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DESIGNING FOR YOUNG CHILDREN: LEARNING, PRACTICE, AND DECISIONS

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This paper presents a vignette of our development of a robot-based app sponsored by the corporation producing the robot. The discussion in this paper begins with the affordances of humanoid robots that enable transformative pedagogical approaches to address children's needs. Next, we present our design case, where we develop a humanoid robot-based English-learning curriculum for young children to learn English as a second language. This case highlights a multifaceted app development process that involves synergistic, multidisciplinary teamwork and design enhancement through repeated observations of child/robot interactions. We present a few snapshots from the design case to illustrate the teamwork and design enhancement. From our observations in repeated user-testing, the robot app seems to induce independent navigation, sustained attention and engagement, and rich learning experiences for children. The design challenges and the way we address them may be useful for others developing similar interventions for young children.

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INTRODUCTION

Sponsored by an international corporation, SK-Telecom, a university-based team from a mountain-west state in the United States was charged with developing robot-based curricular apps for children who learn English as second or foreign language (ESL or EFL). The robot used in this project was a combination of a mobile phone and an embodiment (see Figure 1). A variety of advanced technological capabilities were embedded in the robot, including multimedia, bodily movements, optical and proximity sensors, speech recognition, and interaction logs. The robot targets preschool or kindergarten-aged children.

Our task was equipping the robot with high quality educational apps, and this meant doing more than simply developing a new mobile app. It was important that each part of the curriculum made use of the robot's unique technical features and supported social affordances that conventional mobile phones do not have. Unfortunately, there is a lack of literature that describe the details of the design process of advanced learning technologies, particularly, humanoid, educational robots. The design case introduced in this paper describes the design process, focusing on the decisions surrounding the designs.

ASSUMPTIONS PRIOR TO DESIGN

The design team started by identifying theories from child development and human/computer interaction that could serve as the framework for the overall process of our curricular design, decision-making, application development, and user testing in schools and homes. Over time we were able to build on (and sometimes shift) our assumptions to improve our design. Some of the most significant assumptions are explained in the following two sections.

Children's Affinity to Sociable Robots

One of the most important assumptions we started with was the importance of play. Young children learn in a social context while they play with others (Carpendale & Muller, 2004). Their learning improves when the context is meaningful and

relevant to them. Thus, a simple computer screen without social contexts may not be as effective for young children as a technology design that embeds a social and relevant context in its application (Gopnik, 2012, Perkins, 2001).

Humanoid robots demonstrate stronger social and affective benefits, compared to ordinary computer and mobile technologies. The robot can serve as a playmate, and a child can develop companionship with a robot friend as they play together (Breazeal, 2002). Children seem to develop affective relationships with a humanoid robot (Robins et al., 2010), interact with the robot enthusiastically (Chang, et al., 2010), and voluntarily give sustained attention to learning tasks mediated by the robot (Kahn & Shen, 2013), regardless of their cultural and linguistic backgrounds. Based on this understanding, the design team used the metaphor of a toy friend and believed that children would confidently collaborate on tasks with the humanoid robots and interact freely without social embarrassment.

Robot Affordances: Transformative Design and Pedagogy

Learning via a humanoid robot presents not only a new learning context but also several new learning opportunities for ESL children. Our next assumption was that this robot curriculum could offer three unique affordances: (a) incorporating the old and creating the new, (b) focusing on learners' needs, and (c) transforming established pedagogy in language and literacy.

Incorporating the Old and Creating the New

Learners interact dynamically with other participants, tools, and contexts while they perform learning tasks (John-Steiner, 2003; Pea, 2004). Every tool has a unique affordance that supports learning and motivation (Salomon, 2001). To be effective, technology-based interventions should be able to make use of various tools and resources to enrich learning experiences. Our robot embeds a variety of advanced technological capabilities, including multimedia, bodily movements, sensors (optic, touch, and proximity), speech recognition, interaction logs, and accompanying materials (e.g., physical books and cards). These capabilities may enable the designer to integrate well-known instructional tools and strategies into a new learning environment while expanding the interaction modalities between the learner and robot. For example, using optical sensors, the robot system can interface with physical books and cards.

Nurturing Learners' Sense of Agency

Children are more likely to engage in learning tasks and perform at a high level when they are given appropriate resources, opportunities, and environmental conditions (Brophy, Biswas, Katzlberger, Bransford, & Schwartz, 1999). A robot's uniqueness may come from its humanoid appearance and, thereby, sociability. In previous studies, ethnically diverse students engaged more seriously in interactions with animated, digital characters acting as tutors or peers, compared to their mainstream peers (Kim, Baylor, & Shen, 2007); the students tended to build more developed social relationships with artificial beings (Kim & Lim, 2013). The humanoid robot may be able to provide a valuable mediator between isolation and full human-to-human contact, particularly in public school classrooms where one overburdened teacher often struggles to provide individualized help to dozens of young children. More importantly, children are placed at the center of play; the robot pays full attention to them.

Transforming Established Pedagogy in Language and Literacy

Children develop early literacy effectively through systematic, explicit instruction in an interactive context (Silverman, 2007). Young learners generally require explicit awareness of the phonological structure of spoken words; also, vocabulary development is foundational for children's learning of English language. The use of technology is acknowledged as a way to expose the children to more words, as well as reinforcing the words children have already learned (August, Carlo, Dressler, & Snow, 2005). A humanoid robot can be designed to offer personalized and explicit instruction through verbal and graphical illustrations. Children may benefit from early and heavy exposure to this instruction (Lipka & Siegel, 2007), as well as repeated instruction as many times as needed.

THE DESIGN CASE

Our design case offers several *snapshots* of different phases of design and development that were key in our decision-making. This design case describes decisions involving both curriculum and functionality. The robot we worked with had several unique, multimodal affordances, but for various reasons, there were limitations to how much we could incorporate each affordance into the educational application. In the sections that follow, we describe the affordances and limitations of the robot and how we made decisions that balanced our commitment to pedagogical principles and our desire to make full use of the robot technology.

The Robot

The robot used in the project was about the size of a toaster and had many multimodal functions build in. Figure 1 presents the robot image and specs.

A phone was cradled on the robot's head; Android mobile apps controlled its sensors and movements via Bluetooth technology. There were two touch sensors on the robot's forehead, similar to the touch sensors on the phone's screen. These sensors allowed children to signal specific responses (e.g., left side equals wrong answer; right side equals right

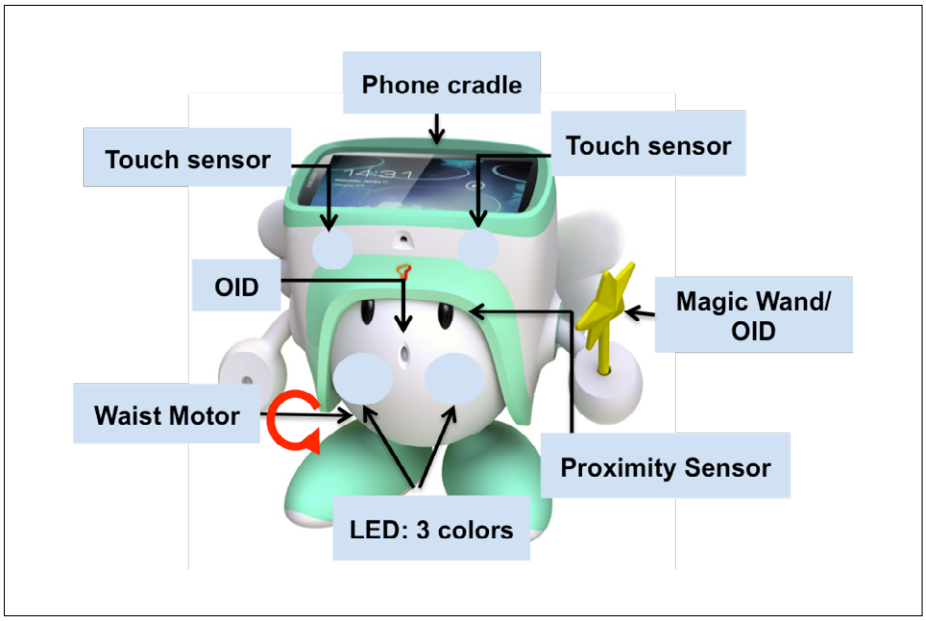

FIGURE 1. The robot system.

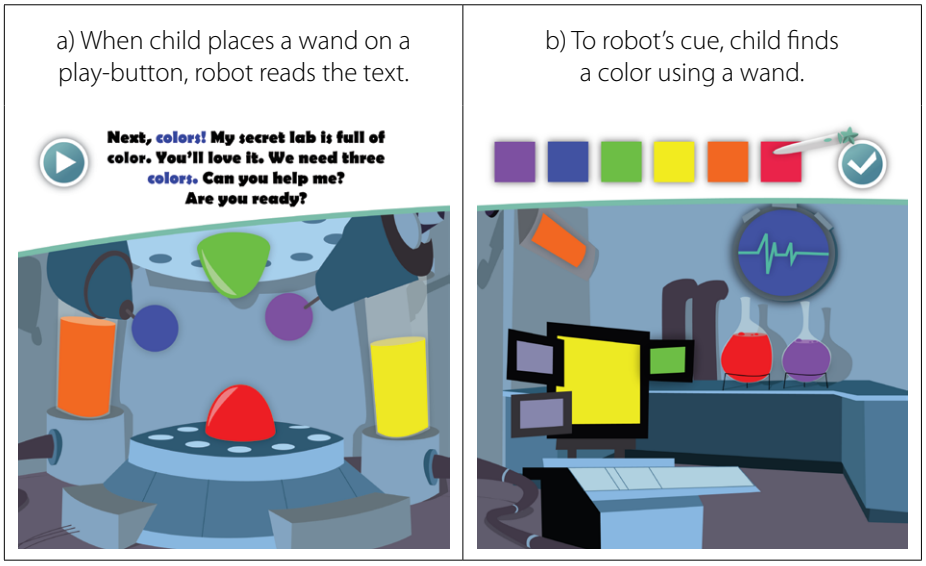

FIGURE 2. The wand use with a printed book.

answer) during games. Two proximity sensors in the robot's eyes prevented the robot from running into walls. The robot also had two LED lights that could flash in the robot's cheeks and help create the illusion of emotional expressions (excitement, happiness, embarrassment, etc.).

The robot had a motor connected to four small wheels on its feet so was capable of moving forward and backward and turning in a circle. The robot could also bend forward at the waist, changing the child's view of the screen and mimicking the bowing motion that is an important part of Asian greetings. The robot's arms could be adjusted manually to move up and down.

Last but not least, the robot had an object identification device (OID) sensor in its mouth and wand, which allowed the robot to recognize codes printed on cards or other print materials. The robot's wand was removable, so children would hold the wand like a pen and use it to select words, shapes, and numbers, as well as other items on cards and in a book (see Figure 2). For example, when the child held the bottom of the wand over a bolded word in the book, the OID sensor would read a code embedded in the printed word. Then using Bluetooth technology, send a signal to the robot to say the word aloud.

The Robot-Based App (Rapp)

The curriculum design was focused on learning outcome and, at the same time, creating learning activities that were developmentally appropriate and engaging for children who are 3-5 years old. The learning objectives included identifying basic shapes (triangle, circle, square, rectangle), basic colors (red, orange, yellow, green, blue, purple), and initial consonant sounds. The activities and resources also were chosen to carefully balance the familiar and the new. This balance in the materials was achieved with songs and the accompanying book and cards (familiar educational tools) connected to the robot and app (new educational tools). The balance of the familiar and new in content also came from having familiar items that are identifiable and easily recognizable (items from home, simple colors and shapes) and new, imaginative content (spaceships, secret labs, etc.). Three activities (songs, games, and a book) were designed to play a specific role in mastery of the learning objectives. Figure 3 presents excerpts from the Rapp and children using the robot at home and in a media center in the school.

The activities build on each other by introducing, reinforcing, and extending understanding of the target English vocabulary. The song portion of the app was designed to expose users to all of the target vocabulary. The songs are based on familiar children's songs (i.e., "Twinkle, Twinkle Little Star"), and after each verse the robot invites the user

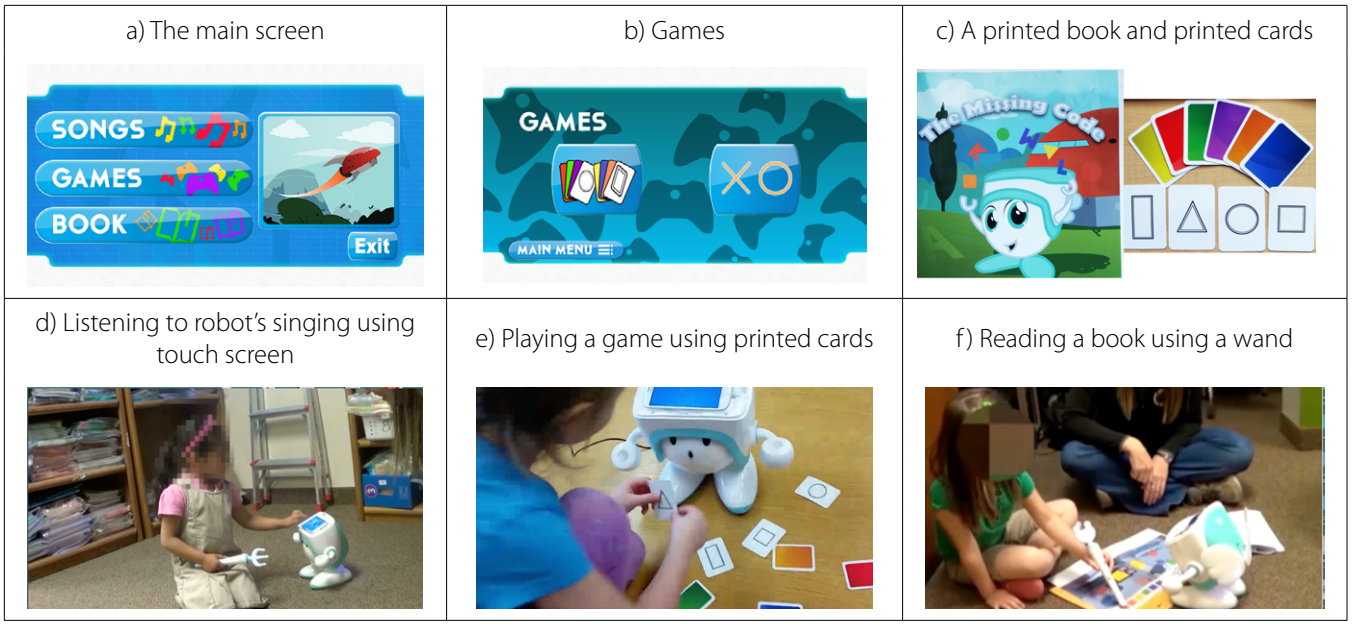

FIGURE 3. Excerpts of the Rapp screens & children's play.

to repeat target vocabulary or sounds multiple times. The game portion of the app allows the user to practice all of the target vocabulary introduced in the songs. Users either find the correct matching card (with shapes or colors), or identify the correct initial sound for objects in an OX (true/false) game with both letters and pictures as visual cues. The book extends what children have already learned by giving new contexts to the vocabulary. Children see the target words used in the text and hear the robot ask for their help to find shapes, colors, and words in the spaceship. To help the robot, children play I-Spy games on the book pages using the robot's wand

Reflections on Teamwork

Nonaka and Takeuchi (1995) pioneered the effort to acknowledge the value of multidisciplinary teams. Due to the innovative technology and the important educational goals involved in our project, it was clear that diverse expertise in our team would be crucial for success. Our design team included four different academic disciplines, four different ethnicities, at least five languages, and a wide range of background experience in industry, education, and research. This diverse team was not only essential in having everyone grasp the technical aspects of creating an app, but also helped everyone understand foundational principles of language pedagogy, cultural expectations of young English language learners, and the important role of play in language learning.

In his book on cooperation, Sennett (2012) discusses both the benefits and challenges of working as a team. One area that he focuses on is conversation, specifically dialectic and dialogic ways of talking through issues. Dialectic conversations are the kinds of discussions where synthesis of two or more perspectives evolves into a common understanding. While much of teamwork involves finding common ground, Sennett also advocates for dialogic conversations (see Mikhail Bakthin) because when people disagree or think differently, "people may become more aware of their own views and expand their understanding of one another" (Sennett, 2012, p.19). We believe that understanding how a team navigates both dialectic and dialogic conversations is vital because these critical conversations can lead to better decisions. Also, teamwork helps to build a sense of camaraderie (Anderson & Shattuck, 2012). To be effective, the design team must strive to be objective and even skeptical about their work, with "comradeship, enthusiasm, and a willingness to actively support the intervention" (Anderson & Shattuck, 2012, p. 18). Infusing these qualities into a design process is not always easy, but it was an essential part of our process, especially when making decisions about how to best utilize the multimodal functionality of the robot to meet our pedagogical aims.

Iterative Design Enhancement

The design and development of our robot-based curriculum included three phases: design, development, and evaluation. In each phase, the team conducted multiple sessions of user testing, where we observed children's reactions to our prototype and continuously refined the prototype as we moved along with the testing. The foundational approach to designing and developing the curriculum was interventionist (focused on improving specific learning outcomes), iterative (involving recursive stages of research, design, development, and evaluation), and collaborative (incorporating multi-disciplinary expertise and user feedback). Sections

from each phase of our design and examples (i.e., snapshots) are described in the next section.

Phase 1: Design and Critical Conversations

In this phase, we produced written scripts of the curricular content and robot/child interaction scenarios. Following that, a low-fidelity prototype (print-based mockups without a robot) was developed. The user testing in this phase was conducted using a Wizard-of-Oz method, where a designer controlled the missing components of the system (i.e., a researcher played the role of the robot and interacted with the children). This test was used to observe the children's reactions and determine revision needs in the curricular content and interaction scenarios. Given the information gleaned, the design team continued refining the design.

Snapshots of the Design Phase:

In the design of educational technologies, it can be especially tempting to overlook the *why* questions (why we are designing this in this way) and jump straight to the *what* and *how* questions (what we will make, and how it will affect learning). One challenge that encouraged many *why* questions for our team was the tension we felt between maintaining our commitment to educational values (such as a developmentally appropriate curriculum) and creating a product that was innovative and flashy enough to compete with the many other commercial applications designed to entertain young children. *Why* questions were important throughout the entire design process, and the power of these questions was particularly apparent during discussions about the kind of story we would create for the book that would be used with the robot.

Both the storywriter and the instructional designer had backgrounds in teaching English language learners in public school. They began with the understanding that the target audience comprises children from ages three to five, so most of the vocabulary included in the materials should be simple and included everyday objects from home. Initially they wrote several drafts of stories with titles like *My Room*, *Getting Dressed* and *Cleaning Up*. In team meetings, however, the rest of the team did not react very enthusiastically. In particular, the graphic designer (who had worked with toy companies and educational television in the past) questioned the subject of the stories. He pointed out that the stories needed to involve more imagination and creativity if they were going to appeal to children. Thus, we began a series of dialogic conversations that helped us view the curriculum from a child's point of view and consider a child's motivation (e.g., *Why would I want to read a story about cleaning up my room? What next? Why did I get dressed?*).

Overall, the importance of these dialogic questions did not come so much from their capacity to lead us to answers, but rather from their function to lead us to new questions and new ways of thinking (Sennett, 2012). McCall (2010) notes "using feedback-driven, critical conversations to promote creativity has crucial implications for rationale methods used in software projects" (p. 13). Based on our experience, we felt that the same could be said for design and research in educational technology. Dialogic questions that helped promote creativity, in turn, promoted an energized and committed spirit within the team. The graphic designers were more interested in creating pictures for the story; our game designer was more excited about the games he could create to go with the story; and our software coders were full of ideas about how to program the robot to respond with movement, lights, and sound effects. For example, when we developed a song involving simple shapes, one of our team members suggested that we have the robot actually create the shape as it sang. So while it sang about triangles, it would roll across the floor and turn three times as if it were drawing the shape of a triangle with its feet on the floor. The robot would also flash pictures of the triangle on the phone's screen, but the added movement seemed to engage children much more than the screen by itself.

Our dialogic conversations involved some conflict and frustration, but the time and energy they took were worth it because these discussions infused confidence and clarity into our decision-making processes. For example, despite our best efforts, we were not actually able to get the robot to make the shapes consistently during the songs. Part of the problem was that the robot's small wheels did not always move very smoothly on carpet, and sometimes it would stall. We initially considered taking out the movement all together, but other team members argued that we should keep the movement as part of the song because even if it didn't meet our original expectations, the movement kept the children interested in watching the robot, encouraging them to move and play while they sang along with the shape songs rather than sit and passively listen. Thus, allowing everyone's expertise and creativity into the design helped us to ensure that our final product was both educational and fun. We saw evidence of this as we introduced our design to children in real world settings.

Phase 2: Development and Strategic Design Refinement

The development phase began with an initial robot application (Rapp), where curricular content for the Rapp was implemented to develop a beta version. For user testing, this draft was taken to the target-aged children to assess coding completeness, technical errors, and learner reactions. During this time, the children interacted with a robot individually. The Rapp was refined continuously as the team moved on with the testing sessions.

Snapshots from the Development Phase:

Since we were under contract with a corporate client, we had a very strict time frame for development. Our initial

plan included only a few weeks for design, and the bulk of the time was reserved for development and evaluation. The initial design phase took several weeks longer than expected, but as explained in the previous section, taking the time to fully address questions and creative possibilities helped us to be more productive in the long run. Once we had a clear, shared vision for the design goal, we were ready to devote our full attention to development. User testing was also essential for helping us identify how the robot's affordances could be used to enhance learning outcomes.

As we met with various individual children in schools and in their homes during the development phase, we were concerned with three major things: (a) whether or not children could easily navigate the interface and the accompanying materials (cards, book, etc.), (b) whether or not children would engage with the robot and content, and (c) whether or not children could successfully learn the content. One key goal was to encourage the child to produce spoken language during interaction with the robot.

During an initial user test with a three-year old Somali-American boy, the designer noticed that while the boy was very interested in touching the robot and following its movement, he always needed additional prompting from adults to repeat key vocabulary words. When she tried to elicit a response from the child, she would typically repeat the word three times and use different variations in her voice (high and low tones, different emphasis on syllables, silly voices, etc.) to encourage the child to respond. She reported this to the team and we implemented this same pattern of repetition and variation to the robot's dialogue. For example, after singing a song about a triangle, the robot would say: "You say it! (pause) triangle (pause) triangle (pause) triangle (pause). This relatively simple addition made a huge difference not only in the boy's willingness to respond but also added more fun to the activity as he tried mimicking the playful tones of the robot's speech. As we tested the revised application with other children we noticed a similar pattern of increased responsiveness and engagement. An adult might have to prompt the child to respond the first time, but the pattern and variation in the robot's speech helped the children respond on their own during the bulk of their interaction.

Through this and other experiences, it became clear that it was essential not only to observe the user's behavior but also to be aware of our own natural responses to failed interaction. When our design did not work as intended, often it was necessary to simply watch how the children adjusted and what solutions they came up with on their own. On the other hand, it was also necessary for the designers who knew the desired learning outcomes to produce a creative solution to accommodate user behavior and explicitly guide the learners to the outcomes. This transactional reflection on both user behavior and intended learning outcomes helped lead us to a viable product.

Phase 3: Evaluation and Ecological Validity

Close to the final stage of our design and development, we brought the refined Rapp to classrooms and children's homes to secure ecological validity. This field-testing guided the team to address feasibility needs and identify any technical issues in the natural setting. Through the iterative user testing sessions, our initial design evolved substantially before we finalized and delivered our application to the client.

Snapshots from the Evaluation Phase:

In this phase, our designs had generally reached what Pinch and Bijker (2012) call *closure*. In other words, the major decisions had been made and, rather than looking for ways to change the design, user testing now was done to polish and refine the final product. While this final phase of refinement was vital for delivering a viable product, it was also a time when we gained a real understanding of how a product fit into authentic learning settings. The evaluation stage not only helped us refine our Rapp, but also taught us surprising things about how it could be used by children in school.

One of our final sessions of field-testing occurred in the media center of a dual-immersion elementary school, where students spoke both English and Spanish in all of their classes. This setting gave us a sense for how students would respond to the robot even when there were a lot of environmental distractions. As we observed individual students working with the robot, other classes would come in and out of the library to listen to stories and check out books. Despite the noise and movement of other students, we were impressed by the focus of each child as they worked with the robot. Part of this focus and engagement might have come from the fact that instead of being confined to a desk and chair, a child was on the floor with the robot. The close proximity to the robot and freedom of movement seemed to make the entire learning environment feel more natural. When children talked about the robot, they frequently used the word *play* to describe the experience.

After one child involved in user testing was finished, two seven-year-olds from another class approached our team and asked if they could play with the robot. This led to one of the most important discoveries in our evaluation phase: the possibility of small group interaction instead of only one-on-one interaction with the robot. As we watched, the two children voluntarily took turns solving the tasks presented in our Rapp. Rather than trying to beat one another, the boy and girl collaborated to score points in the games and find the robot's secret passcode in the book. As we watched them interact with each other and the robot, we became

more and more excited about the ways the robot became a tool to support English language learning and, more importantly, a venue for children to collaborate and socialize, which serves as a building block for language learning. This experience reinforced the value of conducting ecologically valid field-testing; moreover, it gave us insight into future research questions (i.e., how multiple robots might be used in classrooms with several small groups). These questions might help us find footholds for our future design efforts.

Observations and Implications

We observed children interacting with the mobile-robot app both at home and in a preschool as we designed the Rapp. The preschool ran a Dual Immersion program for Spanish-speaking preschoolers; all activities were run primarily in Spanish. The children we observed spoke little or no English. We videotaped our sessions and later analyzed their interactions. We observed how children would use the Rapp, and how interacting with the mobile-robot would engage children in the activities and promote their production of English language.

Independent Navigation

In the user testing, the children were able to work independently and also work either alone or with a peer during interaction with the robot and materials. A big challenge in designing educational software for young children is ensuring that they are able to navigate and use the interface easily. After repeated tests with children as young as three years of age, it was clear that young children could easily figure out how to use each part of the application. The youngest children particularly enjoyed the songs, and the older children (ages 5-7) seemed particularly to enjoy the book. However, no matter what the activity might be, the children were able to participate with minimal instructions from a member of the team.

Sustained Attention and Engagement

It was exciting that children were engaged and focused during their time with the robot. Children were eager to touch the robot and follow it if it moved from one space to another. Even when the robot did not respond automatically (there were a few bugs in the prototype), the children were willing to try interacting again and again until the robot responded. Children normally do not have long attention spans. But the children aged 3 to 7 used the robot app and attended to it for over an hour even after repeated use – a response that cannot be attributed to the novelty effect. Further, as we observed their interactions with the robot, we noticed that even when they were not looking directly at the robot, children would still repeat the English words it spoke and sing along as it sang songs. Overall, we were impressed by the amount of excitement and intensity in children's expressions while they played and learned with the robot. If we returned for repeated testing, the children were always ready to play with the robot again, and even if they were repeating the same activities, they still displayed high levels of engagement.

Rich Learning Experiences

The robot app supplied a variety of learning activities, integrating established strategies and materials into a new environment. Easily recognizable and memorable songs were used to prepare children for more intense practice/instruction. Games helped children get quick practice with concepts and enabled the children to repeat a task again and again until the concepts were mastered. The interactive book was full of context rich sentences. Based on our observations, teachers and parents of young children can expect to see learners engaged with the creative, fun, fantasy-filled world of the robot. Also, the robot app could be used either one-on-one or in small groups of two to three children. In individual use, a child had a time to build confidence with a friend-like robot; in small-group use, the robot served as a center for collaborative work among human peers. Overall, the robot app helped the children with explicit, systematic, and personalized English instruction, as well as building their confidence in their use of English.

CONCLUSION

In this paper, we attempted to address both the pedagogy and design of robot-based curriculum. The design was repeatedly refined in multiple rounds of observations of the ESL children's behavioral (both verbal and non-verbal) reactions to the robot friend when they played together to learn academic English skills in home and school settings. Through this iterative process, our designed product could support children's learning and practice (i.e., their learning will be readily transferrable to their performance in academic work).

Also, future designers may need information about not only the results of previous studies examining the effectiveness of robot-based interventions, but also explanations of the problems, decisions, and creative solutions that have been an integral part of the intervention design in progress. By opening up the black box in our design work, we have attempted to make our specific challenges and process of problem solving visible to others. This might help design researchers learn as they examine commonalities and specificities in designing technological tools for learning.

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