Robot Diaries: Broadening Participation in the Computer Science Pipeline through Social Technical Exploration

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Abstract

In this paper we describe the results of a series of robotics workshops for secondary school girls. Specifically we show that, in a new pilot program, a group of eight girls was engaged by the workshop and gained technical knowledge over the course of a three-month workshop. The Robot Diaries program is unique in that it creates a social narrative approach to robotics education. The robotic technology becomes a tool for expression and communication rather than the sole focus of the workshop.

Introduction

As technological interaction and electronics artifacts integrate ever more tightly in our lives, it is disquieting to note that engineering enrollments continue to drop throughout the United States (Vegso 2006). Even more alarming is that gender diversity continues to drop in fields such as computer science, whereas virtually all science and business fields show significant improvement in terms of female participation (Vegso 2005).

One popular movement to stem the current tide evolves out of a recognition that the pipeline is both the source of today's trends and the strategic place for leveraging real change: improve the technology literacy of students at the primary and secondary level, and the statistics of the subsequent decade may finally turn around (Adams 2007; Arsenault et al. 2005; Cannon et al. 2007; Doerschuk et al. 2007; Frost 2007; Hylton, Otoupal 2005; Morris, Lee 2004).

Robotics has served as a popular vehicle for such pipeline-based technology literacy programs because of its ability to attract and inspire the imagination of students who are often unmotivated by conventional classroom curricula (Druin, Hendler 2000). National contests include US First, BEST and Botball; each creates an after-school locus of activity where students work in teams for a concentrated one to two month window of time to create robotic entrants to a large-scale, high-octane contest (BEST Robotics 2007; Botball 2007; US First 2007).

These programs have jointly engaged more than 50,000 students, and there is no doubt that some of the students have found the contest-driven problem-solving experience to be transformative. However these existing pipeline-focused technology literacy programs share a number of features that may limit participant diversity: they are short-term, high-intensity, competition-driven and technology focused.

We propose a complementary class of activities that we believe can engage and retain the participation of secondary level students who will not be attracted to the currently available pipeline interventions. Our aim is to improve engagement of a more *diverse* student population with technology and engineering, and to demonstrate characteristics of such a program that can be broadly disseminated.

Our point of departure therefore is to design a curriculum that is not driven by competitive and deadline-driven technical problem-solving, but by strong social narrative along a thread that has extant value and meaning to diverse students. Technology is no longer the prime motivator, but an enabler for emotional and social communication in the program that we call Robot Diaries.

A robot diary is a customizable robot designed to serve as a means of expression for its creator. Using light, sound, and movement, users can choreograph their robot diaries to express emotions. They can then share these expressions with their friends in the Robot Diaries community. Ultimately, the robot diary provides a unique means of exploring, expressing, and sharing emotions, ideas and thoughts while promoting technological literacy and informal learning.

Robot Diaries Approach

Our long term goal is to create an exciting activity and supporting technology to engage students who are not interested in existing technology education programs. In order to reach this goal we developed a program which involved middle school girls simultaneously as design partners and students.

Students as Design Partners. We strongly believe that the participation of the end-users of any novel educational activity is necessary throughout the design of that activity, and so we invited groups of girls to work with us in a number of workshops. These workshops had a dual nature. They supported an iterative design cycle in which we could test software, curricular exercises, and the attractiveness of our technology designs with girls. They also were meant to serve as experiences which would both engender learning and motivate our design partners to further study in science, technology, engineering and math (STEM) fields. Specifically, our goals in conducting these workshops were:

- **Appropriate Exercises.** Our program requires students to understand advanced technical concepts such as programming, prototyping, and connecting hardware. We sought to develop exercises which introduced these concepts in a non-threatening way, while providing the appropriate scaffolding to allow students to quickly use the concepts creatively.
- **Software Development.** As part of our program, we needed software interfaces to allow for iconic programming of robots, as well as a messaging client which allows the sending of *roboticons*, or expressive sequences of robot motions.
- **Attractive Technology Framework.** Determining the kit of parts from which students can build robots is crucial, as this kit describes the space of possible robot designs. Through the workshops we hoped to gain an understanding of what to place and what not to place in the kit, as well as an understanding of how much of the initial robot design should be provided.
- **Student Development.** We wished to ensure that our student design partners got as much or more out of these activities as we did, and so one of our goals was to engender student growth through this experience. Specifically, we wanted students to leave the workshop understanding new technical concepts, with improved feelings of self-efficacy and confidence with regards to technology, and motivated to continue studying STEM topics.
- **Evaluation Scheme.** In order to measure student development, we needed to develop a novel evaluation scheme to determine if students gain motivation, confidence, and content knowledge through participation in the workshops.

Project Details

During the summer and fall of 2006, we conducted a series of 17 participatory design workshops. Each workshop taught our team important lessons about working with middle school girls, markedly affected the evolution of our curriculum, and brought us closer to a final technology and curricular design that was appealing to the girls.

Curriculum Progression

We designed the Robot Diaries curriculum to follow an arc from simple to complex, familiar to new. We followed this guideline for the introduction of individual components, throughout the course of a workshop series, and for ourselves as we progressed from one series of workshops to another. We introduced new robotic components with a brief example followed by a free exploration time for the students. We then presented the students with a small design challenge usually to use the component in an expressive manor. Later the students combined the parts to create whole robots that could express emotions and communicate.

We learned from the girls as well. In the early workshops we focused on mechanical design, and learned which design challenges worked as effective learning experiences and creative inspiration. We also learned what materials worked well for ease of building, expressive features, and fun robot designs. Then we were able to introduce more complex technology and more complex design challenges in later workshops as well as progress beyond mechanical design and introduce aspects of robot programming. Brief outlines of the curriculum are included with the relevant sections below.

Materials and Technology

We chose to use craft materials to construct the robot forms because these materials are familiar and approachable. We provided the students with cardboard and foam board to build the structure of their robots. They used markers, felt, beads, bells and other items from a local craft store to transform the plain cardboard and give the robots personality (Figure 1).

Beneath the craft materials we used a variety of technical components to move and automate the robots. We began with simple circuits which the students assembled from AA battery packs, alligator clips and switches. We taught them how to operate motors and light emitting diodes (LEDs) using this direct method. The students used radio transmitters designed for model airplanes to operate servo motors.

Once they understood how the various components functioned and how they could use them in expressive robots, we introduced the Qwerk controller board (Nourbakhsh et al. 2006). The Qwerk replaced the alligator clips and radio transmitters and enabled the students to write simple programs to control their robot creations.

Figure 1. Students building robots from craft materials.

Summer Workshop Series

During Summer 2006 we held a series of six two-hour long workshops at a local Public Library. Two to seven girls attended each workshop, with the same three girls attending almost every session. The primary purpose of the summer workshops was to engage a small group of girls in a series of participatory design activities that would lead toward the development of a working prototype of a "Robot Diary" for use in the more structured Fall 2006 study. The summer workshops allowed the research team to work closely with a group of representative girls over an extended period of time in direct, "hands-on" cooperative exploration of robotic technology. This, in turn, provided three important opportunities: a) to experiment with a variety of participatory design activities and discover which were most effective and compelling for middle-school girls, b) to develop research themes and observational measures, and c) to progress the concept (both form and function) of a "Robot Diary". See Figure 2 for a brief outline of the summer curriculum. A more in-depth description of the summer workshops can be found at (Nourbakhsh et al. 2007a, Nourbakhsh et al. 2007b).

Session 1: Introduction.
Session 2: Expressive motion. Motors, servos, basic circuits. Brainstorm robot ideas.
Session 3: Expressive motion. Motors, servos, basic circuits. Generate and prototype initial robot ideas.
Session 4: Sound, expression, and emotion. Mechanisms for physically producing sound.
Session 5: Light for expression. Introduce LEDs and means of altering light.
Session 6: Build final designs and present to parents.

Figure 2. Summer 2006 curriculum outline.

Single-Day Workshops

We distilled the activities developed during the summer for two one-day workshops in the early fall. We held these workshops in collaboration with C-MITES, a university affiliated organization that provides educational programming for academically talented elementary and secondary school students. By advertising through C-MITES, we obtained significantly higher attendance numbers than over the summer – 15 girls attended the first workshop and 12 attended the second. These workshops served as a chance to observe a larger audience of girls using craft materials to create communicative robots.

Fall Workshop Series

Our most extensive workshop was held from late September 2006 to mid January 2007 with a group of 8 girls from a private, university-affiliated middle school. Sessions were two hours long, and held immediately after school. We began the workshop in much the same way as our summer workshops, gradually introducing the students to important robotic technologies over the first four sessions (Figure 3). A major difference was the early introduction of the Qwerk, a controller which allows the girls to create programs which actuate motors, servos, and LEDs. In addition, we began to introduce the girls to chat software designed by our group that was later used to control the robots. The early introduction of the software was essential to easing the girls into eventually creating programs for their robots. The chat software also enabled the students and researchers to communicate as part of a private, informal, online community between workshop sessions.

Once students had the foundational robotics knowledge to make cogent design decisions, we began a series of participatory design exercises which yielded a final robot design in session six. This design was selected by the girls from a set of five after a group discussion. The girls then each constructed a variant on the design, with the same underlying morphology, but widely varying cosmetic touches. Once the final robots were constructed, the girls took their robots home each week to experiment with programming the robots in a novel software framework which was refined weekly based on the students' feedback.

At the conclusion of the workshop, we had successfully created a programming interface that was usable for the students, proved the robustness of the robot kit and its installation in the homes of eight middle school girls, and gathered extensive data on the effects of the workshop on the girls along several metrics. The remainder of this paper will focus on the outcomes of the fall workshop series.

Session 1: Introduction.
Session 2: Motors, servos, basic circuits. Generate ideas for expressive robot components.
Session 3: Introduce LEDs. Prototype various forms of communicative robots building on previous ideas.
Session 4: Introduction to Qwerks, programming software, and sensors. Select robot design.
Session 5: Build individual robots based on selected design. Review programming. Bring robots home.
Session 6: Introduce robot messaging software. Make changes or repairs to robots after one week at home.
Session 7: Add speakers to robots. Get the girls' ideas on design changes for the messaging software.
Session 8: View messaging software changes based on girls' ideas. Girls create a web site to document their experiences.
Session 9: Demonstrate robots and software to parents. Show parents the completed web site.

Figure 3. Fall 2006 curriculum outline.

Evaluation

The Robot Diaries research agenda encompassed two main objectives. First, we wanted to ensure that our approach of using communicative robots was an effective way to engage our target audience. Our second objective was to document participants' knowledge gains during the program.

Methodology

Eight girls participated in the fall Robot Diaries workshop. Participants ranged in age from 11 to 13 years old. All participants attended the same private, university-affiliated middle school where the workshops were held.

Our research utilizes methods drawn from the learning sciences and interaction design. Collected data includes interviews with participants and their parents, written surveys, workshop observations, home visits, and electronic activity logs. The analyses reported in this paper will focus primarily on the participant and parent interviews, and activity logs.

Participant Interviews. Participants were interviewed individually at the beginning of the workshop (pre), and again at the end of the workshop (post). Interviews included questions about relevant declarative knowledge (e.g., identify and provide a definition for relevant parts, such as sensors and servos) and designed systems (e.g., examine an electronic toy and describe its components/how it works). Participants were also asked to imagine how they might build a new system (an alarm) using a fixed set of components (a battery pack, alligator clips, switch, LED, servo, and sensor). Pre-interviews ranged in length from 16 to 32 minutes. Post-interviews ranged in length from 21 to 45 minutes.

Parent Interviews. Parents were interviewed in their homes at the beginning of the workshop, and again after the workshop was completed. In the pre-interview, parents were asked about their child's previous experience with robotics and related technologies, and about the family's activities related to science and technology. Post-interviews mainly focused on parents' impressions of the workshop, and what their child gained from participation.

Capturing a New Audience

Parent interviews revealed that children in the workshop group were generally interested in using and/or exploring technology. A subset had attempted to participate in other technology workshops, but these experiences were not always positive. One parent described her daughter's experience in the following ways:

> She has been fascinated by robotics for a long time… every time we sign up for one of those [technology] camps… we'll get there on the first day and it's all obnoxious little boys and she just goes, 'never mind'

Another parent provided the following explanation for why she thought her daughter would enjoy Robot Diaries:

> The problem with some of those [technology workshops] was that there were often more boys there than girls, and so she didn't feel quite as comfortable. So that's why this [Robot Diaries] looked more interesting.

As comments from this small sample of parents suggest, existing resources may not be fully serving the needs of middle school girls interested in technology exploration. These parents point to the male-dominated culture of these activities as being particularly problematic for their daughters. One of the girls echoed this sentiment when she commented that her school's LEGO League team, which she had joined briefly, was "more geared towards boys." However, three of the girls enjoyed their participation in other girls-only technology workshops run by the university community. This suggests that girls-only robotics programs, such as Robot Diaries, may serve an important role in bringing robotics and technology exploration to a new audience.

Engagement and Learning

An important question for Robot Diaries is whether participants found the 'social narrative' approach to robotics engaging. A quick look at the robots created during the workshop (Figure 4) suggests that most of the participants became engaged with their robots in a narrative way. Nearly all of the participants personalized their robots through decoration, and a few created additional narrative elements (such as accessories for the robot). One participant created a back-story to explain her robot's appearance:

> Dear old elderly professor Bob suffered from a head injury when he ran into an Eskimo… so now he has a band-aid on his head. And he's a professor so he has to dress up. The tie. And he has certain vision problems so he wears a 'monocule' [monocle].

Additionally, six out of the eight participants named their robots.

Figure 4. Robots created during the fall workshop series.

An examination of the electronic activity logs showed that all eight students participated to some degree in the Robot Diaries online community from home. Each girl posted messages to the custom messaging program used during the workshop. Half of the students posted roboticons to share with the Robot Diaries community. An example of one such roboticon was a program expressing sadness. The robot's eyes were lit by green LEDs as the robot's arms rose to cover the eyes and then slowly lowered. Network problems contributed to at least some of the remaining girls' inability to share roboticons from home.

Learning gains were measured through analysis of pre- and post-workshop interviews with participants. Two main types of knowledge were assessed in the interviews: declarative knowledge and knowledge of technical systems.

The majority of participants showed gains in declarative knowledge. On average, participants were able to identify and correctly label 4 (SD = 1.31) out of six robotic components at pre-test and 5.9 (SD = 0.35) at post-test. A paired t-test indicates this increase is statistically significant, $t(7) = -4.26$, $p < 0.05$. Additionally, there was a significant increase in the comprehensiveness and accuracy of participants' descriptions of a sensor and electric motor, as indicated by Wilcoxon matched-pairs signed-ranks tests. Six out of eight participants showed improvement in their descriptions of a sensor at post-test (the other two participants were already knowledgeable at the start of the workshop), $z = -2.27$, $p < 0.05$. Seven out of eight participants showed improvement in their descriptions of an electric motor, $z = -2.43$, $p < 0.05$.

The American Association for the Advancement of Science (AAAS) recognizes knowledge of technical systems as an important component of scientific literacy for children in grades 6 through 8. The following benchmark is included in their Atlas of Scientific Literacy (AAAS 2007, p. 57):

> Analyze simple mechanical devices and describe what the various parts are for; estimate what the effect of making a change in one part of a device would have on the device as a whole

We assessed knowledge of technical systems in two ways. First, we presented participants with an electronic toy (a Furby, a Meowchi, or an iDog), and asked them to explain what parts were inside the toy, and how it worked[1]. At post-test, all seven children were able to identify parts from the workshop (e.g., servos or LED's) in the electronic toys. Additionally, six out of seven children were able to provide more sophisticated explanations of how the toy worked at post-test. The increase in sophistication of explanation was significant, $z = -2.25$, $p < 0.05$.

Participants were also presented with a set of components (battery pack, sensor, servo motor, switch, LED, alligator clips), and asked to describe how they could build an alarm system with these components[2]. Responses were coded for the number of connections (indicating the complexity of the system) and number of explanations (indicating an ability to describe the function of individual parts or groups of parts). The number of explanations provided for the alarm systems at post test increased for four of the participants, and decreased for two (one showed no change). The increase was not statistically significant.

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[1] Results for this question are out of 7; an electronic toy was not available during one post interview.

[2] One participant was not asked this question, so results are out of 7.

There was little change in the number of connections present in alarm systems at post-test. Future research will examine the impact of participants' prior knowledge and experience with robotics on their performance in this task.

Conclusions and Next Steps

Robot Diaries workshops provide an opportunity for middle school girls to engage in robotics and technology explorations in a unique way. Data collected during this small pilot study suggest that this approach has great potential. The eight girls enrolled in the fall workshop were engaged by the social narrative approach to robotics, and actively participated in the community formed by the workshop. Participants also gained valuable technical knowledge. Future data analysis will focus on the ways in which prior experience impacted participation in the workshop and community.

In the future, we hope to see community groups hosting alternative technology experiences for students in this age group. We are currently working on a stand-alone version of our Robot Diaries curriculum, which will include a training manual, lesson plans, and specific lists of off-the-shelf parts needed to conduct the workshops.

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