# Using Educational Robotics to Engage Inner-City Students with Technology

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**Abstract:** This paper presents a pilot project using an educational robotics curriculum that was developed to enhance teaching of standard physics and math topics to middle and early high school students in inner-city schools in New York City. The lessons are centered around the LEGO Mindstorms robotics kit and the RoboLab graphical programming environment. The pilot project, testing the curriculum in two summer programs for early high school students, was conducted in 2003 at two locations in Harlem, New York City, USA.

## Introduction

This past summer, we were given an opportunity to conduct a pilot project integrating a hands-on robotics component into two summer programs for inner-city high school students: the *Science and Technology Entry Program (STEP)* (1) and *Playing2Win (P2W)* (2). Overall, approximately 50 high school students participated. Our goal was to enhance the science and math educational opportunities offered at each program through the development and implementation of curriculum and materials using the LEGO Mindstorms Robotics Invention System(3) (LEGO robot hereafter). The target population for this project was not the typical upper-middle-class suburban population that frequently gets the chance to interface with robotics. On the contrary, this project addresses students from the Central Harlem neighborhood of Manhattan, New York City, where at least 51% of all residents are from low and moderate income households (New York City Department of City Planning, 2003) and 67% of residents are of African-American descent and 20% are Hispanic (New York City Department of Health and Mental Hygiene, 2003). As an evaluation of the project, we conducted a pilot study examining the learning experience of the 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 paper describes the curriculum and resources developed, our implementation experiences and lessons learned. We begin by outlining some background of the project followed by detailed description of the project design. Then we discuss lessons learned through the process of implementation as well as our pilot study aiming to examine how their interest and perceived ability in technology changed during the course of the summer and if any improvement in their problem-solving skills was evident. We highlight some issues particular to the inner-city population and conclude with future directions.

## Project Background

The main purpose was to enhance science and math learning experiences through educational robotics for students who have not had this type of opportunity in their regular school setting. The project had multiple goals to support its main purpose. The primary goals were to develop and test curriculum, curriculum materials and supplemental resources using the LEGO robot, geared toward an inner-city public school population. A secondary goal was to examine the use of practical applications for the technology within a non-traditional educational environment in order to anticipate technical difficulties in our implementation plan.

The project was composed of four stages: *(I) Curriculum Development, (II) First Implementation, (III) Innovation and Modification,* and *(IV) Second Implementation*. Before discussing the details of each stage, we describe the project participants and introduce the theoretical framework employed for the project design and curriculum development. We also describe the robot kits and programming environment used.

### Participants

The participants in the project were inner-city high school students who attended one of two programs during Summer 2003 (see Figure 1). The first program was STEP, hosted at Barnard College, Columbia University, located adjacent to Central Harlem. STEP is a 5-week summer program available to New York City public high school students where they attend classes in mathematics and science. The purpose of this program is "to increase the number of historically underrepresented and disadvantaged students prepared to enter college, and improve their participation rate in mathematics, science, technology, health related fields and the licensed professions[1]." We offered our robotics curriculum to two classes of about 12 students, ages 14-16. Each class met two times per week for 90 minute sessions. The gender balance was 25% male and 75% female.

Figure 1. Participants.

The second program was held at P2W, a community center located in Central Harlem that offers year-round educational programs for the community for all ages (including adults). In the summer, they offer special programs for kids. As part of a 6-week technology program, we offered our robotics curriculum to two classes of students, ages 14-16. Each class met two times per week, for 2 hours each meeting. There were approximately 20 students in each of two classes. The gender balance was 50% male and 50% female.

Two undergraduates worked with us to develop the curriculum[4], and they implemented and tested it in both programs, with help of three additional undergraduates. The team was comprised of two male and three female students, two juniors and three seniors, all majoring in Computer Science. 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 we observed some incidents that suggest that a little parental pressure might have been exerted on the students to attend. The vast majority of participants in both groups were minorities and more than 50% in the combined population were female – i.e., the participants were mostly from groups typically disenfranchised from engineering subjects.

## Theoretical Framework

We have employed the theories from four pedagogical approaches: *Constructivism, Constructionism, Learning by Design* and *Cooperative Inquiry*. The theory that provided the primary influence was Piaget's *Constructivism* (Piaget, 1972, 1973, 1977). His theory states that learning takes place as the result of mental construction by the learner. Emphasis is placed on the learner and not the instructor. The learner interacts with objects and events and thereby gains understanding of the features held by such objects and events. In this way, the learner constructs his/her own conceptualizations and solutions to problems. Through this methodology, autonomy and initiative are encouraged. Educational applications of constructivism lie in creating curricula that simultaneously match and challenge students' understanding while fostering growth and development of the mind.

The second approach, *Constructionism* (Papert, 1992), is a natural extension of constructivism and emphasizes the hands-on aspect. The learner in a constructionist environment builds something on their own, preferably a tangible object that they can both touch and find meaningful. The goal of constructionism is "giving children good things to *do* so that they can learn by doing much better than they could before (Papert, 1980s)." The LEGO robot, an outgrowth of Papert's LOGO programming language created in the 1960's (Logo Foundation, 2000), partners technology with constructionism ideas. The goal is to find ways in which technology enables children to actively use knowledge they have acquired.

The third approach, *Learning by Design* (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998), is a methodology in which students learn as a result of collaboratively engaging in design activities and reflecting appropriately on their experiences. They learn science concepts through hands-on experience and real-world applications. The methodology incorporates teacher scaffolding to prevent classroom chaos. Learning by Design has been shown to enhance problem-solving, decision making and collaboration skills (Nagel & Kolodner, 1999; Puntambekar & Kolodner, 1998).

*Cooperative Inquiry* (Druin, 1999), involves a three step process. First, the teacher engages in *Contextual Inquiry*, observing how students interact with the technologies that are currently available. Second, the students engage in *Participatory Design*, sketching ideas by building. Last comes *Technology Immersion*, in which students are exposed to technology that they might not encounter otherwise.

### LEGO Robot

Using the LEGO robot, we modified a "tankbot" created by the CMU Robotics Academy[5] so that the robot can be built starting with a "go-cart" (a vehicle without motors) and then adding pieces to it, including motors and the LEGO RCX[6]. Additionally, we created both a touch sensor and a light sensor add-on to be used with the corresponding parts of the curriculum.

### Programming Environment

We used the RoboLab programming environment, which was developed at the Tufts School of Education and the Tufts School of Engineering[7]. RoboLab has a simple graphical interface for writing programs. Entities such as motors and sensors are represented as rectangular icons on the screen, and users drag them using the mouse to create "code". The icons must be strung together using "wires". The environment is highly visual and provides a good first experience with procedural programming concepts.

## Project Description

### I. Curriculum Development

Throughout the development process, we asked a set of questions (described in Figure 2). We attempted to divide the students' learning process into three broad phases: (1) *Construction*, (2) *Programming* and (3) *Application*, engaging them throughout through a series of *Challenges*. In the Construction phase, students first learn about design and then how to build and improve their designs. Through this hands-on experience, they gain exposure to and begin to acquire understanding of engineering and design principles. During the Programming phase, the students first learn the basics of the RoboLab programming environment and then how to apply that knowledge. In the third phase, students are exposed to problems in physics and mathematics that the robotics can help illustrate. At the end, students make presentations to share their solutions with each other. The sharing portion of the program enables students to reflect on the entire learning process.

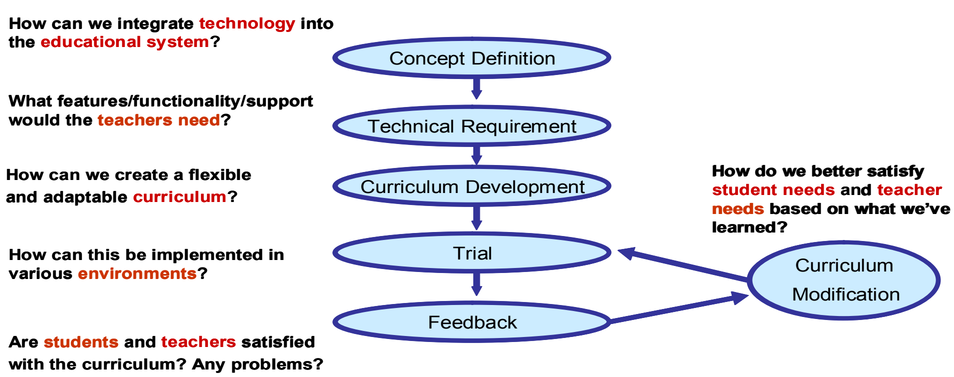


Figure 2. The Development Process

#### Phase 1: Construction

In the Construction phase, students design and build two structures: a go-cart and a robot (see Figure 3). The main purpose of making students build both is to illustrate the differences between manually-operated and autonomously-controlled objects. First they build a simple go-cart, a four-wheeled vehicle without motors, sensors or an RCX. This also helps students become familiar with the specialized pieces of the LEGO building set, learning how the pieces were designed to reinforce each other. The curricular content here centers on mechanical engineering design principles. The go-cart is used to help students learn about the physics concepts of forces and motion. They build a ramp and let their go-cart roll down the ramp. Using math, they calculate how far it will travel if they let go of the cart at the top of the ramp. Then they run experiments and measure how far it actually goes. This also provides lessons in scientific method – hypothesis, prediction and measurement. Students learn about multiple trials, statistical analysis and error.

Figure 3. Go-cart, on left, and Robot, on right.

## Phase 2: Programming

It is beneficial for all students to use the same robot design for the phase in which we introduce programming. This assures that the same program will run on every student's robot. This is extremely useful when trying to teach fundamental programming to a large number of students. The key programming concepts covered include: *sequential execution, ordering, logic, conditional statements, repetition, nesting* and *debugging*. Many of these key concepts are illustrated in every RoboLab program (see Figure 4).

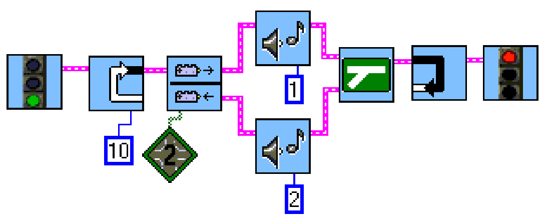


Figure 4. A sample RoboLab program: The figure executes a program that will read the input from the touch sensor on port 2. If the touch sensor is released then sound #1 will play or else if the touch sensor is pressed then sound #2 will play. This will repeat 10 times.

The programming phase can be subdivided into three sections: *basic programming, touch sensor programming* and *light sensor programming*. To ensure that students understand the material, handouts with challenges are given to students during each class. For example, a challenge in the Light Sensor lesson reads: "If the robot begins on a black area, move forward; but if the robot begins in a white area, go backwards. The robot shouldn't go forwards or backwards forever." Students are given multi-step challenges so that those who catch on quickly will have a next level task to work through. These challenges are completed in groups, allowing students to cooperatively test their solutions. With each lesson, at least one of the challenges used the sound card in the LEGO robot to play "music". This engages students with broader interests and is also useful for teaching debugging.

Topics covered in each programming section include: Basics - *Begin/End, Motors, Wait For Time, Stops, Music*; Touch Sensor - *Wait Fors, Jumps, If/Else, Loops*; Light Sensor - *Wait Fors, Jumps, If / Else, Loops*. Since each lesson is built upon the previous one, students who miss the beginning classes lack the background necessary to implement more advanced challenges. Absenteeism is a significant factor in our population; and in our future work, we need to develop methodologies for coping with this aspect.

## Phase 3: Application

The third phase of the curriculum focuses on pulling together all of the previous lessons in order to solve more complicated challenges. In the "Cup Challenge", students need to create an algorithm to push all the cups placed on a floor outside of a bounded area. The only condition is that the robot is not allowed to leave the bounded area marked by a black line. Groups record the time to complete the task and try to make improvements to lower their time. In addition to using the programming skills acquired, we observed that many students used creativity and design skills to develop bumper extensions. Topics covered in the application section are advanced programming including *Nested Structure, Multi-tasking, parallelism, event-handling* and *the use of both light and touch sensors*.

### II. First Implementation

The STEP program began two weeks earlier than P2W, which gave us the opportunity to implement lessons at STEP first and then modify them for P2W, if necessary. In the first two lessons (Basic Construction and Basic Programming), we decided to give students sample programs to copy. They seemed to have an easier time learning by example, starting with working code, testing its limitations, modifying it and testing again.

We tried to cater to the needs of all the students. Sometimes this meant presenting the material in numerous ways. For example, some students were having difficulty understanding when to use different programming structures like conditional statements and *for loops*. First, we discussed the power each structure adds to a program. Then we created a mapping of English words to the various structures – words like *forever, continuously, repeatedly,* or *for X number of times* all signaled the use of a *loop*.

The students were divided into groups. Each group used one robot kit. There were 3-4 students per group at STEP; however, only 1-2 students per group at P2W due to behavioral issues in the P2W population. Although we feel that 3 students per group is optimal, forcing the students into larger groups would not be beneficial to the teachers or the students. Some of the students in P2W absolutely refused to work with other students, and others only wanted to work with certain people. Despite these issues, we were told by the staff at P2W that students responded better in the robotics class than in other classes. This demonstrates that educational robotics has the potential to attract this population of students and to provide an effective and motivating learning experience.

Finally, we found that disinterested students could be enticed to participate with challenges they found "cool". This encouraged us to develop more "cool" challenges to attract these potential learners.

### III. Innovations and Modifications

The First Implementation stage provided us with valuable experiences that helped us modify and create more useful and effective curriculum materials[(8)], which we then used in the Second Implementation stage (described below). These include additional lessons as well as supplementary materials to accompany all lessons.

Although time permitted us to teach only as far as the Advanced Programming lesson in both STEP and P2W, we have developed further lessons that demonstrate high school math and physics concepts using the robots. For example: *Discrete versus Continuous Systems; Angles, Torque, Friction and Robot Body Design; Circumference versus Speed; Importance of Wheel-Size* and *Distance, Velocity and Algebraic Manipulations*. These lessons allow students to explore the scope of the physical robots while experimenting with basic principles.

We observed in both programs that students would have benefited from additional resources that provide guidance with RoboLab. As a result, we developed a workbook and a design journal. The workbook contains *Tips and Tricks* and a *Cheat Sheet* on RoboLab. In both STEP and P2W, we found that at times students became frustrated because they could not find a specific RoboLab icon. The Cheat Sheet contains a concise representation of the most common icons. Similarly, Tips and Tricks is aimed at helping students avoid and troubleshoot problems. The design journal presents ways for students to reflect on how they solved challenges as well as to identify their personal contributions to their group.

A major difficulty with teaching RoboLab in a classroom environment is that often teachers do not have access to a computer projector in their classroom to show programs to the students. To solve this, we created a set of enlarged, magnetic RoboLab icons to enable teachers to demonstrate RoboLab programming without such technology. Subsequently, we discovered that these are available commercially[(9)].

### IV. Second Implementation

The modified curriculum and new resources were presented at a teacher workshop held at the end of the summer at Columbia University. By the time of the workshop, a website with supplemental online resources had been developed[(10)]. This workshop provided us with an opportunity to test the additional materials with the teachers.

## Lessons Learned

This project provided us with valuable learning experiences in a number of different areas. First we discuss the lessons learned by the undergraduate mentors. Then we examine the student experiences.

### Undergraduate Mentors

At the conclusion of the summer, we interviewed all of the undergraduate mentors about their experiences focusing on their teaching interests and abilities and on their personal impressions of the project (E Sklar & Eguchi, 2004). Two of the mentors stated that they had had previous teaching experience working with students of their own age; however, none of them had experience teaching high school students. Additionally none of them received any instruction on teaching prior to the program. Statements from all of the undergraduates indicated that they learned various pedagogical strategies including: methods for building rapport and sound relationships with students, balancing their authority with friendly relationships with students, helping students become engaged in their activities and providing useful support to enhance the students' learning experience.

The mentors found broad diversity in students' knowledge and skill levels. Additionally, attendance rate for students was not constant. However, the undergraduates came up with their own strategies to cope with these issues and to keep the students focused. For example, they placed all the students who were not grasping certain concepts in one group. Furthermore, they provided extra personal attention to the students who needed additional help.

The undergraduates all agreed that the ratio of mentors to students was crucial for successful lessons. They explained that if there were too many students per mentor, the students became unruly and the lesson fell apart. But if there were too few students per mentor, the students used the mentor as a crutch and did not learn to do things for themselves. Especially with the P2W participants, it was observed that some students performed better when they had mentors' constant attention with step-by-step instructions.

Initially, most of the undergraduates had difficulty solving technical problems when they were not familiar enough with the lesson plans, the technologies and/or the materials prior to teaching. It was agreed that mentors need to learn all the components well enough to troubleshoot problems they encounter while teaching. Although each of the undergraduates who were previously inexperienced with the LEGO robots received briefings prior to the summer programs, they suggested that we offer a more comprehensive workshop on how to use the technology and materials at the beginning of the summer.

### Surveys

Our intention was to evaluate the effects of the project using the classic method of administering pre and post tests. In both STEP and P2W, we gave pre and post surveys that we developed with the intension of measuring students' problem-solving abilities, cognitive processes and levels of interest in math, science, technology and robotics. The post survey included a section providing us with direct feedback about each program.

We found this aspect to be probably the most difficult of the entire project, although we have had experience at evaluating educational robotics in the past (E. Sklar, Eguchi, & Johnson, 2002). To begin with, we had a hard time collecting consent forms from parents before the programs started; as a result, only thirteen students (five from STEP, eight from P2W) completed both the pre and post tests. The cause seems to be a mixture of students who kept forgetting to get the forms signed and parents who were resistant to the idea of their children being involved in a research project. As a consequence, our samples were too small to generalize from the survey data.

Another issue concerns separating the robotics program from other learning experiences that the students had during the period of implementation. Because the robotics program was one of several classes that all the students were taking in both summer programs, their responses to the assessment tests might have been influenced by their experiences in other programs. For future development of the assessment tools, we need to consider how to separate influences from other learning experiences as well as how to establish triangulation between multiple experiences.

Even though the sample size is too small to project any conclusions to a general population, there appears to be evidence of a correlation between students' computer usage (for entertainment, communication, information and homework) and their level of interest and ability in computer-related subjects (math, science, computers, robotics and computer programming). Students that showed higher levels of interest and ability in these subjects tended to use computers more frequently. Similarly, students that demonstrated lower levels of interest and ability tended to use computers less often. No causation can be determined. Additionally, it appears that the students tended to score their interests and personal abilities higher in the direct feedback questions than in the less direct pre and post test questions. This is an issue with our survey methodology, which we need to examine in future work.

Although systematic observation was not conducted during the implementation stages, observations by the undergraduate mentors can be used to highlight possible influences of the project. In both programs, there were students who lacked the self-confidence to propose solutions to the challenges; however, once these students were engaged by the mentors, they exuded more confidence. By the end of the program, many of these students felt comfortable sharing their ideas with others. One student in particular came to class initially with the attitude that she could not do robotics. With the support of a dedicated mentor, she slowly became engaged in the subject matter and overcame her anxieties. When she solved her first advanced challenge, the smile that beamed across her face said enough. By the end of the program, she was very involved and even contributed suggestions to the final challenge. This example suggests that self-confidence develops through accomplishing tasks that students initially think are too hard and overcoming initial hesitations allows students to engage in areas they might avoid otherwise. This is particularly important in the population addressed here, which is traditionally disengaged from computer and engineering topics.

## Conclusions and Future Work

The mentor-student ratio is crucial for successful implementation of robotics lessons. The undergraduates suggested that one mentor per two groups of students was ideal. The number of students in a group can vary; however, we feel that three students per group works best. To accomplish this, there is an issue of how to secure the appropriate number of mentors. Recruiting more undergraduate mentors is an obvious solution. Training the adult supervisors is another solution, which would also provide added benefits as outlined in the next paragraph. An additional suggestion is to involve pre-service teachers. This has the further benefit of expanding the base of teachers trained in educational robotics and giving them the tools, experience and confidence to integrate robotics into their curricula in the future.

The attitudes of the adult supervisors made a significant difference in students' attitudes towards learning. For example, the supervisor of one of the STEP classes provided a strong positive influence for his students during the robotics lessons. Although he did not have much knowledge about robotics or RoboLab, he showed interest in students' activities and cheered their accomplishments. His positive attitude and interest motivated some of his students to succeed in the challenges in order to show him their accomplishments. On the other hand, the supervisors in the other STEP class did not pay any attention to the robotics program. They came to class with their students, but spent most of their time surfing the internet. This negative attitude did, indeed, lower the students' motivation in comparison with the other class. The undergraduates suggested that we should include the supervisors in future mentor workshops in order to familiarize them with the robot kits and RoboLab in order to provide help and create a positive atmosphere.

Another factor that might provide positive influence on students' motivation is an opportunity for the students to show their work to their parents. STEP had an Open House at the end of the program where the students could show off their achievements to their parents. It was observed, toward the end of the program, that some of the students were racing to complete the most difficult challenges. When they were done, they were thrilled to be able to show their parents at the Open House. This indicates how robotics is a "cool" topic for students to proudly show to their parents, even in the age group here (14-16 years old).

Versions of our educational robotics materials have been tested in numerous New York City public schools through Columbia's Technology Integration Partnership[10]. With continued iteration, we expect to improve our lessons, materials and resources in order to satisfy the needs of teachers in a wide range of settings. We are continuing development of a comprehensive and teacher-friendly website to provide useful resources as well as a forum for sharing experiences. Additionally, we are currently working on developing a valid and reliable survey, working in cooperation with researchers in psychology and education in order to create measurement tools to accurately assess the influences of educational robotics, including students' self-motivation in math, science and technology related subjects. The summer project provided us with significant learning experiences along the road to accomplishing our goal.

## Endnotes

(1) http://www.highered.nysed.gov/kiap/step/step.htm
(2) http://www.playing2win.org
(3) http://www.legomindstorms.com
(4) The lead developer is the first author here.
(5) http://www.rec.ri.cmu.edu/education/teachertraining/tankbotbldginstr.pdf
(6) RCX stands for Robotics Command Explore. It is the component that contains a microprocessor housed in a LEGO brick.
(7) http://www.ceeo.tufts.edu
(8) The developed curriculum and materials can be found at: http://satchmo.cs.columbia.edu/er/curriculum Additional robotic resources can be found at: http://satchmo.cs.columbia.edu/er
(9) http://www.pldstore.com/pld/catalog.cfm?dest=itempg&itemid=8298&secid=9&linkon=subsection&linkid=45
(10) http://tip.columbia.edu/

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