Learning while Teaching Robotics

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Abstract

This paper outlines a mentoring experience in which undergraduate students majoring in Computer Science spent their summer teaching robotics to high school students in Harlem. We describe two programs in which we worked with undergraduates to develop and implement robotics curriculum. Then we report on a valuable and often overlooked piece of the project — the learning experience of the undergraduate mentors.

Introduction

Summer 2003 began with the following story:

Once upon a time, you had to be an engineer to do robotics — a real engineer with an advanced degree and a big lab filled with computers and heavy machining equipment. But today, you only have to be an eight-year-old child with a PC and a penchant for playing with LEGO. The LEGO Mindstorms robot kits are showing up in classrooms all over the world, where creative instructors are using them to teach a myriad of science topics.

But what about mathematics? Our research has shown that even students who interact regularly with robotics have not made the connection between the concrete engineering concepts they are now comfortable with and the abstract mathematical concepts from their high school classrooms (Sklar, Eguchi, & Johnson 2002). Mathematics at the high school level is typically taught from a textbook, in a lecture class. High-level concepts are presented and students are given exercises on paper to practice the mechanics of proofs and learn how to manipulate formulas. Girls begin to lose interest in math at this age. The challenge before us is to engage students in mathematics classrooms, where time is tight and curriculum is frequently geared toward standardized testing.

Research in technology education has indicated that student-centered learning environments supporting design (Martin 1996; Lepper & Henderlong 2000), constructionism (Piaget 1972; Papert 1980; 1991) and teamwork (Gardner 1983) generate the strongest outcomes. The use of robotics as a hands-on educational medium incorporates all of these aspects. As well, students simply find robots exciting (Miglino, Lund, & Cardaci 1999; Sklar, Johnson, & Lund 2000; Sklar, Eguchi, & Johnson 2002). Thus we were motivated to take advantage of this excitement and find a way to use the concrete, motivating medium of *educational robotics*[1] as a vehicle for demonstrating the abstract concepts of high school mathematics curriculum.

The summer ended with two results: first, the creation of educational robotics materials geared toward high school students, tested in two inner-city environments by a population of approximately 50 high school students; and second, the surprising learning and growth experience on the part of the mentors. Here, we describe both the materials developed as well as the lessons learned by the teachers — five undergraduate *mentors*.

Background

This past summer (July–August, 2003), we were given an opportunity to integrate a robotics component into two summer programs for Harlem high school students (see figure 1). In this central Harlem neighborhood of Manhattan, New York City, at least 51% of all residents are from low and moderate income households (NYC-DCP 2003) and 67% of residents are of African-American descent and 20% are Hispanic (NYC-DHMH 2003). The first program was the Science and Technology Entry Program (STEP) at Barnard College[2], a 5-week program for local high school students where they attend classes in mathematics and science. The second program was at a Harlem community center called "Playing2Win" (P2W)[3]. STEP ran all day, 4 days per week, for 5 weeks. P2W ran all day, 5 days per week, for 6 weeks.

Through a CRA-W Distributed Mentorship Award, we funded two undergraduate female students to work with us to develop the curriculum and implement it at STEP. The curricular focus was to introduce students to robotics and programming, attempt to foster an interest in technology and demonstrate how mathematics is used in a practical, hands-

[1]We use the term *educational robotics* to refer to the use of robots as a vehicle for teaching subjects other than specifically robotics.

[2]Barnard is the women's college of Columbia University, located on the same campus in New York City.

[3]`http://www.playing2win.org`

Figure 1: Participants in the summer programs.

on setting — while still having fun. Playing2Win funded three additional undergraduates (two males and one female) to implement the same curriculum.

Overall, approximately 50 high school students participated in this project. We conducted a pilot study, examining the learning experiences of the high school students, in an attempt to see how their interest in technology changed during the course of the summer and if any improvement in their problem solving skills was evident. This type of study is frequently conducted, focusing on the students who are the subjects of the new curriculum.

However, as the summer unfolded, we began to realize that we were overlooking a tremendous learning opportunity by studying the *mentors*, the undergraduates who were developing and delivering the curriculum. What follows is our evaluation and assessment of the undergraduates' experiences, obtained through observation and interviews with these mentors at the end of the summer. Note that for the remainder of this article, we use the term "mentors" to refer to the undergraduates and the term "students" to refer to the high school students who attended the summer programs.

We begin by outlining the curriculum developed, to illustrate the types of lessons the mentors were implementing. Since the focus of this paper is on the mentors' experiences, rather than the curriculum developed, this description is brief. Complete details of the lessons can be found on the web site referenced at the end of the paper.

Curriculum

The curriculum developed for the summer programs is centered around LEGO Mindstorms robotic kits (see figure 2) and the RoboLab graphic programming environment (see figure 3). The assumption is that the students have no prior experience programming or building robots.

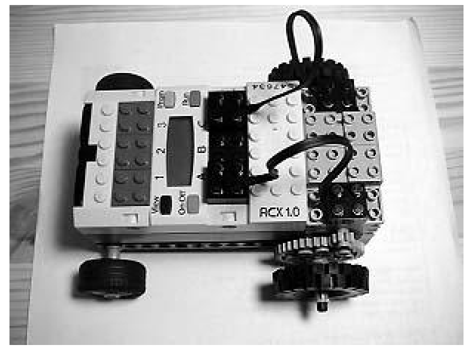

Figure 2: LEGO Mindtsorms Robot kit.

A sequence of seven basic lessons in robotics were created:

- Basic Construction
- Basic Programming
- Touch Sensor
- If Structures
- Loop Structures
- Light Sensors
- Advanced Programming

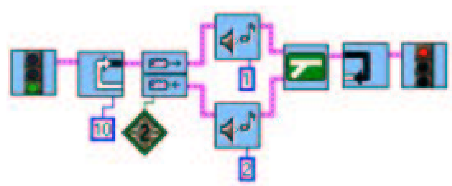

Figure 3: RoboLab programming environment.

In the first two lessons (Basic Construction and Basic Programming), students were given a model robot and sample programs to copy. We found that giving them a physical model to emulate was more educational than providing the students with step-by-step building plans to follow. Similarly, the students seemed to have an easier time learning how to program by starting with working code, testing its limitations, modifying it and testing again.

Then, with each subsequent lesson, the students were given a *challenge* — a task to perform given the new material they were presented with that day. For example, with the Light Sensor lesson, students were given the following specification: "If the robot begins on a black area, then move forward; but if the robot begins in a white area, then go backwards. The robot shouldn't go forwards or backwards forever." With each lesson, at least one of the challenges included the use of sound. The RoboLab programming environment has a nice and simple interface for writing "music" for the robots. We observed that this aspect seemed to be particularly engaging for the female students.

Following the Advanced Programming lesson, specific lessons that demonstrate high school math and physics concepts using the robots were developed. For example:

- Discrete vs Continuous Systems
- Geometry
- Circumference
- Algebra

These lessons let students explore the scope of the physical robots while experimenting with basic principles.

Experience

The bulk of the robotics curriculum was developed by two female undergraduate students majoring in Computer Science. Both entered their third year in college in the subsequent fall term (i.e., after the summer experience was over). These two students implemented the material at STEP. Three other undergraduates — two male and one female — all entering their fourth year in college and all majoring in Computer Science — delivered the same material at Playing2Win. Four of the undergraduates are students at Columbia University; the fifth is a student at Oregon State University.

There were about 12 students in each of two classes in STEP. At Playing2Win, there were approximately 20 students in each of two classes. In both programs, adult teaching staff was present to help the undergraduates by providing extra pairs of hands and to intervene if and when discipline problems might occur. The students in both programs were self-selected — i.e., participation was voluntary, though any parental pressure exerted on the students to attend is an unknown factor. Both programs were co-ed, and most students were in the first two years of high school, ranging in age from 14 to 16 years. The vast majority of participants in both groups were minorities, more than 50% were female — altogether, the participants were mostly from groups typically disenfranchised from engineering subjects.

The two STEP classes met four days per week, for 90 minutes in each session. The two Playing2Win classes met twice per week, for 2 hours per session.

At the conclusion of the summer, we interviewed all of the undergraduates about their experiences, focusing on their teaching interests and abilities and on their personal impressions of the project.

Two of the undergraduate mentors stated that they had had previous teaching experience working with students of their own age; however, none of them had experience teaching younger students. None of the undergraduate mentors received any pedagogical instruction prior to the program. Statements from all of them indicated that they learned various pedagogical strategies through their summer workshop experience. The pedagogical strategies they learned included strategies of building rapport and sound relationships with students, balancing their authority with close and friendly relationships with students, helping students to become engaged in their activities and providing useful support to enhance the students' learning.

Because of the characteristic of these summer programs, the attendance of the students was not constant (i.e., absenteeism was an issue). The undergraduates had difficulty dealing with the diverse levels of students' knowledge and skills coming into the program, exacerbated by the attendance problem, and they found this to be frustrating. However, they came up with their own strategies to deal with the situation and keep the activities going. For example, they decided to place in one group all the students who were not grasping certain concepts.

They quickly discovered that the ratio of mentors to students was crucial. If there were too many students per mentor, then the students became unruly and the lesson fell apart. But if there were too few students per mentor, then the students used the mentor as a crutch and did not learn to do things for themselves.

One of the most important lessons learned by the mentors was "flexibility." There were significant cultural differences between the mentors and the Harlem students, particularly for the mentors who did not grow up in an urban environment. In the beginning, it was challenging for the mentors to understand the students: how they reacted and why they reacted in various ways. But, gradually toward the end of the program, the mentors learned how to be flexible and meet the needs of the variety of students they were facing.

For all five undergraduates, the experience was positive. They gained confidence in themselves, their teaching abilities and their presentation skills. They also learned about themselves and enjoyed teaching, as one of the male mentors remarked: "I learned a lot about teaching, patience, classroom dynamics. It's all really interesting. I learned that I get really hyper when teaching a lecture, but it's fun. I like to break formality and let the students feel personally connected to the material, let them take charge and gain confidence — that's the ideal of course." He continued by responding to the question, "Did you regret that you did it?": "I'm quite glad I did it — I hope that the students all go on to do really cool things."

The experience of encountering problems related to the technology and materials that they were conveying became a motivating factor for the undergraduates to master the technology and materials themselves. Most of the mentors had difficulty solving problems they encountered at first, because they were not familiar enough with the lesson plans, the technologies and/or the materials beforehand. They all agreed that they need to learn all the educational robotics components very well — well enough to troubleshoot problems they encounter while teaching, while under time pressure and pressure from students watching them impatiently and harassing them if they cannot fix problems right away. Moreover, the difficulties that the mentors faced during the first stages of the program motivated two of the female students to develop educational robotics lesson plans, teaching materials and a workbook with useful resources including the possible problems and troubleshooting tips. These are available from:

`http://agents.cs.columbia.edu/er/curriculum`

Summary

In summary, we have briefly described two summer programs in which undergraduate Computer Science students acted as mentors for inner-city high school students. We have outlined robotics materials developed and implemented by these mentors. We observed through the summer growth not only in terms of educational robotics materials but also in terms of the social, pedagogical and communication skills of the undergraduate mentors involved in the program. This led us to begin to examine the mentoring experience from the standpoint of the undergraduates. We include a preliminary report here, which showed that all of the undergraduate students involved gained confidence through the program, improved their teaching and communication skills, and also improved their technical skills and knowledge through teaching.

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References

Gardner, H. 1983. *Frames of Mind: The Theory of Multiple Intelligences*. BasicBooks.

Lepper, M., and Henderlong, J. 2000. *Turning “play” into “work” and “work” into “play”: 25 years of research on intrinsic versus extrinsic motivation*. Academic Press.

Martin, F. 1996. Ideal and Real Systems — A Study of Notions of Control in Undergraduates Who Design Robots. *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World*.

Miglino, O.; Lund, H.; and Cardaci, M. 1999. Robotics as an Educational Tool. *Journal of Interactive Learning Research* 10(1).

NYC-DCP. 2003. 2000 Census Tract Community Development Block Grant Eligibility Maps. Technical report, New York City Department of City Planning.

NYC-DHMH. 2003. New York City Neighborhood Health Profiles: Manhattan, 2000. Technical report, New York City Department of Health and Mental Hygiene.

Papert, S. 1980. *Mindstorms: Children, Computers, and Powerful Ideas*. BasicBooks.

Papert, S. 1991. Situating Constructionism. *Constructionism*.

Piaget, J. 1972. *To Understand Is To Invent*. New York: The Viking Press, Inc.

Sklar, E.; Eguchi, A.; and Johnson, J. 2002. RoboCupJunior: learning with educational robotics. In *Proceedings of RoboCup-2002: Robot Soccer World Cup VI*.

Sklar, E.; Johnson, J.; and Lund, H. 2000. Children Learning from Team Robotics: RoboCup Junior 2000 Educational Research Report. Technical report, The Open University, Milton Keynes, UK.