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Pedagogical and technological augmentation of mobile learning for young children

The ubiquity and educational potential of mobile applications are well acknowledged. This paper proposes six theory-based, pedagogical strategies to guide interaction design of mobile apps for young children. Also, to augment the capabilities of mobile devices, we used a humanoid robot integrated with a smartphone and developed an English learning app that applied the design strategies to this environment. Our observations of children's one-on-one use support the promise of the strategies and the combined use of robots and mobile devices to be a viable option to help optimize mobile learning.

Keywords: mobile learning; media devices; technology-assisted language learning; interaction design; children's use of mobile technologies; humanoid robots

Introduction

Over the last decade the use of mobile devices has grown dramatically. According to a recent study, over a third of U.S. children under two have used mobile devices to access media (Common Sense Media, 2013). Since more and more young children are using a variety of mobile devices to communicate, learn, and play, many researchers and educators have been increasingly interested by the affordances of mobile learning and examined the ways that mobile devices could effectively be used to benefit children's learning (Liu et al., 2014). Because of ease of portability, touch screens, and improvements in user interfaces, researchers expect that mobile devices offer tremendous educational potential especially for young learners in preschool and kindergarten (Judge, Floyd, & Jeffs, 2015).

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As highlighted in this special issue call, mobile technologies (smart phones and tablet computers) can adopt other technological applications, such as e-books, digital videos, podcasts, social networking, and cloud computing. This paper presents an innovative way of integrating a smart phone into an embodied toy robot to augment the benefit of mobile learning for young children. More specifically, the paper introduces an English learning application for preschool children employing six specific pedagogical strategies grounded in theories of child development and also our preliminary observations of children's use. Because of the focus on both design and pedagogy, this paper should be particularly useful in not only informing interaction design of mobile devices with young children, but also helping fill the current gap in theoretical foundations for efficacious use and design of mobile applications (Judge et al., 2015).

Theoretical background

Opportunities and challenges for young children

Exploring the educational potential of mobile devices for young children is important and increasingly urgent. In 2011, Common Sense Media's research team conducted a study on the media use of zero to eight-year-old children across America. Just two years later they repeated their study and discovered a dramatic increase in young children's access to and use of mobile devices. From 2011 to 2013, the number of children age 8 or younger who used mobile devices to play games, use apps, or watch videos jumped from 38% to 72%. The amount of children who used smartphones or tablets at least once a day more than doubled, from 8% in 2011 to 17% in 2013. Additionally, while screen time with television, DVDs, computers, and video games decreased from 2011 to 2013, screen time with mobile devices (i.e. smartphones and tablets) increased from roughly 5 minutes a day to 15 minutes a day. Since young children are often unable to make individual decisions about when and how they will use mobile devices, it is important to remember that parents, teachers, and caregivers are primarily responsible for this increase in use and will continue to play the main role in deciding when, where, and how content will be viewed on mobile devices.

Another significant finding from the Common Sense Media study (2013) is the decreasing gap between socioeconomic classes and mobile use. The number of lower-income families with smartphones rose from 27% in 2011 to 51% in 2013, and the number of lower-income children who have ever used mobile devices rose from 22% to 65%. Although the decreasing cost of smartphones seems to be helping to close the *digital divide*, unfortunately, an app gap still exists between the higher and lower-income families (Common Sense Media, 2013). While 75% of higher-income parents with smartphones reported downloading educational apps for their children in 2013, only 35% of lower income parents with smartphones had done so. Clearly, there is an urgent need for educationally sound apps at an affordable range, which help support equity in young children's development.

With the dramatic rise in mobile use, many have wondered how these devices will affect learning. Research from the Joan Ganz Cooney Center at Sesame Workshop identifies five affordances of mobile learning: (1) "encourage 'anywhere, anytime' learning", (2) "reach underserved children", (3) "improve 21st century social interactions", (4) "fit with learning environments" and (5) "enable a personalized learning experience" (Shuler 2009, p. 5). These affordances are connected to the *seamless* (moving from device to device and/or context to context) and *ubiquitous* (increasingly open access in any place at any time) nature of mobile devices (Judge et al., 2015; Sharples & Pea, 2014). Mobile devices have increasingly blurred the line between the educational activities in school and at home, likely making learning a natural part of any moment in a child's day (Erstad, 2012). For example, children can use an app to learn shapes while their parents drive, play an educational game while they sit in a shopping cart, or access facts about the local environment on a trip to a neighborhood park.

While these opportunities are exciting and encouraging, it is also important to consider the challenges that come with incorporating mobile learning into everyday lives of young children. In their recent overview of mobile learning for young children, Judge et al. (2015) identify three categories of mobile learning challenges: social, theoretical, and technological. Social challenges to mobile learning for young children come primarily from apprehensions about screen-time. Both pediatricians and parents have expressed concerns about the amount of time young children should spend on mobile devices, and these concerns primarily stem from worries that too much screen-time may interfere with the development of self-regulation, social skills, and sensorimotor skills (Radesky, Schumacher, & Zuckerman, 2015). The theoretical challenge for researchers and developers in mobile learning is that there is no unique framework or overall theory to guide the design of effective mobile learning environments. Further, there are some technical challenges that come with using mobile devices for educational purposes. Designers must make apps that work on a relatively small screen and are user friendly for both emerging digital natives (usually the child) and digital immigrants (usually the adult caregiver). Particularly for young children, adults might have to be on hand to trouble-shoot any technical difficulties during learning activities.

It is noteworthy that some of these challenges (e.g., screen time and guiding design theory) are not unique in mobile devices but could be applied to other advanced digital learning environments. Nonetheless, particularly with the growing use of mobile devices, it would be ideal if parents, teachers, and other caregivers cautiously monitor each child during mobile learning activities, rather than doing what seems to be most common: using the device as a diversion so the caregiver can work independently on other tasks. As far as the design of mobile learning is concerned, Sharples et al. (Sharples, Arnedillo-Sanchez, Milrad,

& Vavoula, 2009) suggest that we can look to human-computer interaction and instructional design theory. There is still much work to be done in developing strong theoretical foundations that optimize the value and reliability of mobile devices as learning tools.

Augmenting affordances through an embodied robot

These pronounced challenges seem to discourage parents and teachers from broader use of mobile learning and interfere with its full benefits for young children. It is not surprising that there has been a dearth of research in mobile learning for young children as compared to the rapid growth of mobile learning research on upper-grade students and adults (Liu et al., 2014; Vincent, 2015). One strength of mobile technologies, however, may be its adoptability, which allows researchers and designers to integrate mobile devices to other advanced technologies so as to overcome the constraints of mobile devices and expand the affordances of the devices. He et al. (He, Ren, Zhu, Cai, & Chen, 2014) combined augmented reality (AR) and mobile learning to overcome smartphones' small screen. The study revealed that mobile-based AR learning was effective at helping to develop English vocabulary of Chinese EFL children.

Along these same lines, we have examined combining a smartphone with a toy robot, taking into account that: (1) media devices for children are most efficacious when they are appropriate for children's developmental level (Vincent, 2015), and (2) children learn in a social context while they play with others (Carpendale & Muller, 2004); their psychological and behavioral changes often occur through vicarious experiences (Schunk, 1991). An embodied robot, acting as a toy friend, can provide a social context and augment interactive capabilities of mobile devices. When mediated by an embodied robot, children's interactions with mobile apps are no longer limited to a small screen. It is also well documented that children develop social and emotional attachments to digital toys like embodied robots

(Robins et al., 2010), interact with robots enthusiastically (Chang, Lee, Chao, Wang, & Chen, 2010), and voluntarily give sustained attention to learning tasks mediated by robots (Kahn, E., & Shen, 2013). When mediated by a toy robot, mobile app use is not merely screen-time any more. It is playtime that could support children's social and emotional development.

Furthermore, pediatricians recommend that use of media devices supply sensory-motor activities that support young children's development of visual motor skills (Radesky et al., 2015). They also note that this development is particularly important because it can contribute to successful performance in mathematics and science later on. The portability of mobile devices encourages children's motor skills (Buckieituer, 2010; Judge et al., 2015), and a mobile robot might further stimulate sensory motor activities. Children move along as the robot moves, their hands do not have to hold the device, and children can respond through not only a touch screen but also through various optical and proximity sensors integrated into the robot. Therefore, the integral use of a mobile device and an embodied robot might supply a favorable context that could facilitate children's development and thereby augment the affordances of mobile learning.

Children's language and literacy development

A literature review conducted by Liu et al. (2014) identifies language learning and vocabulary building as popular areas in mobile learning worldwide. Mobile applications could help accelerate language development seamlessly in both school and home contexts (Saunders, Goldenberg, & Marcelletti, 2013; Sharples & Pea, 2014).

Learning a new language requires not only cognitive skills but also reconfiguration of cultural perspectives. Such affective characteristics like identification with the target language, willingness to try, and confidence in learning the language, are strong factors in the language acquisition process. The interlocutor's sensitivity in responding to the children fosters children's language and literacy development (Hamre, Hatfield, Pianta, & Jamil, 2014). Similarly, responses from interactive media that are contingent on children's actions facilitate retention of taught material. Roseberry et al. (Roseberry, Hirsh-Pasek, & Golinkoff, 2014) report that socially contingent media such as videophone apps are just as effective as real-life encounters in teaching language to 24 month olds.

Although younger children are generally more amenable to social and affective influences when learning a language, some are timid and less likely to participate in conversations in the target language. Such students might be more forthcoming with a mobile robot designed as a playmate. In order for this collaborative interaction with a robot to occur most effectively, however, it is important that the application be grounded in pedagogical theory.

Pedagogical strategies for designing for young children (PSC)

The great potential of mobile learning should be realized only through careful design of interactions and learning activities that are grounded in theories of child development. A careful review of these theories has led to six focal strategies that guide effective interaction design so as to optimize language and literacy development of young children.

PSC 1: Multiple channels for interaction

Children, especially young children, are active and like doing things. As they move and interact with the world around them, they build important sensorimotor and cognitive skills (Radesky, Schumacher, & Zuckerman, 2015). Although school has traditionally been a place to be quiet and sit still, many children thrive in learning environments where they can engage in haptic and kinetic activities. In particular, some culturally and linguistically diverse students are known for their behavioral engagement (i.e., being behaviorally active) in learning tasks, which might be viewed as disruptive in the traditional classroom (Uekawa, Borman, & Lee, 2007). The integral use of a mobile device and robot system might support both active and culturally responsive teaching. In this environment, children are encouraged to not only interact with the attached phone screen, but also to move, speak, touch, and communicate with the robot as the robot moves around and also through various sensors embedded in the robot's body.

PSC 2: Autonomy support

A review study conducted by Gopnik (2012) reveals that the way young children organize and build knowledge of the world surrounding them is "structurally similar to scientific theories (p. 1623)." According to the study, even preschoolers have their own intuitive theories of their worlds, test hypotheses, and make inferences based on their observations of the surroundings. So it is misguided that early childhood interventions attempt to provide more structured academic programs that do not allow room for experimentation and even occasional failure. Autonomy, which involves the opportunity for self-directed discovery and decision making, is one key determinant of motivation and engagement (Blumenfeld, Kempler, & Krajcik, 2006). Children are behaviorally and emotionally engaged when programs support their autonomous interest, needs, and preferences (Jang, Reeve, & Deci, 2010). Hamre et al. (2014) also report that respecting children's autonomy has facilitated their recall and quality relationship building, contributing to children's language and literacy development. To be effective, applications should support that children choose, direct their own activity, and have a sense of agency in their interactions.

PSC 3: Simulation of peer interaction

Children learn while they play with others and imitate them (Carpendale & Muller, 2004;

Vygotsky, Cole, John-Steiner, Scribner, & Souberman, 1978). In particular, the benefits of peer interaction are broadly established (Saenz, Fuchs, & Fuchs, 2005; Schunk, 1987); peer interaction has been simulated actively in the design of technology-based learning (Frost & McCalla, 2013; Kim & Lim, 2013; Matsuda, Cohen, Sewall, Gustavo Lacerda, & Koedinger, 2007; Ryokai, Vaucelle, & Cassell, 2003; Schwartz et al., 2009; Woolf et al., 2010). According to a recent study, children improve their language learning when a sociable robot matches the story level to the child's abilities than when a robot does not (Westlund & Breazeal, 2015). Also, children are motivated to do things when they feel "liked" or "included," (p. 16) and have a sense of companionship (Gregory & Chapman, 2013). Applications could be designed to serve effectively as a playmate, stimulating the child to listen to and mimic the intended behaviors.

PSC 4: Stimulation of imagination

It is well known that many children find digital toys engaging. There is also evidence that elements of fantasy can increase students' interest in learning (Gee, 2007); fantasy can even help students who struggle to learn (Guthrie et al., 2006). Storytelling can also help increase interest and curiosity, which are two important determinants in young children's motivation to read (Guthrie et al., 2006). As they interact with the robot, children can visualize the robot as not only a fun learning tool but also a character in a unique story-world. This could facilitate the children to imagine a larger context for play with the robot. Overall, the combination of technology and fantasy might engage children in both immediate and extended ways as they play, imagine, and learn.

PSC 5: Repeated exposure

Language and literacy development requires heavy exposure to language use in a social and interactive context (Goldenberg, Rueda, & August, 2006; Trumbull & Pacheco, 2005). Also, children develop language and literacy effectively through repeated practice in systematic, explicit instruction (Carnine, Silbert, & Kame'enui, 1997; Fuchs, Fuchs, Mathes, & Simmons, 1997; Guthrie & Alao, 1997; Silverman, 2007). Additionally, August, et al. (August, Carlo, Dressler, & Snow, 2005) emphasize the importance of vocabulary development in early language and literacy and also list limited practice as one major challenge for second language learners. They acknowledge the benefit of learning technologies as a way to repeatedly expose the children to more words as well as reinforce the words children have already learned.

PSC 6: Synergistic use of old and new technologies

Digital media and print tools each have unique affordances mediating children's learning experiences (Kozma, 1994). They could be used complementarily to achieve learning goals more effectively. Many digital technologies have used metaphors of familiar materials when presenting educational content, such as flashcards and story books (Zaffke et al., 2014). However, some parents and teachers have shown reluctance to introduce new technologies to children and prefer to stick to familiar materials. The combined use of a smartphone and a toy robot helps address this concern. Using optical sensors, the robot system interfaces with physical books and flashcards. This allows children and their caregivers to transition naturally to new technologies and also multiple options to adapt both old and new technologies to their individual needs and preferences. It seems likely that mobile learning could be broadly adopted if more applications would use familiar materials integrally (books, cards, manipulatives, etc.) and let the synergy of both old and new technology combine to enhance learning at all levels.

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A robot-based mobile application

Background

Globally, and in the United States in particular, it is a constant challenge to meet the literacy needs of diverse learners. Literacy education is especially complex when students are required to read, write, and speak in a non-native language, and in the U.S. alone, the number of children whose home language is not English has risen from 3.8 to 11 million in the last three decades. Since language minority students, often called English learners (ELs), benefit from focused, planned interaction and corrective feedback, it is important to design learning tools that can support learners in these areas (Goldenberg, 2008; Saunders et al., 2013). Technology can also be an important part of meeting students' needs, especially for young children who benefit much more from early, tech-based interventions than older students (Cheung & Slavin, 2013). With the combination of a robot and a mobile learning application, we worked to help young learners, especially ELs, develop literacy skills in a way that is engaging, developmentally appropriate, and pedagogically sound. Although this application was designed for ELs in the U.S., we believe it (or similar projects) could benefit students internationally as well.

The smartphone-robot system

(Figure 1. The smartphone-based robot system.)

Figure 1 presents the smartphone-based robot system called *Skusie*. In the system, a phone is cradled on the robot's head implying the robot's visible brain. The robot body is equipped with optical, touch, and proximity sensors, accompanied by a wand having an optical sensor. The robot's movements and sensors are controlled by Android smart-phone apps via Bluetooth technology. There are two touch sensors on the left and right sides of the robot's forehead, two proximity sensors on each eye, and two optical sensors on the mouth and on the wand. Children can touch the forehead on the right and left sides of the robot to interact. Physical cards and book pages are printed with unique OID (optical identification device) codes, so the robot reads and responds when the child feeds the card to the mouth and touches the card or book page with the wand. The robot nods its head, vibrates, and moves around on the wheels on its feet. These sensors and motions can be enabled/disabled by designers. The robot can express emotions with LEDs on its mouth, cheeks, and wings, and these expressions are also programmable. Figure 2 presents some snapshots of children's interactions with the mobile-robot app. The system is in an affordable range (costing approximately US $400) and has potential for broader use in homes and public schools as compared to full-fledged humanoid robots.

(Figure 2. Children's interaction snapshots.)

Curricular activities

Table 1 presents how the six pedagogical strategies have been applied to child/robot interaction design. Overall, our application included three major components: songs, games, and a book. Children were able to start anywhere in the application. The songs were designed as a foundational activity to introduce content, invite children to vocalize English sounds and phrases, and engage children with audio, visuals, and movement. To use the song part of the application, the child would simply select the songs button on the touch screen of the smartphone, and then choose one of three options: shapes, colors, and letters. While singing, the robot moves, and children can dance or follow the robot's path until it reaches the end of the song. After each song the robot prompts the child to repeat key words or phrases. The child can repeat a song as often as they wish.

The games portion of the application was also designed with a combination of audio, visual, and kinesthetic features. While playing games, children could use the touch screen, move their hands towards a proximity sensor on the robot's face, or use the robot's wand to touch cards printed with shapes and colors. Again, children could repeat each game as often as they wished and, since the questions are randomized, children experience a new challenge every time they play.

The book is the most complex part of the application in terms of content and has printed pages. The robot reads aloud and responds to children if they touch icons within the book using the robot's wand. As the children work through the book, they are prompted to find shapes, colors, and letters that will help break a secret passcode that will allow Skusie's spaceship to take off. The child is prompted to interact with the story in a variety of ways: looking for images in the book, listening to the robot's voice, and watching visual animations on the phone's screen. As the child works, the robot gives feedback about their choices and thanks them for their help.

Through combined exposure to content in songs, games, and the book, children are able to learn not just from the robot, but also have the sense that they are learning with a friend. While the child believes they are simply playing, in reality, they are experiencing English vocabulary in multiple contexts with almost unlimited opportunities for repeated, low-stakes practice. This learning environment could help children to absorb language more naturally and be especially effective due to the framework provided by the six specific pedagogical strategies mentioned previously.

(Table 1. Six pedagogical strategies and designed activities.)

Observations of children's use

We observed children's use of the mobile-robot app both at home and in a preschool as part of our iterative design process. The school ran a Dual Immersion program for Spanish-speaking preschoolers through middle school students. All preschool activities were run primarily in Spanish, so many of the preschool children spoke little or no English. We videotaped our observations and later analyzed their interactions. The focus of the observations was on understanding whether or not the six pedagogical strategies were actually working in practice, as well as the effectiveness and usability of the app. We sought to understand how interacting with the mobile-robot promoted students' engagement with activities, understanding of the content, and production of English language.

In this paper, we introduce our observations of four children aged three, four, and five. We observed each child individually two to three times, each taking about an hour. The intervals between the observations spanned about two weeks. The following four narratives illustrate some of the key findings from our analysis of several videos. These four selections were chosen because they reflect the different parts of the application as well as a diverse sample of the children who we observed.

Child 1

Child 1 was a three-year-old boy whose home language was Korean, we observed him at home.

> *Interaction scene (the song activity):*
>
> *Designer places robot on the floor and presses a button on the touch screen for a song.*
>
> *Child 1 does not look at the robot, but begins singing with it as he plays with another toy in another part of the room.*
>
> *Designer tries a different song and the boy responds the same way. After a few more tries, the designer starts to pick up the robot and take it away.*
>
> *Child 1 looks up and says "No! I continue to play."*
>
> *Designer returns the robot and Learner 1 continues to play at a distance,*

singing along and repeating after the robot.

This boy seemed to enjoy parallel play with the robot, and rather than interacting face to face, he chose to talk and sing with it while playing with another toy nearby. Parallel play is a common behavior for preschool aged children (Wittmer, 2012).

Child 2

Child 2 was a five-year-old boy whose home language was Spanish. We observed him in the school media library.

Interaction scene (the song activity):

After the designer showed Child 2 how to use the touch screen with the "Letter Song," the designer invited the child to choose a song.

Child 2 selects the "Color Song" and then selects a yellow circle. As the robot begins moving and singing a song about the color yellow, the boy tries to sing along.

Robot stops singing. Then says, "Yellow." There is a short pause, and the robot repeats "Yellow" in a slightly different tone.

Child 2 repeats "Yellow" and tries to mimic robot's tone.

Robot repeats "Yellow" one more time in a low tone.

Child 2 repeats "Yellow" with a lower tone.

Robot says "We said yellow."

Child 2 repeats "We said yellow."

The phone screen cradled on top of the robot's head goes back to showing several different circles.

Child 2 selects the blue circle and tries to sing along with the robot.

Robot sings and moves away from Child 2.

Child 2 watches the robot move, and when it stops, the child crawls over to it and repeats "Blue" after the robot (just as he did with "Yellow"). Once again he also repeats, "We said blue."

This child focused much more attention on the robot and the mobile device's touch screen than Child 1. His interaction with the robot also seemed to demonstrate peer-like interaction. Child 2's efforts to mimic the robot, watch it move, and follow it were all completely voluntary. He was very willing to repeat the robot again and again. This showed the potential for not just exposure to language, but also repeated opportunities to practice and produce language.

Child 3

Child 3 was a four-year-old girl whose home language was Spanish. We observed her in the school media library.

Interaction scene (the game activity):

After helping Child 3 learn to play the "True/False" game, the designer observed as the girl played independently.

Child 3 kneels in front of robot and waits for prompt.

A picture appears on the touch screen with a picture of a dresser next to the word "closet" and the robot says, "Closet."

Child 3 sits up and then moves her hand to the left side of the robot's face to indicate "false."

Robot says "Good job!" (There is a "ding" noise.)

A picture of a jacket next to the word "dresser" appears on the touch screen, and the robot says, "Dresser."

Child 3 moves her hand to the left side again to indicate "false."

Robot says "Good job!" (There is a "ding" noise.)

A picture of a lamp next to the word "chair" appears, and the robot says, "Chair."

Child 3 moves her hand to the left side again to indicate "false."

Robot says "Great!" (There is a "ding" noise.)

A picture of shoes next to the word "shoes" appears, and the robot says, "Shoes."

Child 3 moves her hand to the left side again to indicate "false."

Robot says "Nope." There is a "ding" noise.

A picture of a bed next to the word "bed" appears, and the robot says, "Bed."

Child 3 pauses and taps her the fingers in her right hand on top of her left hand. Then she moves her hand to the right side to indicate "true."

Robot says "Great!" A picture of a lamp next to the word "bed" appears, and the robot says, "Bed."

Child 3 moves her hand to the left side again to indicate "false."

Robot says "Nice job!"(Game continues until the child has completed ten questions).

Of all the children we observed, she was one of the shyest. She did not speak at all during her time with the robot, but having a variety of other options for interaction seemed to help her feel fully engaged with each activity. In this particular activity, rather than using the screen to communicate with the robot, the girl was shown how she could give answers via the robot's proximity sensors. Her focus during this game was evident from her gaze, and also from the way that she began tapping her fingers while thinking about her decisions. Her response to the "True/False" game revealed the importance of *wait time* after questions. Once her strategy of always choosing the left side stopped working, she seemed to feel motivated to slow down and choose more carefully. Because the robot could wait patiently and provide immediate feedback, the girl was able to adjust her responses to solve each question. Given a few seconds to think about why she got a wrong answer, she was able to answer all of the rest of the questions in the game correctly.

Child 4

Child 4 was a five-year-old boy whose home language was Spanish. We observed him in the school media library.

> *Interaction scene (the book activity):*
>
> *The designer opens the book up to a colorful page.*
>
> *Child 4 touches the play icon on the top, left-hand corner of the page with the wand and looks up when the robot begins speaking.*
>
> *Robot says "There are lots of shapes in my kitchen. Let's look here. We need three shapes. Let's use the magic wand. Are you ready?" The designer points to an icon that has the shape of a check mark.*
>
> *Child 4 touches the check mark with the wand.*
>
> *Robot says "Find a square." A picture of a square appears on the touch screen.*
>
> *Child 4 tries selecting a square from the example shapes at the top of the page in the book.*
>
> *Designer drags her finger along the colorful picture and says, "Can you find another one? Find a square in the picture. (Pause…designer points to a pink square) Try this one."*
>
> *Child 4 touches the pink square with the wand.*

Robot says, "Good job! Find the next one. Find a rectangle." A rectangle shape appears on the touch screen.

Child 4 independently finds a yellow rectangle and touches it with the wand. Looks up at robot.

Robot says "Good job! Find the next one. Find a square." A square shape appears on the touch screen.

Child 4 sits up and scans the page. He looks back towards the pink square and moves the wand towards it, but pauses. Then he selects a blue square instead.

Robot says "You found the shapes!"

Child 4 smiles and continues on with the rest of the book.

After trying the songs and games, this child finished by working through the book. This activity blends old and new technology, and his familiarity with books seemed to support his ability to find content quickly while the newer technology of the robot and wand seemed to engage and motivate him to explore. As he did this activity, his eyes constantly shifted back and forth between the book and the robot. He looked for context clues in the pictures and text, but also had audio and visual support from the robot. In this particular observation, we were impressed by his willingness to explore multiple answer options rather than just selecting a shape he had already found. Thus, the book provided not only multiple channels for interaction and repeated exposure to content, but also presented a possible challenge for more advanced learners who were ready to explore a variety of options.

Discussion

Media devices have great potential to serve as an accessible learning tool for young children. These devices also might help increase the likelihood of achieving equity in the use of educational technology because their decreasing costs allow greater access to lower-income families. Nonetheless, there is a great need for solid pedagogical foundations to guide the effective use of these everyday media devices. In this paper, we propose six theory-based strategies summarized as (1) multiple channels for interactions, (2) autonomy support, (3) simulation of peer interaction, (4) stimulation of imagination, (5) repeated exposure, and (6) synergistic use of old and new technologies.

These strategies are best understood in the context of our observations of actual children's use of the robot system. First, the four children demonstrated clear differences in their preferred interactions. Child 2 liked to touch the robot and the screen and constantly repeated after the robot, Child 3 liked to use proximity sensors, and Child 4 liked to use the robot's wand. Once the designer introduced songs, games, and book activities, all the children were eager to explore by themselves. They liked to choose their activities and rarely asked for help even when they were stuck. Rather they patiently tried again and again until they figured it out. The children's behavior (more obviously Child 1's and Child 2's) suggested that simulated peer interaction truly did apply when they worked with the robot. Despite the presence of a mobile phone on the robot's head, Child 1 did not feel he had to focus on the screen, but instead simply treated the robot as if it were a playmate. This observation helped us see the potential of the robot to allow a child more autonomy in movement and interaction than a mobile device would on its own.

Repeated exposure to words and sounds seemed especially helpful to the children who spoke little English. At first, when the robot said "Can you say 'yellow'?", children didn't respond; they just silently gazed at the robot. When we adjusted the program so the robot repeated the word in different tones, however, they repeated the word and mimicked the robot's changing tones. It also appeared that children did not initially understand what the robot read on each page, so we used a chime to signal page turns. Probably because they are familiar with book reading, none of the children missed this. Also, the same familiarity-effect was observed during the card game activities. Even though the robot was a new tool to these children, their familiarity with books and cards seemed to make them comfortable with interacting and playing games with the robot.

Overall, the six strategies helped us to focus not only on creating a product but a multifaceted learning experience. When looking for clues for how to improve the application, focusing on these strategies helped us make deeper observations about each child's engagement, task completion, and problem solving. Nonetheless, it should be noted that these strategies are not considered a comprehensive solution for the aforementioned challenges in mobile device use. They can, however, serve as a baseline framework to guide initial design of interactions for young children. Designers should make continuous refinement through multiple observations of children's actual interactions with the designed tool and, importantly, the learning goals should drive the designer's choice of appropriate strategies.

Also, teachers, parents, and other caregivers should be aware that they can and should facilitate mobile learning environments in a variety of ways. Children will be more likely to fully access all options for *multiple interaction* and receive the full affordances of both old and new technologies if adults model how to do this by activating various sensors, pushing buttons, and using the robot's wand on the cards and book. Children will also be more likely to speak to and react to the robot like a peer when an adult encourages this kind of play by allowing the child to move freely and praising them when they respond vocally.

Lastly, our study has focused on the combined use of a toy robot and a smartphone to support young children who learn English. The six strategies and our iterative design processes might be applied to other emerging technologies and learning domains for young children. We hope that these strategies assist others in the design of interactions between a child and a technological device and help optimize the educational benefits of these

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accessible devices. Also, as future researchers explore ways to design a media device to enact positive change of children, understanding the effectiveness of previous interventions or new tools might not be sufficient. Access to detailed explanations of the problems, decisions, and creative solutions that have been integral part of the intervention design in progress is essential. We believe continuous dialog between design decision and child behavior is the most likely way to continue to find viable educational solutions.

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