Kim, Y., Marx, S., Pham, H., & Nguyen, T. (2018). *Designing technology as a cultural broker for young children: Challenges and opportunities*. The 13th International Conference of the Learning Sciences (ICLS): London, UK. June 23 - 27, 2018

Designing Technology as a Cultural Broker for Young Children: Challenges and Opportunities

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Abstract: This study developed a socio-technical learning community of a humanoid robot, one child from a native-English-speaking background, and one child from a Spanish-speaking background, both living in the U.S. Grounded in pedagogical and communication theories, a bilingual robot mediated two children's interaction activities to invite both children to participate equitably. Core research questions included i) What does it take to design a robot to mediate equitable, collaborative interactions among young children? and ii) What themes arise in children's interactions with the robot and each other? We adopted a design research approach to developing interaction episodes and the robot's mediating utterances delivered using a Wizard of Oz method. Our designs were continuously revised as we observed triadic interactions in a kindergarten setting. This paper discusses our design experiences, as well as themes that emerged from ethnographic observations over a four-month period.

The major issue addressed

Recent National Assessment of Educational Progress test results in the U.S. indicate an achievement gap and a very flat trajectory for lower-performing students, especially language and cultural minority students (McFarland, et al., 2017). More problematically, deficit thinking and marginalization prevalent in the classroom have taken a toll on both the learning and the identity of these students. Minority children are often viewed by educators and classmates as having deficits in language and culture that prevent them from successfully contributing to the classroom community (Valencia, 2010). Over time, children can adopt these messages and learn to identify themselves with marginalized communities. This identification with marginalization can start as early as preschool and become more entrenched as children grow older (Van Ausdale & Feagin, 2001). Once they develop a negative learner identity, children are less likely to recognize mainstream paths to success through schooling (Nasir, 2002). The high dropout rates for minority students in U.S. schools are tied to this marginalization from the mainstream learning communities of schools and classrooms (Gándara, 2010). Even though many students reach proficiency levels in English language as they move through their school years, their academic achievement often times does not improve. Rather, the dropout rates of language minority students increase as they age (Boone, 2013).

In reality, children coming from diverse backgrounds can enrich the mainstream school culture with their unique cultural and linguistic assets if they are only given the chance to do so (Vasquez et al., 2011). It is very warranted to provide an inclusive learning community, where every student is valued and welcome. In such a community, all children are encouraged to build on their prior experiences (Donovan & Bransford, 2005) to participate actively and make progress toward academic success. While coordinating educator training and efforts to overcome unconstructive deficit thinking is imperative, such processes can be quite time consuming and difficult to achieve as educator beliefs about children are often subconscious and difficult to change (Borg, 2009). As an alternative, the authors explore ways to provide an inclusive and equitable learning community for diverse children quickly, with the help of an unbiased, embodied technology, in this case a humanoid robot.

In our research introduced in this paper, we sought to develop a socio-technical, inclusive learning community of a robot and children, where the robot might facilitate equitable collaborative interactions among children coming from different backgrounds. We first developed the theoretical model for robot-mediated collaborative interactions, grounded in theories of child development, multicultural education, and intercultural communication. This model was implemented in human-mediated and robot-mediated interaction activities sequentially with kindergarten children. The robot's mediating utterances and the interaction activities were refined in an iterative cycle as we ethnographically observed the interactive sessions in a classroom setting.

Potential significance of the work

As the student population becomes increasingly diverse worldwide, designing inclusive school learning environments that embrace linguistic and cultural diversity has been a constant challenge. Also, being able to collaborate and appreciate differences are essential skills children need to master as they grow inside and outside schools. However, these skills are not always addressed in regular school curricula. This study explored using a humanoid robot to help close this gap, creating an inclusive socio-technical community where children learn to work together equitably regardless of their backgrounds. As we observed children's interactions with each other and with the robot in a natural setting at their school, we were better able to identify children's needs and learn what worked well and what was lacking in our designs. Here, we discuss our design challenges and lessons learned, which could be useful to other researchers designing for young children.

Research in learning sciences has traditionally treated cognition and affect as distinct constructs and explained the processes and roles of cognition and emotions for learning separately. However, recent neuroscientific research informs us that our thinking, feeling, and context are by nature invariably intertwined (Immordino-Yang, 2016). That is, children's emotions and cultural contexts serve as an inseparable rudder to steer their learning and intellectual development. In designing programs, therefore, learners' holistic experiences as intellectual, social, and cultural beings should be taken into account in order to bring successful learning in the long term. Likewise, the development of positive learner identities through positive learning experiences is equally as important as academic skill development since positive identity is foundational for persistence in learning difficult topics, resilience to failure, and academic success. Our design approach to a supportive socio-technical learning community aims to reinforce positive social and emotional experiences as children develop academically.

Technologically, we have a long way to go to be able to implement natural dialogue between a robot and children. In general, research on designing for young children has not been as popular as designing for upper age groups. Speech and voice technology, particularly, is quite limited in recognizing young children's speech. There is a great need for children's interaction data to help build analytic models to advance this area of research. A corpus of speech data sets generated by this study can be a resource for researchers in natural language processing, who are interested in designing tools for young children.

Theoretical Background

Developmentally appropriate, multicultural pedagogy

According to child development research (McDevitt & Ormrod, 2015), kindergarten-aged children improve in fine and gross motor skills and like to engage in fantasy play. They are rarely able to sit quietly for long periods and like to spend much of their time with peers. They become aware of themselves in relation to peers and begin comparing their performance to that of their peers, recognizing that the needs of others are often different from their own. Their family and cultural backgrounds have a great influence on their developmental characteristics. Not surprisingly, large individual differences are observed in motor agility, temperament, sociability, and academic performance among kindergarteners. For this age group, therefore, developmentally appropriate pedagogy may involve i) accommodating diversity in interests, background knowledge, and talents; ii) allowing children's play and autonomy; iii) encouraging children to explore fantasy worlds; iv) providing the opportunity to practice new skills; and v) guiding children in ways to successfully interact with peers (e.g., in resolving conflict and playing in collaboration).

Multicultural pedagogy acknowledges children as cultural beings and fosters an egalitarian view of diverse languages and cultures (Paris, 2012; Ladson-Billings, 2009). This pedagogy seeks to make use of children's prior linguistic and cultural heritage in the design of curricular materials and learning activities. In a culturally-sustaining learning community, a child's home language and culture are respected as assets rather than deficits. These assets, or funds of knowledge (González, Moll, & Amanti, 2009), help children maintain a positive identity and transfer knowledge and skills from home to school (Moll, Amanti, Neff, & Gonzalez, 1992). Children are invited to share their cultural experiences and have an opportunity to become fully-engaged participants in the design of learning activities. In such a supportive community, all children may develop intellectually, socially, and culturally in an equitable way.

Intercultural communication

Communication is a process through which individuals or groups share information to develop understanding of each other and the world in which they live. Communication involves people, message, and context, which is fundamentally intertwined with culture. To understand individuals' communication, it is necessary to understand the interlocutors' sense of self, their relationships with each other, their background cultures, and the context where the communication takes place (Carter & Fuller, 2016).

Identity is not only personal but also social and cultural since how we view ourselves is molded through interaction with others (Harré & Moghaddam, 2003). When involved in a dialogue, we maintain our own unique sense of individual identity and build a common base of understanding (Bakhtin, 1987). By telling our personal stories, we get closer, bond, and disclose things about ourselves. Empathy and listening with unconditional positive regard for one another are key to meaningful communication since these actions create a supportive psychological climate where the interlocutors will be willing to tell their stories (Littlejohn & Foss, 2011).

An opportunity to participate repeatedly in communicative contexts with empathy and positive regard are especially important for interlocutors coming from different cultures. Newcomers to a community learn the meanings shared in the community and participate in communal conversation, through which they negotiate between individual self-concept and community membership. Through prolonged exposure to the new culture, newcomers come to transcend their original culture and gradually build up new cultural schemas. Cultural schemas are sets of knowledge about appropriate behaviors and roles in specific situations in a particular culture. They are created from repeated participation in interactions with people who share common cultures in the same situation (Nishida, 2005).

A model of cultural mediation

From the review of educational and communication literature, we have derived three core approaches to the robot's cultural brokering actions: invitation, opportunity, and empathy. Invitation is necessary to welcome children into a learning community where they will be positioned as contributing, integral members. Opportunity is a set of circumstances that is frequently under-supplied in many formal education settings. With the robot, children will be given ample opportunity to initiate their interactions, practice conversation topics repeatedly, and participate in creative, challenging activities. Empathy requires that children be treated with respect and understanding; it is closely linked to relationship building that supports social and intellectual growth (Gudykunst, 2005; Littlejohn & Foss, 2011).

In addition, robot mediation aims to help children achieve three communicative goals (building common ground, building an equitable partnership, and building a co-cultural schema), which offer optimal conditions for equitable, inter-cultural communication. The first step for enabling children to work together is building common ground. Children need to feel comfortable with each other and share their personal stories in order to establish a minimum level of common experience and trust. Equitable partnerships emphasize that another's autonomy and identity are as important as one's own. This respect is developed through careful listening, openness to new experience, and collaborative interactions. Cultural schemas are built up through repetitive experiences in cultural situations. While they engage in interactive, imaginative activities in the robot-mediated learning community, children co-construct meaning, understanding, and identity in the unique activities they share. Figure 1 presents the robot mediation model geared toward achieving these communicative goals.

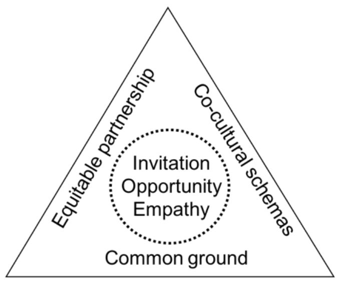

Figure 1. Cultural mediation for equitable interactions.

Guided by this mediation model, we have instantiated a socio-technical interactive triad of two culturally and linguistically diverse children and a bilingual robot as an interaction mediator. Our design research took a grounded-theory approach and started with two foundational questions: i) *What does it take to design a robot to mediate equitable, collaborative interactions among young children?* ii) *What themes arise in children's interactions with the robot and each other?*

Methodological approaches pursued

Over a span of one semester, we conducted design research, where we crafted initial designs for triadic interactions and refined them as we reflected upon our own designs and ethnographically observed children's reactions to the robot and their interactions with each other in a natural kindergarten setting. For the interactions between the robot and children, we employed a Wizard of Oz method (Riek, 2012).

The robot system

Figure 2 illustrates an overview of the system's four components: The robot *Skusie*, robot controller, main controller, and server. Skusie is combined with a mobile phone and controlled by Android apps via Bluetooth technology. The phone is cradled on the robot's head, acting as the robot's visible brain. The body is equipped with sensors and mobility, accompanied by a wand with an embedded optical sensor and microphone. We employed a voice synthesizer that allows Skusie to speak in both English and Spanish. In the interaction sessions with children, the researcher (acting as a wizard and controlling the Main Controller) can manually provide speech utterances for Skusie, or select them from canned utterances in the interaction scenarios. The researcher can also control the Skusie's motions.

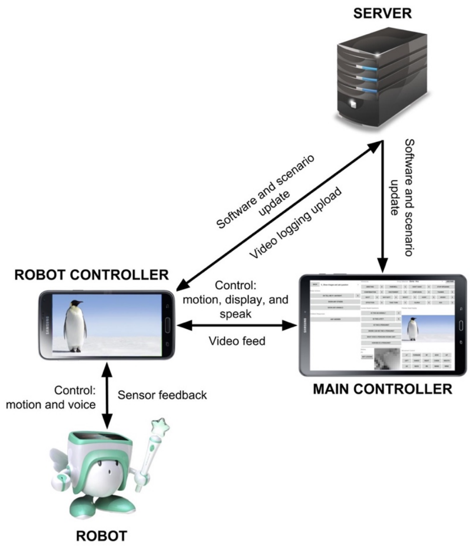

Figure 2. The robot system.

Participants and context

Participants were twenty-four kindergarten children in a public elementary school in a mountain-west state of the United States. The school has a high rate of families living near or below the poverty line. School children were predominantly white English-speaking and Latino Spanish- and English-speaking. All participants were identified as low performing by the school and attended a supplemental class that provided additional practice with language and academic skills for an hour around lunchtime. For the study, children were divided into twelve pairs, with an intent to form cross-cultural, cross-linguistic (English and Spanish) partnerships. The number of two language groups were not balanced. While all children participated in the interactive activities, the research team studied nine culturally diverse pairs.

Design of interaction episodes

In an interaction triad of robot and children, we personified the robot, *Skusie,* as a new friend who just arrived from another planet and did not know much about life on earth. In this learning community, Skusie needed children's help in order to learn about everything, including human language and culture. Skusie spoke both Spanish and English but its speech was not always perfect. Children were asked to work together to teach Skusie. The research team reviewed children's books in schools and libraries and chose four very popular topics for conversation: animals, birthdays, school, and family. Referring to our mediation model, the design team drafted utterances, which were used by a bilingual research assistant who acted as the mediator for the first six weeks. Based on these human-mediator sessions, we crafted the robot's utterances and flows (called scenarios) for each episode, which were deployed later in robot/children triads. Simultaneously, the developers worked on software and hardware systems for robot-mediated sessions.

During robot-children interaction sessions, another bilingual research assistant sat behind Skusie as a moderator to clarify instructions or intervene for smooth flow if necessary. Her utterances were recorded and added to the robot's utterances in the following sessions. By doing so, the moderator's intervention became minimal and later not necessary at all as robot interactions improved. Weekly, the research team met in full to review digital recordings and assess the strengths and weaknesses of the tested episodes and robot functioning. Improvements were suggested, honed, and then deployed the following interaction sessions. Overall, the robots' utterances and the flows for each of the four topics were drafted, tested, and refined over the entire four-month period.

Data collection and analysis

Researchers and assistants visited the same, supplemental kindergarten class two days a week from mid-February through mid-May, 2017. For the first six weeks, a bilingual research assistant acted as the cultural broker after she was educated about the robot mediation approaches. Adopting the approaches, the research assistant led a 15-minute activity with each pair of children. Children were presented a conversation topic and encouraged to interact with one another to engage with the topic through a loosely structured flow. Being bilingual, the research assistant was able to adjust the activity as necessary. During the second six weeks, we deployed the robot to interact with the pairs of children, using a Wizard of Oz technique. In this method, a researcher acting as a wizard controlled the robot while sitting unobtrusively in the corner of the room. The wizard controlled the timing and content of the robot's utteraences. The robot met with pairs of children on the floor of a media center in the school. All interaction sessions were video-recorded and later typed into English- and Spanish-language transcriptions. A researcher also took ethnographic field notes of each activity, recording them in a researcher journal.

Forty-three 15-minute sessions with a research assistant or a robot interacting with pairs of children were digitally recorded and then transformed into detailed typed transcriptions. These transcriptions were analyzed in concert with the researcher's journal, which included field notes from all classroom interactions and weekly research team meetings. Given the iterative nature of the design processes and the constant improvement of the scenarios, researchers looked for evidence of improvement in the four tested scenarios, using the framework of building common ground, building equitable partnerships, and building a co-cultural schema as markers of high quality interactions. Additionally, researchers used traditional ethnographic methods to constantly compare phenomena that occurred across scenarios and children to ascertain additional findings.

Findings and implications

Major design challenges and our solutions

Our first question asked, *What does it take to design a robot to mediate young children's equitable, collaborative interactions?* We faced four major design challenges. First, compared to adults, the language of 5- and 6-year-old kindergarteners is not yet always clearly articulated. Children are still developing their language skills so often use words that approximate the meaning they intend, rather than exact, accurate words. Their word order is often different from adults; their verbs are often incorrectly conjugated; and their speech is often not clear. Speech-recognition software that can readily understand and respond to kindergarten language does not yet exist. Therefore, we used a human controller who acted as a wizard in the Wizard of Oz method. The strength of this arrangement was that the controller could hear what children said and input an appropriate reply. Limitations included an occasional delay between controller's input and the robot's utterances. This often resulted in Skusie not responding for several seconds, and then responding with too many utterances at once, interrupting the children's interactions While some children simply laughed at Skusie's "hiccups", other, shier children often became quiet as the following example of two girls, one Latina and one white, illustrates.

ROBOT: Tell me more about animals. What do you do with animals?
GWAV: [Starts to say something.]
ROBOT: Explícame mas sobre los animales. (Tell me more about animals.)
GWAV: [Starts to say something again.]
ROBOT: Que haces con los animales? (What do you do with animals?)

Our second focus was to design a robot friend that could communicate with children in a kind, casual, yet direct manner. To do this, we first had Skusie greet children with their names. Hearing their own names from Skusie was disarming and also engaging for children. At first, they could not believe the robot was talking directly to them. After repeated interactions, many children responded to Skusie as they would do to a friend.

ROBOT: Hello BLED and BWLA. Good to see you again. **BLED and BWLA**: [Laugh and sit down.] [robot moves closer to them.] **BLED**: Uh oh. **ROBOT**: Hello BLED and BWLA. **BLED and BWLA**: [Laugh]	**ROBOT**: Hello. **GWAV:** Hello. **GLGL:** Hello. **ROBOT:** Good to see you again. **GWAV:** [Whispers to GLGL.] **ROBOT:** I'm learning about school. Can you help me again today? **GLGL and GWAV:** Yes.

Designing a conversation flow that was appropriate for children took some experimentation. Designers added questions to Skusie's utterances so it could prompt children to speak more: questions included, "Why?" "Why not?" and "Tell me more." We also added the statement, "I'm confused," which successfully got children back on topic if they digressed or spoke in a manner the wizard could not understand. In addition, some language sounds, such as "aww" or "ah," which were meant to convey understanding, fell flat when the robot (using a synthesized voice) pronounced them phonetically rather than naturally. This resulted in those sounds having no meaning.

Our third design focus was triggered by the fact that children were divergent thinkers and actors, and their responses were very often unpredictable. The adult developers imagined what children would do or say in a particular event, but our imaginations were limited by our own adult experiences. Thus, our development process considered this unpredictability in our design scheme. First, as a team, we crafted a 15-minute long activity, creating utterances for Skusie to spark the children's conversation and then imagining how children would respond. After observing triad interactions, the design team met, examined the video recording, and made adjustments to the scenario for the following sessions. In the example below, the children could not agree when asked to choose a birthday present for Skusie's friend. The children repeated their own choices and were not able to reach an agreement by the end of the triad session.

ROBOT: Will you help me choose a birthday present for my friend? [both children lean forward to look at the picture]
BLJE: Un biciclo, un coche, unos jugetes- (A bike, a car, some toys-)
ROBOT: ¿BLJE- Cual debo darle a mi amigo? (BLJE, which should I give my friend?)
BLJE: Si es de tu tamaño, escoge un coche. (If it's your size, choose the car.)
GWVI: You could get her a doll. The Barbie, with the dress-
BLJE: Que? (What?)
GWVI: With the dress.
…[The children went on and on, repeating their different choices]

As a result, the design team added statements to Skusie's utterances in the following sessions to promote cooperation between children: "Can you two talk first and choose one for me?" and "Can you two choose together?" This simple addition encouraged children to talk with each other to reach an agreement.

Our fourth design challenge was that children have short attention spans in general. It was very beneficial for the robot to call on children, ask questions, or repeat instructions. In the example A below, Skusie was able to get a child's attention by calling his name and moving toward him. Having Skusie call on the child it wanted to invite into the conversation worked very well, especially for shy children and our bilingual pair. Skusie's invitation led the children to take turns in their response. Also, Skusie expressed confusion and showed images on its smartphone brain to draw children's attention. During the first part of the triad, GLAL, a Latina girl, was quiet and not overtly engaged. However, when Skusie showed pictures of her school on its smartphone brain, GLAL was immediately engaged as in the example B.

A	B
BWTY: [Whispering to Moderator] How did he get here? **Moderator**: He came to visit me. **BWTY**: [Still whispering] How? **Moderator**: From far, far away. **ROBOT**: BWTY. **GNSA**: [Whispering] BWTY. Your turn. **ROBOT**: Would you like to have pets? **BWTY**: Uh, yeah.	**ROBOT**: I saw lots of things on my way here. [The robot rolls forward and shows an image of the children's school.] **GLAL**: That's the gym! **ROBOT**: What is this place? **GLAL**: A gym! **BWOL**: That's - that's just like our gym! **ROBOT**: Amazing. Thank you. Do you learn here? **GLAL and BWOL**: Yes.

In all triadic activities with the robot, all children were engaged during the activity and no children were successful in derailing the conversations as they occasionally had been earlier with the research-assistant mediator.

Emerging themes in children's interactions

Our second question asked, *What themes arise in children's interactions with the robot and each other?* In examining the data, four main themes arose.

Engagement with the robot

When children first met the robot, they were generally curious and surprised. They wanted to know what it was and how it worked. While some children were initially hesitant to talk with Skusie, as they met repeatedly with the robot and talked with each other about the triad experience, their engagement with Skusie grew. Often, they would lay on their bellies during the activity, with their heads near Skusie's smartphone brain. Children regularly touched Skusie. They asked the robot questions about previous scenarios and interactions, wanting to catch up with it after some time away. The following examples illustrate this phenomenon.

ROBOT: Tomorrow is my friend's birthday. I don't know what to do. Can you help me?
BWHU: It's Sam? It's Sam? You love Sam? [a character from a previous scenario]

BLJE: ¿Cuando fue tu cumpleaños, cuando fue el cumpleaños de tu amigo? (When was your birthday, when was the birthday of your friend?) [referring to a previous scenario]

BLJE: No traje tus alas- (You didn't bring your wings?) [an accessory Skusie wore last time it met with BLJE]

Another sign of engagement was that most children were hesitant to leave the robot at the end of the activity. They tended to linger by the robot and ask questions about it or to it.

ROBOT: See you next time. Bye, GLGL and GWAV. See you next time.
GLGL: Bye.
GWAV: Do you know where your home is?

Treating the robot like a person

Several children treated the robot similar to the way they would a person. They talked to it directly, asked it questions, and took turns with it, modeling sophisticated, inclusive conversation skills. Often, they used its name or the second person pronoun "you." Other times, they used the anthropomorphic pronouns "he" and "she." BLED, for example, talked to Skusie directly, asking it, "Skusie, what do you know about tigers?" He then told it, "Sharks are very difficult, Skusie. They- they- they have big teeth." Later, when his partner digressed from the conversation topic, BLED tried to get the conversation back on track by asking, "What's going to happen next, Skusie?" BWHU asked Skusie for a high five. When co-constructing an interaction with Skusie, BWOL said, "Let's take him on an adventure. Oh this is going to be the funniest day of school I've ever had." He then dramatically fell down and popped back up to continue the activity.

Forgiving the robot's weaknesses

Children were very forgiving of the robot's many imperfections. Their desire to help Skusie learn more about life on earth seemed coupled with patience and support for its – and our – efforts. Children were generally patient and empathetic with Skusie even when it interrupted them and when it responded inappropriately due to software glitches or controller mistakes. Children cared about it and were always happy to meet with the robot as their hugs and displays of affection readily showed us. These genuine, warm, caring qualities of the kindergarteners allowed our scenarios and apps to improve.

GLAL: Skusie move!
BWOL: It's ok. Skusie's a robot. Skusie doesn't even know about eating yet. 'Cause he's from a different planet, not Earth.

BWOL: What favorite animal do you like, Susie?
ROBOT: I don't understand you.
Moderator: She doesn't know yet. 'Cause she's still learning about all of our animals here on Earth.
BWOL: I'm still learning about other things.

BLED: "You already tried that Skusie." [when Skusie repeated the same picture]

Learning to work together

When encouraged by the robot, children from the mainstream culture and from Latino families gradually learned to work together, sometimes across the language barrier. At the beginning of the triadic sessions, children habitually talked to the robot individually as if each were alone with the robot. Quite often, when asked questions by the robot, they answered simultaneously or gave Skusie opposite answers. In addition, shier children often lacked an opportunity to speak when they were paired with a more talkative child. After a few sessions where the team observed this phenomenon, we added some explicit statements to the robot's utterances, such as "Can you talk one after the other?" "I am confused." And "Can you two talk first and tell me one thing at a time?" These requests from Skusie usually induced children's cooperation immediately. Such immediate improvement had not occurred in earlier human-brokering sessions. Toward the end of data gathering, in May, the robot's communication skills had improved such that triads often had natural, easy conversations where all members - children and robot – contributed equitably.

Implications for designing for young children

The lessons from this design research are summarized with five implications for designing for children. First, explicit, repeated invitation, such as calling on and rolling over to the child, is helpful in gaining children's attention overall and particularly encouraging shy children to talk. Second, children's unpredictability can be used in robot/child interaction design in a productive way. Divergent-thinking children do not seem to expect a robot's responses to flow logically, nor to necessarily be aligned with their statements. Third, the empathy of the robot is contagious. Children are also patent and understanding in their interactions with the robot and each other. Fourth, the robot's repeated utterances help draw children's attention and verbal responses. Children are parallel players, engaging in parallel thinking (Kim & Smith, 2017); quite often, children remain quiet and just gaze at the robot in response to its first utterances and speak out after two or three repetitions of the utterances. Fifth, the bilingual robot helps to reduce stigma associated with language and invites language minority children to actively participate in interactions.

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Acknowledgments

This study was supported by the U.S. National Science Foundation (Cyberlearning and Future Learning Technologies #1623561).