participants

We conducted twelve sessions with seven children aged 4, four boys and three girls, and seven sessions with six children aged 3, one boy and five girls. Children were from a preschool with the same characteristics as the one where the preliminary research was conducted. None of the children had previously participated in design sessions. All children had access to smartphones or tablets at home.

Materials

For introducing the smart home theme to 4-year-old children, we developed a story intended to inspire ideas for smart home use. Our story was called "Clue Hunters". It included four gender-neutral, animal-based characters investigating an empty spaceship with the help of MiniBird (see Figure 4), a voice agent we designed for the story. The story provided examples of two smart home-like items in the spaceship (a lamp that displayed weather information and a chair that could tell characters what was happening outside the spaceship) and showed that there were rooms to explore where more such items could be found.

After conducting the sessions with 4-year-olds, we realized the story we developed for 4-year-olds may be too complex

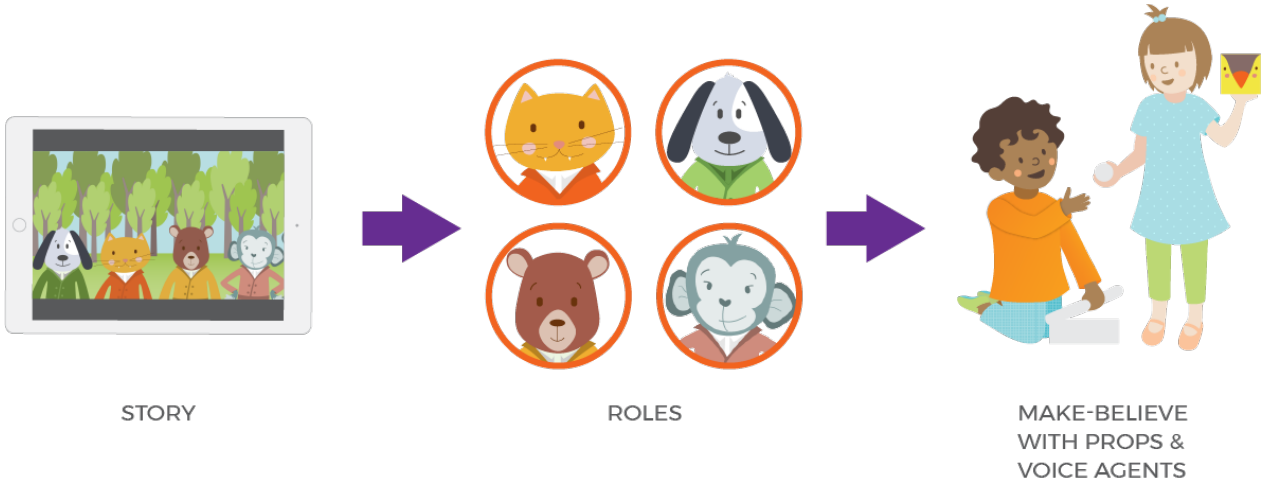

Figure 3. Three steps of play-based design sessions.

for younger children. Therefore, we developed another story for 3-year-old children that was inspired by fairytales and explored the idea of imagining magic items to inspire smart home concepts (see Figure 5). The story, called "A Castle in the Woods," involved the same characters in "Clue Hunters" being led to a castle in the middle of a forest where household objects could be given magical properties. The story also incorporated MiniBird, the voice agent.

After play started, we used a tangible voice agent styled to look like the MiniBird character in the story. The tangible voice agent was constructed from laser-cut layers of cardboard (width=8.57cm, depth=8.57cm, height=7.62cm), with art depicting MiniBird glued on its sides (see Figure 6). Inside the agent there is space for a Bluetooth speaker, connected to a computer where we used an app to type in speech for the agent to speak. The voice of the MiniBird tangible voice agent matched the voice of the MiniBird character in the story in order to make the experience consistent. This design of MiniBird proved light, durable, and easy for children to incorporate into their play.

Procedures

With the group of 4-year-old children, we conducted two warm-up sessions for children to get used to us and the activity. In the warm-up sessions we used stories that had been previously developed for the sole purpose of make-believe play and enabled children to get used to the researchers and the style of make-believe play we sought. We followed these warm-up sessions with 10 smart home-themed sessions using the "Clue Hunters" story described above.

During our play-based design sessions with 4-year-old children, we explored getting ideas for different rooms in the spaceship, which represented typical rooms in a home. The story they experienced in *StoryCarnival* offered two examples of smart home objects in a living room: a lamp and a chair. We later prompted them to think about objects in their bedroom and kitchen. We also experimented presenting three specific objects (e.g., a table, a mirror, and a rug) and asking children to think about what kind of "magical" properties these objects could have.

We conducted three warm-up sessions with 3-year-old children, using a shorter version of a story that was previously developed for 4-year-old children called "Party". This story was unrelated to the smart home theme. After the warm-up sessions, we conducted four smart home themed sessions with the story "A Castle in the Woods" described above.

With 3-year-old children, instead of pre-defining three objects for them to provide ideas, we experimented with smart home style activities, such as conducting a treasure hunt by having them search for an item with MiniBird's help or singing songs along with MiniBird.

Analysis

We conducted a qualitative analysis of our design sessions by coding 396 minutes of video data using BORIS [28]. We coded the videos identifying the periods of time when individual children were off-task, meaning they were not engaged in the activity. Non-engagement involved children getting distracted from play (e.g., using props out of the play context or disrupting the group). We also identified adults' participation in play, by coding the videos for the times adult facilitators played make-believe with children, made suggestions for play, or repeated what the voice agent said to prompt children during play. Finally, we coded children's engagement with voice agents by marking physical engagement and verbal engagement. Physical engagement refers to anytime a child was touching or physically interacting with the voice agent (e.g., holding it, carrying it, building on top of it, trying to feed it, or any use of the props with the voice agent as the direct target). The marker ended if the child moved away from the agent or if there was no direct interaction (e.g., if the child put it in a hat as a nest and then moved to use other props or do something else). Verbal engagement refers to a child verbally interacting with the voice agent (e.g., asking the agent a question and receiving a response, telling it to play a song, telling the agent about what they were doing). The agent's response is included in the verbal interaction time anytime there was one.

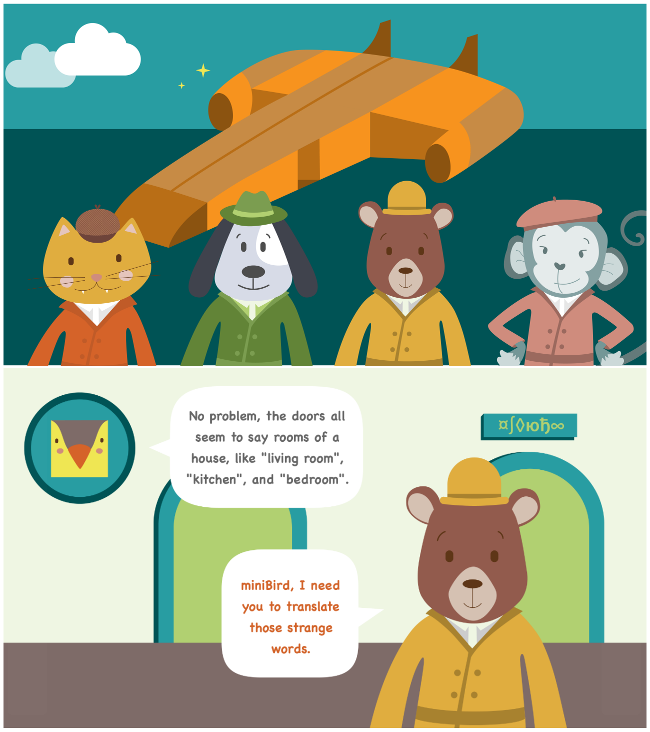

Figure 4. Screenshots from "Clue Hunters" story.

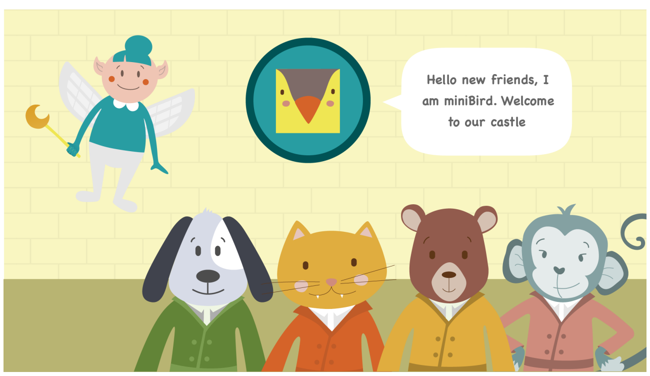

Figure 5. Screenshot from "A Castle in the Woods" story.

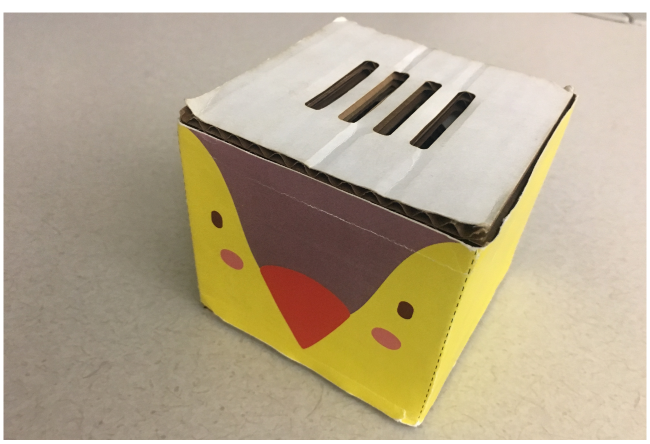

Figure 6. MiniBird agent used during smart home sessions.

One researcher coded all sessions and another coded a randomly selected session. The Cohen's Kappa value of agreement for the randomly selected session was .742 (for 107 codes for different events). We consider it reasonable given the difficulty of identifying, for example, exact periods of disengagement from and re-engagement in play.

In addition, as with the preliminary research, two researchers coded design requirements and their origin based on after-session notes and reviewing session videos.

Results

Below, we present the findings from our analysis organized in three subsections. First, we present an overview of the ideas developed in the design sessions for smart home technologies. Then, we present the analysis of the videos with a focus on the differences and similarities of conducting play-based design with two different age groups. Finally, we present the lessons learned about play-based design through 19 sessions.

Ideas for Smart Home Technologies

We gathered a total of 32 ideas from both groups of children. The group of 4-year-old children provided 19 ideas for smart home technologies, while the group of 3-year-old children provided 13. It is important to note that we had more than twice the number of smart home-focused design sessions (10 sessions) with 4-year-old children than with 3-year-old children (four sessions). In contrast with the *StoryCarnival* and voice agent design sessions, all design ideas except for one originated from children's suggestions or actions, with the remaining one resulting from a combination of observation and suggestions or actions.

An example of an idea developed by 4-year-old children was a lamp that would follow its user. Their general idea was that rather than carrying a flashlight or similar tool, they could walk around a house with a source of light that went with them. There were also many ideas for kitchen technology from 4-year-old children. They included a variety of tools that would be automated to make food and clean up afterwards.

The group of 3-year-old children joined their older peers in requesting tools that would help them clean up by "disappearing" things. They also had ideas for items that would turn into or create toys (e.g., hats turning into castles, castles making kings and queens). One of the more interesting ideas from 3-year-old children included a setup to support play by enabling children to control light, temperature, and wind. For example, children wanted lights to dim when it was night-time in their pretend play. We list all the ideas from both groups of children and how they originated in the supplementary materials (see Table 12).

Sometimes children not having ideas provided insightful information. For example, during two sessions, we prompted 4-year-old children for ideas on smart home technologies for the bedroom, but they were not interested in such items in this setting. We picked three objects to prompt them for ideas for the bedroom: a bed, a bookcase, and a closet. However, none of the groups could come up with ideas on how these items could have "magical" or smart home-type capabilities. The children instead took MiniBird to see the props or parts of the

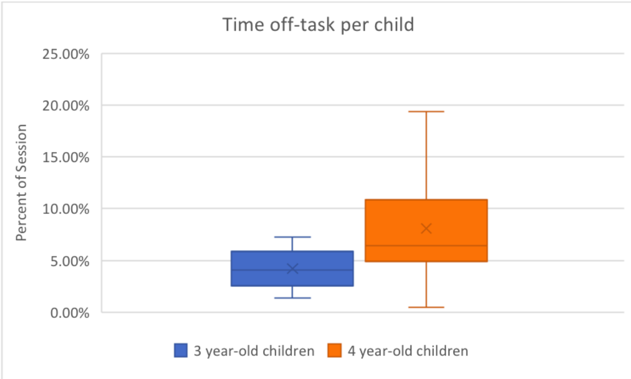

Figure 7. Box plots of average time off-task per child for 3- and 4-year-old children across sessions (i.e., minimum, maximum, and quartiles are for sessions).

room representing the items and then went back to some of the themes from previous sessions (e.g., kitchen items).

Note that while many of the suggestions are impossible to implement, this trend has been reported as a common situation when getting ideas from children in elementary school [32], so it is not surprising that it also happened with children under the age of 5. There is still value in all the ideas in that they give clues as to children's goals. For example, many of the 3-year-old's suggestions for disappearing items had to do with wanting help in cleaning up.

Comparing Play-Based Design Between 3- and 4-year-old Children

As we conducted sessions with the two age groups, we noticed clear differences between them. It is important to keep in mind that both groups of children were small and we made procedural changes for the 3-year-old group, therefore the differences we noticed may not reflect generalizable differences across age groups. At the same time, we thought the differences between age groups were interesting enough to conduct a deeper analysis of the videos to descriptively contrast the two groups.

The main difference we noticed was in terms of engagement. To our surprise, 3-year-old children appeared to be more engaged in design sessions than 4-year-old children. Our analysis of time off-task corroborated our earlier observations. We calculated average time off-task per child by dividing the sum of time off-task for every child in a session over the number of children in a session divided by session length. Older children had more variability throughout the sessions and tended to spend more time off-task (see Figure 7). The mean time off-task for 4-year-olds was 8.1% of session time, while it was 4.2% for 3-year-olds. We consider this result a reason for further inquiry on age differences for this type of activity.

Another area of differences was in terms of researcher engagement, which could also explain some of the differences in time off-task. Adult researchers spent more time participating in play with 3-year-old children (a mean of 23% of session time) than with 4-year-old children (a mean of 13% of session time).

Another way researchers engaged with children was through the voice agents. In this case, the 4-year-old group was more physically engaged with the voice agents (a mean of 61% of session time) than the 3-year-old group (a mean of 52% of session time). On the other hand, both groups had similar levels of verbal engagement with the voice agents (a mean of 23% and 21% of session time respectively).

In other respects, the sessions were similar for 4- and 3-year-old children. These include mean session length (20.9 and 20.7 minutes respectively).

Lessons Learned for Play-Based Design

Overall, play-based design was effective to get young children from both age groups to provide ideas for a complex technology. The right combination of story, characters, prompting, and task-oriented activities, such as brainstorming with preset objects or engaging young children in a treasure hunt, promoted creativity through social play and yielded design ideas that can be incorporated in smart home technologies for children, as presented in the examples above. Both groups of children had low levels of time off-task and plenty of physical and verbal interactions with the voice agents. At the same time, we observed that both groups of children needed adult guidance with a complicated theme, so it was important to have one adult facilitating the session and another controlling the voice agent.

During the 12 play-based design sessions we conducted with 4-year-old children, we observed some of the same behaviors from previous explorations with tangible voice agents [56]. Children listened to MiniBird, they held it and cared for it, whispered to it, and used physical props creatively with the voice agent. We also observed attachment and curiosity toward MiniBird. All these factors enabled effective use of MiniBird by adults to help keep sessions going and children thinking of smart home ideas. The creative use of physical props included children building houses, nests, magic hats, and other items with smart capabilities. Communication among peers included negotiating and planning what they were building together. Addressing one room per session (e.g., bedroom, kitchen) and having typical items in those rooms discussed helped develop ideas or provide clear feedback that the children had no interest in having smart home-type items in a given room.

During the seven play-based design sessions we conducted with 3-year-old children, the design sessions appeared to flow with little effort, with children more easily buying into the story, MiniBird, and make-believe play with props. They also clearly enjoyed themselves with a lot of laughing and smiling throughout sessions. They appeared to be more activity oriented and attentive than their older peers. The use of physical props as symbols was similar to the older children. However, they built fewer structures with props than the 4-year-olds. The verbal communication with MiniBird included offers to take care of the agent's perceived needs (e.g., eat, sleep) and being very attentive to MiniBird's suggestions, making this alternative mode of communicating with children work very well. The 3-year-old children also talked about things they were making or the activities they were conducting giving us something similar to a think-aloud protocol.

The "Castle in the Woods" story we developed specifically for the 3-year-old group worked well as they easily related to the fairytale theme we selected. Having the adult researchers more engaged in play also seemed to help and was well-received by the children. One additional characteristic we noticed with 3-year-olds is that they enjoyed repeating the same activity many times. The need to adjust stories and activity supports based on age is therefore something researchers seeking to implement play-based design should consider.

DISCUSSION

Similar Design Methods

Play-based design is not the first design method to use socio-dramatic activities. Other researchers arrived at similar methods in the past although none of them applied them to children under the age of 5. There are also clear differences between our implementation of play-based design and earlier forms of socio-dramatic design activities.

An early example of socio-dramatic design activities came from Brandt and Grunnet [15]. Like us, they used socio-dramatic activities to study the design of systems that had physical and/or social aspects, set up a scenario for acting based on design goals (similar to our stories), asked participants to role-play, and used physical props. Some of the implementations presented by Brandt and Grunnet [15] used props that tended to stand for the same item over time, physical items on stage that were pre-arranged based on design scenarios, the "stage" to note ideas with sticky notes that would then be acted out, and engaged users as "directors" while the design team acted. In other cases, there were more open ended activities, closer to play-based design. Others explored similar socio-dramatic activities with a range of experiences, for example, using role-play to develop design ideas for specific types of applications [40, 45, 67, 68, 47, 60] and defining a variety of ways in which socio-dramatic design activities could be used and conducted [39, 38, 66, 53, 29, 60, 61]. However, none of the examples above involved children or used the additional supports for activities we use in play-based design, such as interactive media prepared to present stories to users, tools to plan role-play, or voice agents to support the process.

Other researchers have explored socio-dramatic design activities with children, although none worked with children under the age of 5. A simple example was "body storming" [33], which enabled children to contribute ideas for interactions through body movements, acting out what they wanted. A method much closer to play-based design is *Fictional Inquiry* [25]. The main difference with play-based design is that *Fictional Inquiry* uses storytelling to add fiction to children's current context. Children then act as themselves, in their current physical context, taking into account the fictional aspects added to their current situation. Researchers from the same institution later developed the concept of "staging imaginative places" [16]. This concept is closest to ours in that a design context is staged for participants (with an emphasis on modifying the physical space) that significantly changes their current context [16]. Another method sharing traits with play-based design is *embodied narratives* [30]. Under this method, elementary-school aged children brainstorm what to design, then conduct a socio-dramatic performance acting out ideas, which is recorded and shared with a larger group.

There are two key differences between these methods and play-based design: 1) Play-based design is based on *Tools of the Mind* style play, for which there is ample empirical evidence of developmental appropriateness and benefits to 3-4-year-old children [5, 6, 23, 24, 54]. The *Tools of the Mind* approach has clear differences with other socio-dramatic methods, such as children planning and negotiating how play will be conducted, and an emphasis on supporting children to remain engaged socially in play and in their roles [9]. No other socio-dramatic design method is based on activities with similar evidence for developmental appropriateness or benefits to 3-4-year-old children. 2) The technology supports for play-based design are based on 39 design sessions with two distinct groups of children focused on lowering barriers to *Tools of the Mind* style play for this age group, which otherwise would require significant training for adult facilitators [5]. No other socio-dramatic design method is based on a similar process of developing technology supports (e.g., tangible voice agents) with and for 3-4-year-old children.

Classifying Children's Roles in Play-Based Design

In 2002, Druin [26] proposed four roles that children can play in the technology design process: user, tester, informant, and design partner. Out of these roles, the ones that are most similar to the level of involvement used in play-based design with 3-4 year-old children are informants and design partners. Informant design entails working with children at specific stages during the design process when their input is the most valuable [32, 62]. By treating children as informants, researchers expect them to contribute novel ideas rather than confirming what they thought they knew [62] and children are called upon when their thoughts and advice is needed [32]. On the other hand, design partners are equal stakeholders throughout the design process, as children enter into a long-term agreement involving training to learn design methods and techniques for elaborating new technologies in partnership with adults [32]. According to Guha et al. [32], the goals are different between the two roles. Design partners elaborate ideas together with adults, while informants have dialogue with adults [32].

When young children participate in play-based design, they go a step beyond being informants because they are involved in a long-term process and given an outlet to express their own ideas, which can be elaborated with feedback from adult researchers, and iteratively incorporated in the design of technologies. However, they are not exactly design partners because there is no training to learn design methods and techniques and young children are not necessarily aware they are helping adults to design something. We did not incorporate training and awareness of the design process into play-based design because we were not confident it was a good fit for 3-4-year-old children's development. However, it is an idea worth exploring in the future. Based on our analysis we would place children's role in play-based design during our smart home sessions at a point between informant and design partner (see Figure 8).

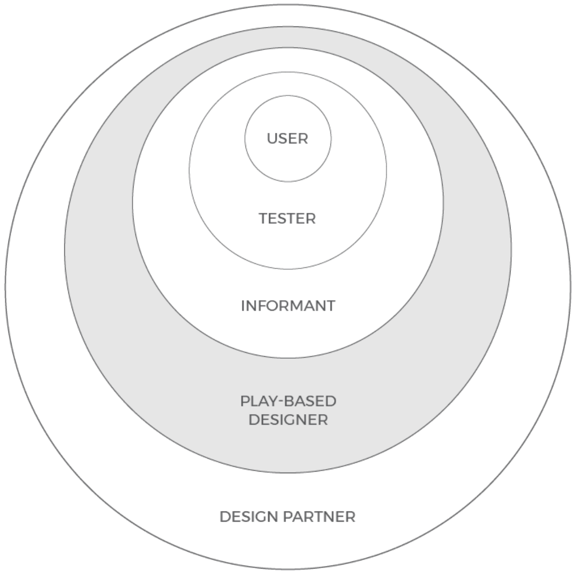

Figure 8. Placing play-based design in Druin's design method classification.

Advantages

Play-based design meets the ideal criteria for a design method for preschool children we discussed in the section titled *Ideal Characteristics of Design Activities with 3-4-Year-Old Children*. First, it is based on social make-believe play, an activity that is age-appropriate given well-established developmental milestones [19]. Second, by being based on the *Tools of the Mind* approach to make-believe play, play-based design is likely to be beneficial to children given the significant evidence backing the benefits of *Tools of the Mind* [5, 6, 23, 24, 54]. Third, play-based design feels like play to children and is an activity that children appeared to enjoy in every session we conducted. In addition to having these three characteristics, our exploration of smart home ideas using play-based design gave us confidence that the method can indeed enable children to contribute ideas to the design process.

Limitations

Since play-based design is a social and physical activity, the first limitation to consider is that it is likely not suitable for developing screen-based technologies intended for single-user activities. However it is likely to work well for the design of tangible, social, and physical systems.

In terms of logistics, researchers must consider that play-based design might be time consuming. There is a need to plan for a few warm-up sessions for children to become acquainted with researchers and feel comfortable in the activity before exploring the actual design context. There is also a limitation in the number of children that can participate in the activity at the same time. Even though we found that larger groups of children can watch the stories together, selecting roles and playing with props works better with groups no larger than four children.

To facilitate access to the technical components, funding has been awarded to make all components open source and freely available, including the ability to access existing stories, create new ones, and access instructions to make voice agents. Given our observations of the videos recorded during preliminary research, it would be difficult for researchers without significant background in storytelling and management of make-believe play to conduct similar sessions without these technical components. We expect that using these components will be more efficient for most researchers than using alternative means to facilitate play-based design sessions. Alternative means could involve the use of multimedia authoring tools to create the stories, the same tools or paper with printed pictures of story characters to facilitate play planning, and any suitable character-like item able to house a small Bluetooth speaker and be safely handled by children to work as a voice agent. If researchers prefer not to use voice agents they could instead role-play with children, with the trade-off of losing a form of communication. If seeking any of these alternative means, researchers should evaluate options based on which are most likely to feel comfortable to both children and facilitators while effectively enabling play-based design sessions.

Future Work

There are many potential paths forward for play-based design. The most obvious is to apply it to more design experiences, for longer periods, with more groups of children, and with a variety of design goals. Another path is to adapt play-based design for other populations, such as older children, children diagnosed with autism, adults, and so forth. A similar adaptation could be made to use play-based design with family groups. Another direction that could be explored is the degree to which researchers could successfully explain the design process to children under the age of 5 and whether such explanations would result in any changes in the design process.

CONCLUSION

This paper presents a novel design method for involving 3-4-year-old children in the technology design process, called play-based design. We contributed a thorough analysis of the use of existing methods to design technologies for children under the age of 5. We also provided a summary of the process that resulted in the development of play-based design and a detailed description of the method. In addition, we presented the results of a qualitative analysis of our implementation of play-based design with two groups of children to develop ideas for smart home technologies. Finally, we concluded with a discussion of play-based design's place among existing methods, considering its advantages and limitations to inform other researchers who might decide to implement it with other groups of young children.

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