Human-Centered Design of a Low-Cost Social Robot for Teaching Children STEM

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ABSTRACT
This paper describes our ongoing efforts to use a human-centered design methodology to create a low-cost social robot to help children learn science, technology, engineering, and mathematics (STEM). In this project, we interviewed tutors and students to discover learning needs and preferences, sketched potential robot designs, created storyboards of human-robot interactions, developed prototypes, and received user feedback. Our proposed human-centered design approach for social robot design seeks to develop emotion and conversation interfaces suitable for interactions with children.

KEYWORDS
robotics, child-robot interaction, learning, education, STEM

1 INTRODUCTION
There is a learning gap that exists for children, including underrepresented populations and girls, in science, technology, engineering, and mathematics (STEM), and robotics. Data shows that children attending schools in economically under-served districts have less access to robotics. Although in the U.S. there are national and regional K-12 robotics programs, few, if any, address education educating STEM students in co-robotics, or collaborative robotics, design, and programming. Although there are existing robotics programs for K-12 students, there are few, if any, that provide low-cost, affordable social robots that can interact to help children learn. The focus of this project is to design and develop a commercially viable, low-cost co-robots to help students learn STEM. Our project builds on previous work in developing robots with emotion and conversation interfaces [4] [6]. Our goal is to provide this low-cost social robot to be used in conjunction with our culturally responsive social robotics curriculum [7]. This paper describes the development process for designing robot interactions with children. Others have done work in developing low-cost, social robots [1]. We describe how these social robots can be used to teach STEM using a culturally responsive pedagogical approach more fully in [7].

2 HUMAN-CENTERED DESIGN OF CHILD-INTERACTION ROBOTS
For a child-friendly robot designer using the human-centered design process, the designer begins by investigating the needs of the child users through interviews and observations [3] [2]. The designer uses these expert opinions and insights to determine the archetypal child user and frames the problem for further investigation. The design team uses this problem statement to begin ideation of solutions to the problem. For robot designers, sketching the potential robot and storyboarding interactions between the robot and the user provides the basis of a prototype [5].

3 NEEDFINDING
In needfinding, the designer conducts interviews and observations of the user to determine the pain points or opportunities to provide a gain of some sort. This section describes what we uncovered in our interviews. We started our user-centered research by interviewing several students who were involved with tutoring—either tutoring others or being tutored themselves. During these interviews, we compiled empathy charts and particularly paid attention to contradictions, surprises, and tensions that each person felt during the traditional process of tutoring. This step is important in the design research phase, as it helped with framing the problem at hand. From our research we found that students who felt insecure about their skill set in a particular subject were less likely to go to a tutor for help. There are also negative connotations that are linked with tutoring. However, the most important thing we concluded from our user interviews was that people all learn differently and that people learn better when it is group-led exercises. Times where students
Figure 1: STEM Social robot sketches and storyboard

were able to empathize with each other, showed us that learning in a group environment were more poignant experiences. From these interviews, we thought about what capabilities/potential this robot could have in a classroom or home environment.

4 PROBLEM DEFINITION
In human-centered design, defining the problem is the next step towards finding an innovative solution. Our problem was defined from our user-centered research. What we aimed to create was a socially intelligent robot that was able to deliver tutoring lessons or homework help in an effective manner that would suit the needs of students. We envisioned it to be the figo-tofi alternative if tutors, parents, and teachers were unavailable. From there we tried to narrow down the needs. How would we design it so that it was good at one thing, and one thing only? How would we design it so that the robot would not hinder the teacher in the classroom, but enhance the learning environment? These questions were the launchpad of our sketching, storyboarding, and prototyping processes.

5 SKETCHING AND STORYBOARDING
During our ideation process, we developed several sketches and storyboards to design potential human-robot interactions for our child-robot learning scenario (Figure 1).

6 PROTOTYPING AND TESTING
Once a need and a potential solution were established within our user demographic it was time to start prototyping. To best match our users, a design criteria was set up which reflected design elements which were ranked by what was felt important. Some of the goals established were, keeping the materials affordable, using existing technology, and most importantly, provide a creative foundation for the student. While sketching and storyboarding provided valuable insight into the user’s needs, a physical prototype was needed to gauge how students would react in practice.

The first big question when starting to prototype the first robot was a question of scale. How does a robot’s size and movement relate to how it is perceived? Furthermore, where would this robot be in a school or classroom? When it comes to designing for people, a user’s perception of an object is vital. To avoid confusion and limit the initial perception of the robot at first glance, the form was to have a simplicity to it. Observational research of students interacting with the Nao robots in the classroom provided a valuable context for making such a decision. It was clear that when students first saw a robot, that they were immediately making assumptions about what it could do, and more importantly, what it could not do. As designers working with robots for the first time, this emotional response was very relatable, because we too found ourselves making preconceptions about robots, based on their appearance without even thinking about function. This discovery was a valuable insight when making decisions about form. The students seemed more comfortable interacting with a robot exhibiting human qualities, and ideas that were relatable to them.

Trying to design within the massive field of HRI, there were clear design challenges, while at the same time, refreshing to explore the opportunities within. With cost in mind, the first prototype centered around designing a low-cost robot using existing technology. From previous sketches, CAD models were quickly mocked-up to get a general sense of appearance (Figure 2). A half-scale foam core model was first built to understand construction methods and other potential oversights. The robot’s main components were a Raspberry Pi 3, an iPhone for the face to use for emotion display and speech recognition [4], and an iPad for chest interaction with users. Through the process of design, understanding a robot had to be broken down into its essential parts. The Raspberry Pi 3 provided many customization options and is educational in its own right. If we had to learn what a robot is the first time, how could this translate to younger students also learning for the first time?

From the half-scale model, we built a full-scale model along with a mini variation robot. The full-scale model offered a new look at the robot, which could otherwise not be communicated on paper. It was clear that the full-scale robot with an iPad for the chest was too large. We kept the overall form of the robot, but we made the new miniature version of the robot significantly smaller. With an iPhone as the new chest display and an Apple Watch for the new head display, the mini-robot was a more manageable size. However, receiving students’ feedback was the most valuable. As a designer, a user’s feedback is crucial and must be focused on
constantly. The feedback given to both models highlighted their strengths and weaknesses, and much was learned. The material choice of cardboard was a negative feature, because it made the robot fragile and easy to tamper. Children thought the overall form was cute but needed color. Children also told us that some elements of the robots were confusing. Two features that struck the students as odd, were the mostly non-functional arms, and the slot cut in the robot for the object detection camera. Because the students saw the robot had arms, they were expecting the robot to act like real arms, and wanted them to grab objects.

From the students’ feedback, it was apparent that the prototype robots were perceived as lackluster, and needed a fun element. Quite simply the robot did not look fun. It is hard to be objective when designing a robot when children value it through subjective means. Perhaps the goal of the robot should be for the children to have fun interacting with it. Disguising education through fun seems to be the contributing factor for success in the robot education market, but also was reflected in the students’ feedback. We established a new direction using this feedback, and we made having fun the central focus of our design.

Having inspiration from the current market of robots, LED’s were a great element to add to a robot, due to their visual nature and overall user interface options LEDs provide a robot. We added a flexible LED matrix as a primary component wrapped on the inside of the robot. The rounded form combined with a flexible LED matrix could glow in various areas of the robot and aid the user visually. The LED matrix would also provide color to reflect the robot’s mood further.” Ideally, the LED could act as another component that a student could customize and make their own. The new form was to be 3d printed because it provides a tailored look, modular components, and faster to prototype. The new robot remained much smaller than the original prototype, making it easier to transport, and more likely that a student would take it with them. As the form of the new robot takes shape, more challenges take shape.

7 CONCLUSIONS
In this paper, we described the human-centered design process we are using to develop a low-cost social robot to help children learn STEM. This project has the potential to provide a low-cost alternative robot to boost the participation of under-resourced and rural school students in learning how to program robots and to study science, technology, math, and science.

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REFERENCES