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Dragons, Ladybugs, and Softballs: Girls' STEM Engagement with Human-Centered Robotics

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Abstract Early experiences in science, technology, engineering, and math (STEM) are important for getting youth interested in STEM fields, particularly for girls. Here, we explore how an after-school robotics club can provide informal STEM experiences that inspire students to engage with STEM in the future. Human-centered robotics, with its emphasis on the social aspects of science and technology, may be especially important for bringing girls into the STEM pipeline. Using a problem-based approach, we designed two robotics challenges. We focus here on the more extended second challenge, in which participants were asked to imagine and build a telepresence robot that would allow others to explore their space from a distance. This research follows four girls as they engage with human-centered telepresence robotics design. We constructed case studies of these target participants to explore their different forms of engagement and phases of interest development—considering facets of behavioral, social, cognitive, and conceptual-to-consequential engagement as well as stages of interest ranging from triggered interest to well-developed individual interest. The results demonstrated that opportunities to personalize their robots and feedback from peers and facilitators were important motivators. We found both explicit and vicarious engagement and varied interest phases in our group of four focus participants. This first iteration of our project demonstrated that human-centered robotics is a promising approach to getting girls interested and engaged in STEM practices. As we design future iterations of our robotics club environment, we must consider how to harness multiple forms of leadership and engagement without marginalizing students with different working preferences.

Keywords Human-centered robotics · Telepresence robotics · Engagement · Interest development · Problem-based learning

Introduction

Early experiences in STEM are important for getting youth interested in scientific and technical fields (Tai et al. 2006). In the research presented here, we explore how an after-school robotics club can provide an informal STEM experience to youth through a focus on human-centered robotics (HCR), particularly because of its emphasis on the social aspects of science and technology. Robotics also provides opportunities for youth to engage in "tinkering" which may be a precursor of sustained STEM interest (Crowley et al. 2015; Swarat et al. 2012). Although the National Science Foundation (NSF) defines STEM fields to include the social/behavioral sciences, mathematics, natural sciences, engineering, and computer and information sciences (Green 2007), STEM curricula regularly separate the development of technical skills and knowledge from analysis of the social and cultural contexts in which people practice and experience them. Scientific discoveries and technological artifacts both affect society through their

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applications and are also affected by societal concerns. STEM education should, therefore, promote understanding of the relationship between technology, nature, and society consistent with both engineering and several crosscutting aspects of the Next Generation Science Standards (NGSS), along with disciplinary knowledge and skills (NGSS 2013). This will prepare students to do work in STEM fields—as future scientists collaborating on interdisciplinary projects, policy makers deciding on appropriate ways to regulate science and technology, and small company owners seeking to transform their marketplace and provide new and better services to clients.

Despite an increase in US girls' math and science scores on national assessments and attainment of post-secondary degrees over the past 20 years, boys still seek out STEM degrees and careers more often than girls. This indicates that there may be an identity gap—even with higher test scores in STEM subjects, many girls (particularly those in non-dominant populations including ethnic minority students and low SES populations) do not *see* themselves as engineers, scientists, and mathematicians (Tan et al. 2013). Social aspects of science are particularly important for bringing girls into the STEM pipeline (Hill et al. 2010). Human-centered robotics (HCR) involves the development of robotic technologies and applications for everyday use, while telepresence robots enable communication, operation, and exploration across enormous distances, making the technology very relevant for today's world (Schaal 2007). The ITEST project intervention studied here aims to pique youths' interest and provide them with the tools and know-how to develop robotic technologies in response to people's needs. In recent years, robotics has become a popular vehicle for introducing K-12 students (Barker and Ansorge 2007; Stubbs and Yanco 2009; Weinberg et al. 2007; Sullivan 2008), undergraduates (Mataric et al. 2007; Verner and Ahlgren 2004), and novices (Hamner et al. 2008) to the principles of computer science and other STEM fields. Providing students with opportunities to learn through hands-on robotic applications has been an effective way to engage diverse groups of students with technology, including women (Hamner et al. 2008). Human-centered applications in particular should motivate and enable more students to grasp the intricacies of scientific principles and technology design and to understand how they can be used to "contribute to society and human well-being" (ACM Code of Ethics 1992). HCR provides a context that highlights the relevance of societal context and human needs for increased motivation in STEM among all students, especially girls who begin to lose interest in STEM during middle school (Pajares 2005; Tan et al. 2013). The open-ended and self-defined nature of the tasks students work on can also accommodate different intrinsic motivations and learning preferences of participating students.

Girls and STEM

Women are underrepresented at the highest level of STEM fields. Although they initially take the same STEM-focused classes as their male counterparts when they are young, their interest and self-confidence tend to drop when they are in middle school (Pajares 2005; Tan et al. 2013). Participation in out-of-school programs focused on STEM is particularly effective at supporting the development of more positive attitudes among girls (Bell et al. 2009). Female mentors are also important in affecting girls' attitudes toward STEM (Ferreira 2001). As the 2010 American Association of University Women report states, "Well-documented gender differences exist in the value that women and men place on doing work that contributes to society, with women more likely than men to prefer work with a clear social purpose." (Hill et al. 2010, p. 22). In the work reported here, we foreground that preference through the creation of an after-school robotics club that featured female facilitators and an emphasis on social aspects and applications of robotics. Understanding learning as situated in social contexts, we designed an intervention with the intention of bringing students, particularly girls, into a community of practice where they might explore their own STEM identities through authentic practice (Lave and Wenger 1991; Tan et al. 2013).

Engagement, Interest, and Informal Settings

Features of learning environments can trigger situational interest that can be a precursor to more sustained interest and engagement. In open learning tasks, students need to have their ideas respected and to feel genuinely appreciated for their contributions in addition to feeling that they understand the content. This is the first phase in Renninger et al.'s (2015) four-phase model of interest development. In this model, which is consistent with our ITEST project design decisions, there is an initial triggering of interest (Phase 1). This triggered interest may or may not lead to more well-developed and maintained interest (Phase 2), where individuals are predisposed to voluntarily return and engage with content. Triggering of interest followed by maintained situational interest can lead learners to reflect and to ask and answer questions out of curiosity (Phase 3). In this phase, individual learners receive feedback that helps them to continually structure goals, and they are invested in seeking answers for their own questions. In Phase 4 of interest development, learners push through challenges, attend to and seek out feedback, and self-regulate to ultimately achieve goals. Renninger et al. suggest that when formal instruction does not catch students' interest, out-of-school science can provide opportunities to engage students in STEM in a more supportive context.

The aim of our out-of-school HCR intervention was to cultivate interest in a robotics project, as well as relevant STEM concepts and essential engineering practices. More specifically, this project aimed to trigger and maintain situational interest—targeting learners who had little developed interest in STEM. Advancing and sustaining student interest matters for persistence in the STEM pipeline, and this persistence is affected by the nature of the activity (Maltese and Harsh 2015).

Informal experiences can provide excellent opportunities to develop sustained interest and engagement as they are leisurely activities without the kinds of performance pressures found in school, but, nonetheless, provide resources and support that allow participants to be successful at ways they can set the pace (Azevedo 2015; Bell et al. 2009). After-school programs offer a looser accountability structure than schools and more free choice as they offer youth opportunities to develop interest and competence in STEM-related activities and practices. Productive after-school activities demonstrate a high degree of personalization and support from the environment as participant interest takes different directions. Another characteristic of these settings is that they offer students extended time with STEM practices. Interest-driven participation in these settings does not necessarily go on a linear path, but may become more or less intense and focused—these are part and parcel of interest-driven participation. One of the challenges is to find hooks for budding interest (Azevedo 2015). We conjecture that the social aspect of HCR may be one of these hooks in an out-of-school setting.

In a life history study of scientists, Crowley et al. (2015) found that a substantial number of their participants attributed their science interest to out-of-school experiences, though only 10 % to *organized* out-of-school experiences. In a prospective study of interest, youth in a citizen science program were surveyed about their interest in science. The results showed that, consistent with the life history study, out-of-school experiences provided a dominant theme for the high-interest group. Notably, this group was fairly evenly split between females and males. Case studies of two of the girls suggested that development of STEM interest was complex, and that surveys and interviews often painted contradictory pictures. The results of these studies from Crowley et al. (2015) suggest that interests are about engaging with particular science-related pursuits rather than a general passion for STEM. Building on Crowley et al.'s findings and Renninger et al.'s (2015) interest development model, our ITEST intervention set the stage for interest development by introducing social robotics in the context of an after-school club. To *see* interest development in our intervention, we focused on multidimensional facets of collaborative engagement.

An important indicator of interest is engagement, but not all forms of engagement are created equal. In conceptualizing engagement as a group phenomenon, Sinha et al. (2015) distinguished four kinds of engagement: behavioral engagement (seen in the display of on-task behavior), social engagement (demonstrated in contributions to small group interaction), cognitive engagement (planning and task-related considerations), and finally conceptual-to-consequential (CC) engagement (how learners engage with knowledge and skills and the extent to which they are applied toward the problem or task at hand). In an engineering-focused unit like ours, we can observe behavioral engagement as students' focus on hands-on interaction with materials, whereas social engagement can look like a lively back-and-forth of questions and responses between group members (e.g., "I think we should do this because…" "I agree, but…"). Cognitive engagement can involve task delegation for the group as a whole or for individual group members (e.g., "You write that code and I'll check it, and you design what the robot body should look like" or, "We should work on getting the robot to move first, and then think about what it should look like"). Conceptual-to-consequential (CC) engagement emerges when students explicitly reference concepts learned in the unit and use them to solve a challenge that arises (e.g., "We used angles when we were pretending to be robots, let's try using angles in the code we are writing"). These facets of engagement provide a framework for examining girls' interest and engagement in an after-school HCR club.

A Human-Centered Robotics Intervention in an Informal Setting

Our work introducing HCR took place in the informal environment of an after-school Boys and Girls Club (BGC) in a rural US community in the Midwest. We presented students with an HCR Telepresence Challenge, which asked them to design and build telepresence robots that could be used to communicate with a distant group of students in Fairbanks, Alaska. This design process provided BGC members with the opportunity to engage in the task of imagining, building, and operating a robot, as they grappled with real-world problems and worked collaboratively toward solutions. The content of our robotics club curriculum was designed from a problem-based learning (PBL) perspective.

Problem-based learning (PBL), which begins with an ill-structured and real-world problem, requires students to work in small groups as they collaboratively figure out what they need to know to solve the problem (and how to find this information). As students work toward solutions in a PBL experience, they are guided by facilitators—first identifying what is needed to solve the problem, then generating ideas about solutions, identifying what they do not know about the problem (what they need to learn), and applying new knowledge to the problem and abstracting this knowledge to future problems (Hmelo-Silver 2004). The PBL cycle aligns well with the Next Generation Science Standards for Engineering Design (NGSS 2013), which we incorporated into our lesson plans and unit plan. Overall, the process BGC members took on in our exploratory study was intended to mirror the design process that engineers must go through in everyday life—brainstorming, identifying problems, applying relevant information, finding solutions, and adjusting iteratively as they reflect (Resnick 2007). In providing an experience authentic to the work of engineers and scientists, we hoped to spark interest in STEM fields. Our research team adapted PBL to fit an after-school setting by enacting the PBL cycle informally and taking advantage of the participants' interests as they considered how they could personalize the robots they designed.

Engineering Design in Our Human-Centered Robotics Telepresence Challenge

As members of a Boys and Girls Club interacted with Arduino boards, play dough circuits, computer programs, handwritten brainstorm charts, and each other, they participated in a design cycle. Our team developed the activities for each session of our robotics club using engineering design principles from the NGSS. The sequence of weekly lessons focused on skills highlighted in the NGSS—moving from brainstorming activities early in the unit to opportunities to ask relevant questions and glean important information, to the testing of solutions, reflection, and re-testing that defines iterative design. We adapted a simple engineering design process: imagine > create > play > share ideas and creations > reflect > imagine new ideas (Resnick 2007) to use in the PBL cycle with the resulting multidirectional cycle shown in Fig. 1. In our adapted cycle, learners "ask questions" to define a problem, "imagine" by brainstorming ideas, "collect information" to determine the affordances and constraints of the problem and context they are working with, "develop and test solutions" through iterative design, and "improve" by using feedback to structure revisions to their designs.

We emphasize that each of these components is related to the others and that, although depicted as a cycle, the process is not necessarily linear, but may go back-and-forth between different aspects of the design process. Each lesson plan we created incorporated questions for facilitators to ask related to the components of this cycle. Furthermore, the unit was designed to be flexible so that we as a research team might move through the same design process—re-imagining possibilities, testing solutions, and inserting new activities when students lacked necessary prior knowledge or information to complete a task.

Focusing on PBL as a key instructional strategy, lesson plans for each week of the robotics club were drafted using a PBL problem template, which included descriptions for how the problem would be presented, an overview of the problem and how it unfolds, and the inquiry approach and sources (i.e., what materials are required or how students might request access to them). These plans were designed to provide Boys and Girls Club members the opportunity to encounter a series of basic engineering problems, work collaboratively toward solutions, and select an optimal solution.

The telepresence challenge also allowed students to use robotics in a form of "place-based" learning (McComas 2014). This intervention took advantage of members' prior familiarity and interest in their local environment, as well as their curiosity about faraway places. In our exploratory study, place-based learning occurred through the programming of a customizable robot equipped with wheels and a camera to give a tour of familiar spaces in the BGC to visitors, and engagement with another group of students in a remote location charged with the same task. Progressing through this unit, students had the opportunity to engage with engineering and systems thinking skills as they moved from sketches of initial ideas, to guided robot construction, to functioning prototypes of telepresence robots showcased in a community event. Lessons included material and resource lists, an overview of the lesson and its purpose, alignment to Next Generation Science Standards (NGSS 2013) a list of activities (with some scripting for facilitators,) and optional adaptations for the lesson.[1] Our lessons also included facilitator suggestions that could be used to guide students' learning—introducing a problem at the beginning of each session, connecting it to the larger problem of the unit, and asking strategic questions to help students compile all necessary information to devise solutions. For example, in the first robotics club experience of the unit, students were asked to imagine how a robot might move in their Boys and Girls Club Space—anticipating obstacles and discussing how a robot might fit into their space's culture. They had to consider: "Where should a robot go and what should it show people?" " Are there places a robot should not go?" "How should the robot be able to interact with people?" This was an important starting point for the development of human-centered robotics thinking skills. This also prepared students to move into the work of programming in order to make their early ideas about what a robot should be able to do in their learning environment a reality.

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[1] Lesson plans and PBL templates are available from the authors.

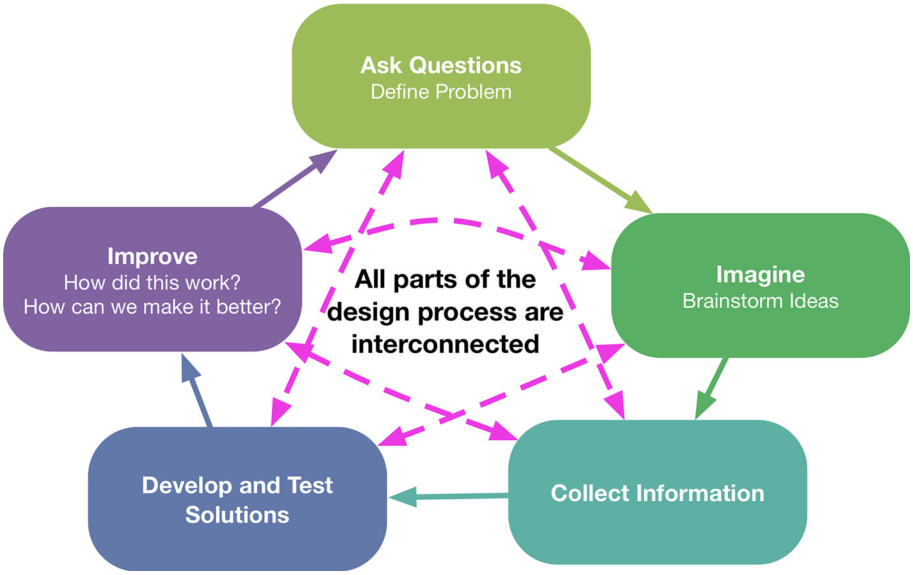

Fig. 1 Design cycle used in the BGC. Adapted from Resnick (2007)

Our study in the BGC environment focused on engagement. Though the design of our unit, lessons, and learning experiences was driven by PBL, many adaptations were made to address the challenges of working in an unpredictable and informal learning environment. In the process of adaptation, we asked: How might the engagement of girls in this informal learning environment inform the future design of human-centered and problem-based robotics activities in both informal environments and formal classrooms—working toward a learning experience that engages all learners? This question is consistent with a focus on Strand 1 of the National Research Council Report on learning in informal environments—developing interest in science as well as motivation to learn about the world around you (Bell et al. 2009). Our human-centered robotics unit provided opportunities for students to engage in science practices, defined in Strand 5 as using the tools of science and engineering. We aimed to provide opportunities for youth (and girls in particular) to engage in engineering practices and use the tools of STEM. The research presented here is an exploratory case study of the first iteration of the ITEST project using human-centered robotics with youth in a BGC environment. Throughout our exploratory case study, we asked:

- How do girls engage with human-centered robotics activities in an informal intervention?
- How does girls' participation in the robotics club provide evidence of understanding of engineering design?

Rather than assuming that knowledge is acquired through absorbing information and later applying it, we expected that the youth in our after-school context would be learning by doing—internalizing the process of design by moving through it individually and as a group (Lave and Wenger 1991). This sociocultural perspective on learning helped us to make claims about future design of contexts that even better support engagement and interest in STEM.

Methods

Context and Participants

The Boys and Girls Club (BGC) where this exploratory study took place offers recreational activities, homework help, and leadership activities between the hours of 2 and 6 PM during the school year. It is part of a national network of Boys and Girls Clubs. Children in this space are referred to as "members" and are respected as participants in a community with a clearly defined culture and set of rules. Members are familiar with the norms and expectations in the space (i.e., transitions between activities and guidelines for respectful interactions). The students in this particular BGC are between the ages of 6 and 18, and their guardians pay an annual fee of $20 for after-school programming. Within our exploratory robotics club case study, students were invited to participate based on their ages and grade levels. We advertised the opportunity to participate in a weekly robotics club to all "teen" members at the BGC via an introductory session in which students had the opportunity to tinker with a variety of robots and to control a robot at a distance with collaborators in Alaska.

The students who chose to participate in the robotics club ranged in age from 13 to 18 years of age. The total number of teenage participants who attended the club included 20 males and 26 females. Over the course of

11 weeks, participants spent 1–2 hours each Friday with our research team designing and building telepresence robots—remote-controlled robots equipped to navigate a space using wheels, sensor data, and a camera. Nine weeks were devoted to telepresence robotics, with 2 weeks devoted to the construction of a simpler tabletop companion robot. The telepresence robots members worked with were iRobot Creates, similar to robot vacuum cleaners in appearance and function, but with the vacuum apparatus removed (Fig. 2). The iRobot Creates were designed as low-cost educational and research platforms.

The number of participants in the club varied from week to week due to unpredictable attendance and the movement of students in and out of the room. This meant that our participant population was in flux, with only a handful of steady participants who attended multiple consecutive weeks and stayed for the majority of the sessions.

This exploratory case study was designed and conducted with the overarching goal of introducing students in an informal learning environment to human-centered robotics and engaging them in the process of brainstorming, creating, testing, reflecting, and reiterating designs—inspiring situational interest in working on a project and in STEM fields. During each week of our unit, members were separated into small groups with one facilitator per group. Facilitators included faculty researchers, undergraduate students, and graduate students in Informatics and Learning Sciences programs at a nearby University. Although the specific facilitators varied from week to week, there was a balance of male and female facilitators.[2] The facilitators met to review lesson plans prior to each week's meeting, worked together to prepare all session materials, and composed reflections after each session.

Data Sources

Interview pre- and post-data were collected to gain a sense of how participants' ideas about robotics and/or STEM changed over the course of the unit (if at all). In early BGC sessions, members interviewed each other about their experience with robotics, ideas about what a robot is, and ways they might use a robot in their everyday lives. At the end of the unit, members participated in post-interviews conducted by the research team. These interviews focused on members' perceptions of what they've learned throughout the unit and how their ideas about robots changed. Post-interviews were conducted with HCR applications in mind—giving students the space to consider how robotics fit into the world around them.

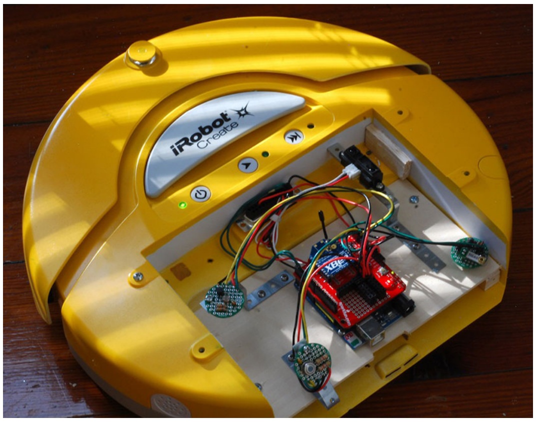

Fig. 2 Robotics platform

During each robotics club session, cameras were positioned to record three small groups of students, with audio recorders placed on each group's table. Data sources included student pre-interviews focused on initial perceptions of robots and prior knowledge about robotics, video and audio records of all sessions, members' drawn and handwritten artifacts, and post-interview audio recordings. Table 1 shows the nine major instructional sessions that occurred throughout the telepresence robotics unit and the associated data sources.

Data Selection and Analysis

This paper presents an exploratory case study. We began our analysis by reviewing all video and student artifacts collected over the course of the robotics unit. Our analysis focused on telepresence robotics sessions, and we began by constructing meta-level research notes about each of these sessions. Meta-level notes were refined as our research questions became more defined. We were interested from the beginning of the study in the way that girls, an underrepresented population in STEM fields, engaged with our human-centered robotics activities and in the authentic practice of the engineering design process.

Following the video analysis recommendations of Powell, Francisco, and Maher (2003) and Jordan and Henderson (1995), we first reviewed all video records collected in the Boys and Girls Club learning environment. We then identified video in which our target participants (girls) were represented. In this setting, participation is defined by attendance at one or more sessions of the after-school robotics club. Intrigued by the different forms of girls' engagement we noticed throughout the unit, we identified girls who attended the club more than once and whose stories painted a picture of problem-solving and engagement in the learning environment. This led us to four focus participants who were captured multiple times on video and whose hand-drawn artifacts allowed us to triangulate what we saw on

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[2] At least two of the authors served as facilitators every week for continuity.

video (see Table 1). Twenty-two students participated in our robotics club in one or more sessions and had consent to be video- and audio-recorded. Seven of these students were male, and fifteen were female. Twenty-four students attended the club for one or more session, but did not complete consent forms. These students' participation in the robotics club was not analyzed, and they did not complete pre- or post-interviews. Pre- and post-interview data were limited due to inconsistent attendance and challenges in getting consent forms in a timely manner in this informal setting. Demographic information about students beyond gender was sparse, as we only recorded demographic information for students who completed an interview. All participants in the club were teens and were students in grades 6–12 in the local school district. Thus, the four participants we selected were a subset of the limited sample of video-recorded female participants with parental consent.

As Powell et al. (2003) recommend, high-level notes on all video data containing the four focus participants were created. Activity was logged in regular one- to 5-min intervals with "critical" events identified and shared with collaborators. Identification of critical events was grounded in our research questions—moments were flagged in which the focal participants were observably engaged, interested, or articulating an element of the engineering design cycle. Following tenets of interaction analysis (Jordan and Henderson 1995), we looked for observable behaviors that demonstrated interest or engagement, such as when participants were manipulating physical materials, closely watching peers, asking questions, and explaining their work to others. We created verbatim transcripts for all available interviews with our four focus youth and also transcribed all critical events identified by co-authors. We then reviewed and annotated these interactions further—highlighting features of the way each girl engaged with physical materials in the space and the other members and facilitators in her group. The interest and engagement frameworks of Renninger et al. (2015) and Sinha et al. (2015) gave us a set of common categories to further analyze these interactions.

Focus group participants' drawings and video were re-examined to further interpret engagement with regard to understanding of the engineering design cycle. Considering learning as situational, social, and participatory (Lave and Wenger 1991), we used verbal descriptions, drawings, and learner actions captured in group work and interviews as evidence for learners' interaction with the engineering design process. We returned to video data and student artifacts for all focal participants—highlighting moments in which an element of the design cycle could be mapped to an interaction or artifact. The girls we feature in this exploratory case study are Carrie (12), Maggie (15), Aurora (12), and Amy (13) (see Table 1 footnote). All girls identify as Caucasian. At the time of the study, Maggie and Amy were 8th grade students and Aurora and Carrie were 7th grade students.

Results

Bringing Them In

In this section, we first introduce each of the four selected girls and their varied forms of participation and

Table 1 Instructional sessions and data sources

Session	Activity	Date (2015)	Data collected	Focus group participants
Instructional sessions				
1	Introductory session	1–30	Video	Maggie[a]
2	Pre-interviews and robot exploration/ programming	2–20; 2–27	Pre-interview Video Drawn artifacts	Carrie Maggie Aurora
3	Bodystorming activity	3–6	Video	Carrie Maggie Aurora
4	Squishy circuits	3–13	Video	Aurora Carrie
5–7	Orthographic drawing	4–10; 4–17;4–24	Video Drawn artifacts	Session 5: Carrie, Maggie, Aurora, Amy Session 6: Maggie Session 7: Carrie, Maggie, Amy
8	Cardboard prototype assembly and post-interviews	5–1	Post-interviews Video	Carrie
9	Community presentation	5–8	Post-interviews	Maggie

[a] All Boys and Girls Club member names have been changed

engagement with human-centered robotics activities and objectives. We highlight vignettes featuring the four girls to provide examples of how these girls and their peers demonstrated engagement with the iterative design process and HCR activities more generally. This engagement is interpreted in terms of Sinha et al.'s (2015) categories of behavioral, social, cognitive, and conceptual-to-consequential engagement. We also use these vignettes to reveal the ways in which these four girls demonstrated STEM interest development. Engagement is used as an indicator of interest, but Renninger et al.'s four-phase model of interest development helps to articulate the development of learner interest even more directly.

Carrie

At the beginning of session 8, her fifth session at the robotics club, Carrie picked up a circular piece of cardboard with slats along its edges and a letter and number etched across its smooth face. The distinctive scent of burning wood lingered—a result of a laser cutter's work to cut this shape. The dozens of cardboard pieces scattered across the BGC tabletop were pieces of prototypes created from student drawings (Fig. 3). On this day, the three students who attended the club were working to assemble prototypes with little direct instruction. Carrie continued to slide pieces together, then apart. She forced them to fit, creating the outline of a sphere. Unable to find space for the last three pieces, she tore her work apart, grunting aloud.

As Carrie went through the difficult work of assembling, assessing, and re-building one prototype, she received encouragement and additional information from two facilitators. The female first author (AG) worked beside Carrie, encouraging her process of trial and error. She was also new to this task and worked through the problem with Carrie. As Carrie built a cardboard prototype body for a robot, she went through an iterative problem-solving process, receiving just-in-time information and support from multiple facilitators as she worked to solve the ill-structured problem. She did so through the trial and error of putting pieces together, obtaining new relevant information, and reassembling. Carrie was frustrated, indicated by sighing and grunting as she pushed pieces together, but never to the point of giving up.

As she received guidance from facilitators, Carrie demonstrated multiple forms of engagement (Sinha et al. 2015). She was behaviorally engaged; physically engaged with the materials on the table and committed to the task at hand. Carrie also demonstrated conceptual-to-consequential (CC) engagement as she took up information from facilitators and applied it to the construction of a complex three-dimensional object. When the cardboard pieces of her 3D model didn't fit together, a facilitator crouched next to her; "Hm. I know that there are Ys and Zs…" Given hints that the pieces of the model were labeled with letters and numbers, Carrie experimented with putting the numbers in order until she found a pattern. As she did, Carrie incorporated feedback into her problem-solving (i.e., a hint from another facilitator that the Zs need to be horizontal and the Ys vertical)—demonstrating maintained interest in the task at hand. As she worked, Carrie was supported by peers and facilitators—an important feature of the environment that makes further interest development possible.

Fig. 3 Assembling 3D models

Throughout this task, both the female facilitator (AG) and Carrie placed their hands on the physical materials, assembling a 3D sphere as two facilitators and two youth peers worked around them. Carrie and the facilitator recognized that they'd made a mistake. Carrie shrugged her shoulders and said, "This one's too hard." "We can do it," the facilitator replied. The two then explained their process to another adult facilitator in the space. Carrie said, "We basically had the whole thing. We had the top and the bottom, and then we had all of the Zs going this way" (*making a horizontal motion with her right hand, palm facing upward).* The two started again, moving through a process of trial and error as they stacked and slid. Carrie developed a process with a facilitator, adding a Y piece with every Z. At the end of this exchange, when the two had successfully completed the shape, Carrie stated "We finished it!"

In this vignette, Carrie was behaviorally engaged as she worked with physical materials and persisted to complete the task of assembling a 3D model. She also demonstrated CC engagement as she took up information from facilitators and applied it to the construction of a complex three-dimensional object. Her persistence can also be interpreted in terms of Renninger et al.'s four-phase model of interest development. Carrie's persistence in completing this task demonstrated triggered and maintained interest (Phases 1 and 2). Carrie provided information about what she tried in order to receive feedback from facilitators. Though she did not ask an explicit question, her interactions with the facilitators might be interpreted as an indicator of movement toward Phase 3—asking questions and soliciting feedback in pursuit of a goal (Renninger et al. 2015). Supported by facilitators, Carrie was able to work through a challenging task. Over time, this kind of scaffolding may lead to Phase 4 of interest development, in which a unique goal is pursued by a learner independently over time.

Maggie

In an introductory session at the BGC, Maggie lingered with a small group of girls. A facilitator asked what they'd like to do with the robots in the room. Maggie replied: "I hate computers" and went on to explain that robots were included in this category. Three months later, the girl who "hated" robots and computers had positioned herself as an influential member of the robotics club. Of the four girls we followed, Maggie attended the most consecutive sessions of robotics club. The act of attendance in itself may be considered a form of situational interest.

Participating in session 7, which focused on orthographic drawings (top, front, and side views of a robot body that can be translated by a computer into 3D printed prototypes), Maggie proudly displayed a digital drawing of a wide-winged dragon on her iPad—holding it in front of her chest so that the group could see it easily. "This is an original," she stated after a facilitator stressed the importance of avoiding drawing copyrighted characters. As the group sketched out ideas over the course of the hour, Maggie behaved as an authority figure. Maggie was asked several questions by her peers. Socially engaged, she helped to coordinate the group and provided feedback. When a younger participant found an image he wanted to draw from multiple angles, he turned to Maggie. "You can draw. Can you draw this?" he asked. Maggie replied: "Let me see that" and began to sketch with quick black marker strokes. Maggie continued to problem-solve throughout the session—telling the participants at her table about the use of applications she'd experimented with outside of the club to sketch particularly complicated 3D ideas.

Maggie handled cardboard 3D prototypes, flipped through images on her iPad, and reviewed the work of her peers. When a facilitator suggested that Maggie refine her dragon drawing to make it more proportional, Maggie asked a clarifying question: "So what did you mean with proportions again?" She went on to demonstrate the size of each part of her imagined dragon with her hands, spacing her fingers far apart and close together. She discussed how to draw the relationship of these parts with the boy next to her and was asked for help by two other boys at the table. When asked for help by her peers, Maggie re-voiced instructions given by the facilitator—becoming a kind of co-facilitator as she took up the guiding role of the adults at the table.

At the end of session 7, the members were asked to select three outstanding drawings to be made into full-size prototypes and mounted on moving platforms. Maggie advocated for her work and was supported by the two boys seated beside her. Maggie worked to persuade the group; "You see [those other designs] every day, you don't see a dragon every day." She went on to ask the facilitator what work she needed to do to make her drawing feasible as a functioning telepresence robot, asking "What else do you need for the dragon?… How would you make wings like this?" Maggie reflected at the end of the session, one of the last teenagers to leave the space; "I've definitely worked the hardest though, [My drawing] is definitely the hardest one."

Throughout the robotics club experience, as seen in this narrative, Maggie was socially and cognitively engaged as she coordinated group activity and planned her individual work. Her words and actions also suggest interest development. As Maggie applied information about drawing 3D objects and scale to the task of providing feedback to her peers and advancing her own dragon design, Maggie showed CC engagement. Despite her initial reluctance to engage, Maggie ultimately demonstrated multiple facets of engagement as she took on the work of designing a telepresence robot. In the work of session 7, Maggie asked facilitators in the after-school club questions as she worked to achieve an independently set goal (to build a dragon). Maggie's planning of individual work, feedback to peers, and use of clarifying and curiosity questions suggest that she has moved through all four phases of Renninger et al.'s interest development model. Maggie's interest has been triggered (Phase 1), she has reengaged with content over time (Phase 2), and she developed her own questions and sought feedback as she pursued a unique goal (Phase 3). She has also independently engaged with the content—working outside of the club to refine her dragon designs (Phase 4).

Aurora

On a gray day in February, Aurora pulled Crayola markers from a bright pink plastic bucket and traced the outline of a head and torso—explaining the details of her drawing as she went. Seated at a table with two girls and one boy midway through Session 2, Aurora was working on a drawing of the kind of robot she wanted to build for the Boys and Girls Club. The group was asked to brainstorm how a telepresence robot might move around the environment of their Boys and Girls Club, how they would like it to interact with humans in the space, and what kinds of obstacles the robot might face. They were then asked to sketch ideas about what the robot they would build over the course of the next several weeks might look like. This was the first part of the design process—engaging participants in conversations about the constraints of the environment and their assumptions about robots.

As the two girls at the table looked on, Aurora explained, “I think she [the robot] should wear a skirt to hide her robot legs because some little kids would be freaked out to see a person walking around with robot legs…if anybody’s seen the movie iRobot, they think that the robots are going to like take control… and also, robots, like it’s a machine so people can feel like ‘oh it’s going to attack me and it’s going to hurt me.’” Here, Aurora anticipated human fears associated with robots and worked to combat these fears with the accessible and human-like design of her robot. Aurora moved on to consider how the robot would fit into the culture of this specific space, stating “on her shirt it should say ‘I love Boys and Girls Club.’” Aurora then highlighted the most important pieces of her design, explaining “As you can see here, these are like gears in her eyes. Her eyes are like gears and they have tiny cameras so like she can see but if anyone wants to know what she’s saying they can type into their computers and they’d see what she’s seeing…this needs to be like a REAL Boys and Girls Club shirt. And she has to be wearing a black skirt because some people would be freaked out by her legs. …And you’d have to change the color of the robot…to make it match her clothes” (Fig. 4). Drawing ideas for the Katie robot, Aurora attended to a variety of attributes—what Katie should wear (Boys and Girls Club t-shirt), what she should look like, and how she needed to operate given possible human needs (gears in her eyes, wheels, extending legs). In this session and those that followed, Aurora played the role of leader in her group, sharing ideas and supporting them with examples. In many of the groups she worked with, Aurora directed activity and exercised a leadership role. In this narrative, Aurora explained the reasoning for her design to other girls at her table. Though Aurora was not always behaviorally engaged in “on-task” behavior when observed on video, when she was behaviorally engaged she was also consistently socially and cognitively engaged, explaining reasoning behind her planning process and coordinating the activity of those in her group to solve the problem at hand. In a club session focused on exploring circuitry using play dough circuit kits, Aurora stated “I don’t want to work with other people!” Twelve minutes into the group’s exploration, Aurora shared responsibility for the circuit she’d created with the girl next to her, using the pronoun “we” as she requested an extra battery pack from a nearby pair of students. “We figured it out! We need it.” Aurora’s behavioral engagement waxed and waned over time—opening the door to other forms of high-quality engagement. Furthermore, her statements in support of her design can be interpreted as maintained situational interest (Phase 2 of Renninger et al.’s model). Aurora applied some of the content she has learned (e.g., that robots can help humans and that there is a fear of robots that must be addressed in design) to her explanation. She reengaged with content that may have initially triggered interest and was using it to move forward with her own ideas (Phase 3).

Fig. 4 Aurora’s robot

Amy

Amy sat with her hands folded in her lap at the far corner of a long rectangular table at the Boys and Girls Club, surrounded by the scattered orthographic drawings of her peers. The facilitator (AG) explained to the group that today they would be designing the body for the robot they would build, encouraging students to draw as many ideas as possible as she said; “Hey, you know what, there’s no failing here. When I did this I went through like twelve sheets of paper. Start again. We have plenty of paper!” This encouragement reflected the design process of engineers—emphasizing imagination, creation, and reflection as an iterative process (Resnick 2007). As the other members at the table began a furious flurry of sketching, Amy sat back in her chair and observed. When asked why she wasn’t drawing, Amy stated; “I’m not very creative.” She put marker to paper, but did not draw.

Though Amy’s hesitation to begin the activity and peripheral position observing the group may be interpreted as disengagement, Amy went on to demonstrate that she was fascinated by the process of making drawings into tangible objects. As the facilitator explained that top, front, and side view drawings can be read by a computer program and printed out with a 3D printer or cut into pieces by a laser cutter, Amy commented softly to a volunteer in the space “That’s tight. That’s really awesome.” When another volunteer in the space came over to look at what the group was doing, Amy explained; “It can make like a cardboard cut out. It's like 3D printing." Here, Amy passed on what she'd heard and expressed enthusiasm about the process. She was taking in what occurred in the group activity, though she may not have been participating in a hands-on way at this point. This kind of vicarious engagement is not often recognized in a classroom environment, but should be considered as another important kind of engagement beyond the four categories presented by Sinha et al. (2015) and may incorporate any of the other types of engagement.

In this small group setting with multiple facilitators, Amy received one-on-one attention. The facilitator in Amy's group spent time examining a 3D printed model and talking about how it might have been drawn on paper before being printed. She then showed Amy pieces of a cardboard model that was deconstructed. Amy called it "really cool" and smiled as she talked with the facilitator about how the shapes fit together to form a larger body. Still, she did not physically engage with the materials on the table. Noticing that Amy had not drawn anything, the facilitator asked her about her favorite things to do—noting that in a previous session, Amy expressed an interest in the action hero "Megaman." With a final push of encouragement, Amy drew a front, top, and side view of Megaman to be made into a prototype. This activity occurred 38 min into hour-long session 4 and was the result of a series of one-on-one interactions with facilitators and peers. In this narrative, Amy appeared cognitively and behaviorally engaged. She was watching and responding, and her comments suggested an internal planning process for the problem of drawing 3D ideas to be made into a robot prototype. By the end of the session, Amy had successfully drawn her idea for a robot body—one that would be made into a full-sized prototype weeks later. She was attending to the task (as evidenced in her comments "that's tight" and "that's really awesome") and her ability to explain the work of her peers to another person. Renninger et al. (2015) identify the need for support to engage as a learner characteristic of triggered situational interest (Phase 1 of the interest development model). Amy needed support to finally complete the task at hand, but she was able to attend to and express interest in the content. Reviewing this interaction, we ask, how might we acknowledge and design for Amy's peripheral and vicarious engagement in our curriculum—creating a space where she can move into later stages of interest development and more complex forms of engagement?

Demonstrating Understanding

To gauge what the participants in our study were taking away from the experience that integrated both personal goals and researcher-designed goals, we turned to the artifacts they created over the course of the unit, their video-recorded activity and discourse, and the narratives of their open-ended pre- and post-interviews. In the following sections, we will delve into the variety of ways the four girls we have highlighted demonstrated understanding about the engineering design process.

Throughout our robotics club, BGC members created a diverse set of robot designs that tended to focus on form, based on their personal interests. Designs created and built by the girls in the BGC included dragons, ladybugs, and softballs (see Fig. 5). Other designs could not be built because of the constraints of the laser cutter and 3D printing capabilities. Our analysis of these four girls'

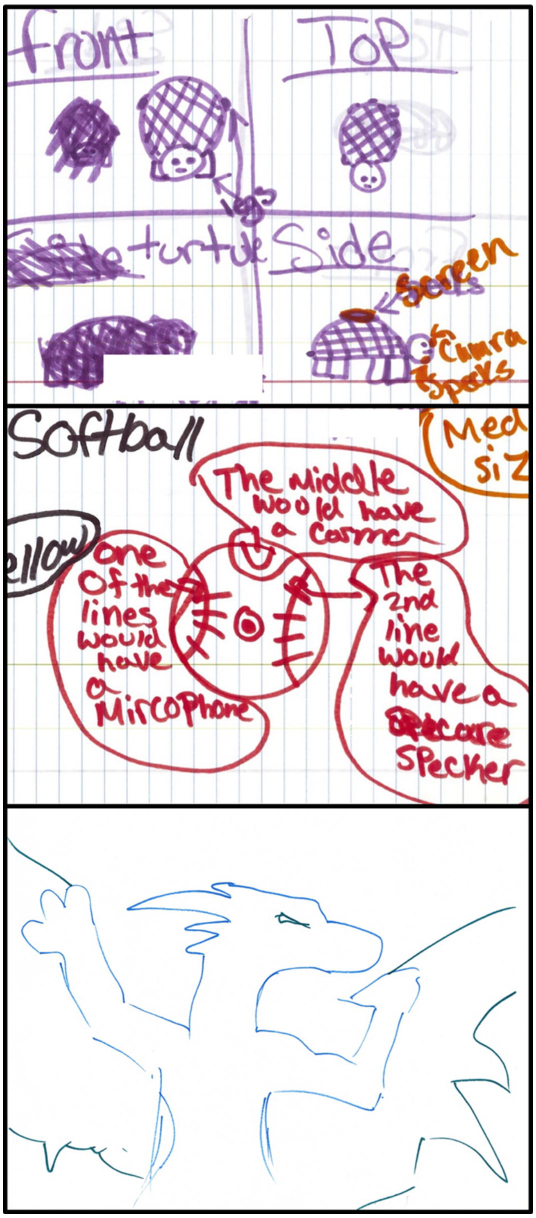

Fig. 5 Design ideas

understanding of the design process is grounded in a sociocultural perspective about learning. As the girls in our focus group interacted with materials, facilitators and each other throughout the process of building a telepresence robot, they learned by *doing*. Learning to communicate changing ideas about design and the system they were working to build together, the girls participated in a community of practice as they developed skills and mental models necessary in STEM practitioner communities (Lave and Wenger 1991). Here, we highlight critical events for each girl that could be mapped to pieces of our HCR curriculum's engineering design process (Fig. 1). In this engineering design process, learners "ask questions" to define a problem, "imagine" by brainstorming ideas, "collect information" to determine the affordances and constraints of the problem, "develop and test solutions" through iterative design, and "improve" by using feedback to structure revisions to their designs.

Carrie: Imagining New Solutions

As Carrie deconstructed and re-built her cardboard prototype, she collected information about how the pieces were numbered and how they fit together—testing possible solutions and improving them as she figured out what did and did not work. In this short episode, Carrie engaged with three parts of the design process. Though she expressed frustration along the way, her efforts led to a final tangible product. In a post-interview with Carrie, she was given the opportunity to reflect upon this experience. During the post-interview, Carrie demonstrated understanding of the design process—generating ideas about how robots might be used in her everyday life (the "imagine" piece of our design cycle), considering what information she might need to make her ideas possible (the "collecting information" piece of our design cycle), and revisiting her own experience with trial and error throughout the unit (the "develop and test ideas" piece of our design cycle).

> **Facilitator:** Alright, what is something you *didn't* like about the robots we made?
>
> **Carrie:** That they weren't tall!
>
> **Facilitator:** Ah. So maybe, if you do this again you could figure out a way to make them tall? What kind of materials do you think you would use to do that?
>
> **Carrie:** Like longer poles and stuff?
>
> **Facilitator:** Poles. Okay, maybe we could bring some poles sometime.
>
> **Carrie:** Like a pole where you could put another bigger pole on?
>
> **Facilitator**: Ah, yeah like they fit together?
>
> **Carrie**: Yeah so then the head would be able to be on that.

In this short exchange, Carrie brainstormed what materials might be used to make her vision a reality. These brief comments, guided by the facilitator, were built upon as Carrie engaged with the other components of the design process. Shortly after this exchange, Carrie anticipated obstacles in an imagined scenario and proposes possible solutions:

> **Facilitator:** How would you use a robot in your everyday life? Would you use a robot in your everyday life?
>
> **Carrie:** Yes. Because I would program her to do my chores and do my homework.
>
> **Facilitator:** What kind of chores would you have it do?
>
> **Carrie:** Well, she would have to be in like cloth so that you wouldn't electrocute her.
>
> **Facilitator:** Oh, you wouldn't want to electrocute anybody.
>
> **Carrie:** Yeah, with the dishes.

Here, Carrie considered the way that her imagined robot would interact with humans—thinking about the physical limitations humans have and how to design a robot in a way that prevents harm, and considering relations between structure (e.g., cloth) and function (avoiding electrocution). This exchange was evidence of the "imagine" piece of the design process in which participants dream up new ideas and think about how to solve a complex problem and could also be mapped to the "collect information" piece of the design process where constraints are considered and inform design.

Maggie: Collecting Information, Testing, and Improving Through Iterative Drawing

Maggie's refinement of her dragon design is further evidence of the way the design process was taken up. During sessions 5, 6, and 7, Maggie refined her original dragon idea—working outside of the Boys and Girls Club to make her imagined robot a reality. On the first day of orthographic drawing, Maggie asked to leave the room so that she could get a picture on her iPad. This image of a hand-drawn dragon (Fig. 6) was brought to the table in three consecutive sessions. After early attempts to draw the dragon in 3D, Maggie solicited the help of facilitators in the space, stating; "I can e-mail [the picture] to you guys."

Fig. 6 Maggie's dragon

In the following weeks, Maggie adjusted the scale, perspective, and details of her dragon drawing so that it could be printed with a 3D printer. Her persistence with her vision was an example of collecting information (i.e., the facilitator's reminder that the drawing needs to be drawn "to scale,"), testing new versions of the drawing, and improvement. In her post-interview, Maggie noted her orthographic drawing experience as the most memorable. When asked what she learned in robotics club that she didn't know before, Maggie replied: "It's incredibly hard to make a dragon drawing 3D." In response to a question about what they know now that they learned in robotics club, Maggie stated "I know there's like a lot of different numbers for colors when you're programming things." With this comment, Maggie articulated her own conceptual leap in programming. Though she has not articulated what a line of code looks like for "colors," Maggie has identified that there are different ways to program one piece of information. This is a step toward understanding the concept of multiple programming languages. In her statement about the difficulty of making a dragon in 3D, she identified a challenge—one that she ultimately worked through by asking questions and receiving insight from "expert" facilitators in the room. Both of these skills were acquired as Maggie moved through a design process alongside her peers.

Aurora: Testing Solutions Through Hands-On Manipulation

Like Maggie, Aurora engaged in an iterative design process. Her testing and re-testing of solutions were most visible during Session 3, which featured "squishy circuits"—circuits powered by small battery packs that use play dough as a conductor. The activity was introduced near the beginning of the unit when the research team recognized that many members lacked prior knowledge and experience with building circuits. As occurred in the brainstorming drawing activity, Aurora led her group in the squishy circuits activity—physically manipulating the materials on the table from the beginning of the session until she left the space. The members in this session were given very little direct guidance, consistent with a problem-based approach. Rather, they were asked to create a working circuit using the materials on the table and to find a way to prove that it was functioning. Members solicited necessary information from facilitators by asking questions and seeking out resources.

Throughout the session, Aurora provided spoken suggestions and extended the problem beyond its initial parameters. Locating a motor amidst the collection of parts on the table, Aurora hooked it up to her developing circuit. When it didn't work, she asked a facilitator to check if she'd connected everything correctly. She had, and the facilitator mentioned that the motors take more power to operate. Immediately, Aurora called out to the group; "Okay, does anyone have another battery? Can I see another battery?" A facilitator replied, "You don't want to use that battery?" and Aurora explained "No I want to use TWO batteries." Aurora then gained access to another battery, and the members around her connected the two batteries to the circuit. In this instance, a new problem was introduced, and Aurora brainstormed its solution and jumpstarted the testing of her solution. About 10 min later, after the motor problem was explored, Aurora devised a new circuitry problem—working to see how many LED lights could be added to the circuit before it was overloaded. Again, she tested and refined—experimenting with LED placement and adding different components to the circuit. She kept her hands-on materials for the duration of this problem-solving process—working alongside several group members and searching for new challenges to change the problem. When the group came across a pressure sensor, Aurora began a new process of trial and error—asking questions as she went. In doing so, Aurora participated in the first several pieces of the design process (defining the problem, asking questions, brainstorming, and collecting information.)

> **Aurora**: Do we bend [the pressure sensors? (*Aurora and BGC member Maureen both put their hands on the sensors and try to separate legs to put into their two balls of play dough*)
>
> **Karl** [Facilitator]: They have pin strips
>
> **Aurora**: Pin strips?
>
> **Karl:** Yes, pin strips.
>
> **Aurora**: Wait! I have an idea. If you take all of the stuff out and put it back in

> **Maureen:** Oh and then you can stick it in…
>
> (*Maureen and Aurora begin rolling play dough out into long strips. They have disassembled the circuit and are working to piece it back together so that it can accommodate the pressure sensor*)
>
> **Aurora:** Ta-da! *(Maureen and Aurora have created a circle of play dough using a green rolled tube of play dough and a black rolled tube. They have the pressure sensor connecting the pieces at one point, and an LED at another so that the play dough pieces do not touch. The LED lit up.)*

In this interaction, Aurora successfully asked a question to better define the problem, presented a possible solution ("Wait! I have an idea…"), and then tested the solution until the desired result (a completed circuit) was achieved.

Amy: Asking Questions and Collecting Information

For Amy, getting past the early work of brainstorming and imagining within the design process took time. In the moments highlighted in Amy's orthographic drawing session, she sat back and observed—taking in the work of her peers through vicarious engagement and considering the longer-term trajectory of the drawings being created (i.e., paper to computer to 3D printer). Near the end of the session 5, Amy was guided through the brainstorming process as a facilitator asked her about her interests. This short burst of scaffolding was followed by Amy's leap into the imagining and "collecting information" pieces of the design process as she drew her "Megaman" character and considered what must happen to make him 3D and translatable to a prototype. Because Amy did not engage physically or verbally in early sessions, it was more difficult to track her progress in the unit using video data. However, her vicarious engagement, watching her peers before her eventual participation in the activity, is an aspect of engagement that warrants further research.

In these highlighted moments from the four girls' participation in robotics club activities, we saw a variety of ways they engaged with the five-part design process. In formal education environments, it is often hands-on engagement with trial and error and iterative testing that is privileged as evidence of the design process (as we saw with Aurora's manipulation of materials). However, we must consider the value of less overt representations of the design process—including the evolution of leadership and refinement of a single drawing (as demonstrated by Maggie) and the kind of thoughtful responses to questions about future scenarios, imagined possibilities, and material constraints we saw with Amy and Carrie.

Discussion

Successes, Challenges, and Insights

Our sessions in the BGC had the ambitious goals of helping youth develop engineering and design capabilities via authentic problems in human-centered robotics. One of our main foci when planning these sessions was scaffolding a design task to facilitate the appropriation of these design skills, technical knowledge, and STEM understanding, a recurring challenge in inquiry-based design tasks (Puntambekar and Kolodner 2005). One tension in achieving these goals was more specific to our context—that the BGC members come from a variety of backgrounds and attend the club on an ad hoc basis. Especially among the participating middle and high school students, attendance at the club was entirely optional and youth could leave at any time. A final challenge was related to the limited prior knowledge and experience with robots that BGC members possessed. Many of the BGC members had never interacted with non-toy robots or some of the tools we used before participating in our program. Several youth, including focus BGC member Aurora, used movies as their sole source of prior knowledge about robots. For these reasons and others, there were many logistical challenges to our intervention development that will need to be addressed in successive intervention design. Perhaps our largest challenge was continuity within knowledge building due to attrition and infrequent participation in the activities. Despite the fairly regular attendance of the four girls we focused on within our analysis, most students did not attend every week, so building on previous activities was very difficult. As a result, our program included repetition and we were less able to explore technical ideas in depth due to members' limited background knowledge. We later adjusted several logistical aspects of the robotics club and curriculum to better afford continuity and deeper disciplinary content development. In the next iteration at the BGC, we had the club on a day with more consistent attendance and group structure. In addition, our distributed interdisciplinary team developed further resources to support technical aspects of design. These resources are tools and artifacts that embody some of the technical knowledge, such as a widget catalog where youth can refer to a curated collection of technical information in the context of identifying parts for their robots.

Despite these challenges, our analyses suggest that the results of this intervention are promising in terms of developing interest in HCR for participants with varied interests and learning styles, engagement with an iterative engineering design process, a major focus of the NGSS for these grade levels, and imagining innovative capabilities for robots' interaction with people. Though we look forward to including more rich disciplinary content within future interventions, our exploratory program did help our students to develop some insight about the challenges of design (i.e., Maggie's reflections about the constraints of 3D printing upon the creation of her complex dragon drawing). We have also found that engagement surrounding the design process emerged, particularly as it relates to how robots could be better adapted to facilitate their inclusion in people's lives. A few students shared ideas in their post-interviews about uses for telepresence robots related to the needs of their teachers, friends, and selves.

In terms of our successes in this exploratory study, forty-six youth were exposed to new technical tools and socio-technical ideas through our program. Furthermore, students were given opportunities to explore new technology and simple programming, and their responses to "what robots are" also shifted. These exploratory case study results suggest that approaching engineering and design knowledge and skill development from a human-centered perspective benefits students from multiple standpoints. However, our inclusion of authentic, ill-structured problems must continue to delve deeper into design practices and disciplinary STEM knowledge, especially as we incorporate increasingly technical activities into the curriculum. To address this challenge, we return to our focus on engagement and to sparking student interests. We strive to provide a learning context where participants are able to construct STEM skills and knowledge as they collectively participate in a community of practice. For this to occur, interest must be triggered and maintained, while supporting multiple forms of engagement (e.g., Renninger et al. 2015).

Promoting Engagement

The first iteration of this project demonstrated that human-centered robotics is a promising approach to getting girls interested and engaged in STEM practices. For the four focus participants highlighted here, we have identified critical events where learners were behaviorally, socially, cognitively, and conceptually to consequentially engaged (Sinha et al. 2015). Our findings have also identified critical moments of engagement for one focus participant, Amy, that fall outside of these four categories—a form of engagement we have labeled as "vicarious." In the results reported here, we clearly saw the girls' behavioral engagement as they completed activities and remained on task. But we also have evidence that they went beyond that to apply newly developed skills and knowledge to situations at hand. For example, although her level of conceptual-to-consequential engagement was not as deep as it could have been with more consistent and sustained work in HCR, Maggie did consider how the drawing and constraints of the 3D printer were related. Thus, she was thinking about the consequences of her potential actions indicating both cognitive and conceptual-to-consequential engagement. Aurora showed evidence of social engagement in the ways that she took on a leadership role. Amy acted as a peripheral participant as she observed her peers and shared information with an observer. In terms of interest, we've highlighted critical moments in which all four participants demonstrate one or more phases of interest development in Renninger et al.'s (2015) model. For all four participants, there is evidence that interest was triggered and (for three of the girls) maintained. Carrie, Aurora, and Maggie all asked questions and worked with feedback from peers and facilitators as they pursued goals. These events suggest later phases of interest development.

The ways that the girls demonstrated their levels of interest and engagement were nuanced and multidimensional. These representations of interest and engagement are important targets for future research and finer grained analysis moving forward. Though we were ultimately successful in getting students, particularly girls, engaged with STEM tools and an engineering design process, we have more work to do as we address STEM content. Moving forward, we must promote deeper engagement with STEM concepts and skills while still allowing the kind of personalization and autonomy that allowed students to follow their interests in an informal learning environment. As we integrate more STEM content, we must not lose sight of the importance of providing an environment that not only sparks interest, but that supports its development over time. This requires recognizing learners' ideas as valuable, providing meaningful feedback as learners experiment with design ideas, constructively challenging ideas, and fostering a community of practice that allows learners to do these things for each other (Renninger et al. 2015). As Renninger et al. argue, students' interest depends on their ability to engage with the *processes* of STEM—not just the content. Therefore, future research should explore how facilitators and researchers might acknowledge and design for behavioral, social, cognitive, conceptual-to-consequential, and vicarious engagement in scientific processes—including the engineering design process. Future research should also explore the bridge between interest triggered in out-of-school settings and reengaged in classroom contexts. Further iterations of the Human-centered Robotics Telepresence Challenge will help us to better understand the relationship between participation in an engineering design process, forms of engagement, and developing interest—setting the stage for longer-term and more comprehensive studies informing policy that brings underrepresented populations into the STEM pipeline in new ways.

An important area for future research is better theorizing how these kinds of interventions contribute to engagement and a trajectory of interest for populations that are not well represented in STEM. We conjecture that several key factors in our design contributed to heightened interest and engagement for the girls in this study. First, the social nature of HCR was one of the key factors in design and creating that social hook was important for getting girls interested (Hill et al. 2010). Second, the product that the students were working toward was tangible—in ways that blend the technical and creative and allowed the girls to tinker with a variety of tools and materials (Swarat et al. 2012). In our continuing collaborative research with Alaska, we hope to better understand how these factors play into motivation and interest development for other underrepresented populations as we refine our problem-based approach to human-centered robotics as a context for engaging with STEM knowledge, skills, and practices. As we develop a more extensive set of curricular materials and a theoretical understanding of the mechanisms behind engagement and continuing interest in STEM learning in formal and informal environments, we will be able to extend our approach to more classrooms and also to inform education policy in ways that diversify the STEM pipeline.

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