AC 2007-1481: A PARTNERSHIP TO INTEGRATE ROBOTICS CURRICULUM INTO STEM COURSES IN BOSTON PUBLIC SCHOOLS

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A Partnership to Integrate Robotics Curriculum into STEM Courses in Boston Public Schools

Northeastern University and TechBoston, a division of Boston Public Schools, are working collaboratively to integrate an innovative robotics curriculum into science, technology, engineering, and mathematics (STEM) courses in the Boston Public Schools and other racially diverse and economically disadvantaged Massachusetts school districts. The project is sponsored by the National Science Foundation (NSF) program, Information Technology Experiences for Students and Teachers (ITEST). The project targets 7th and 8th grade STEM teachers, with students participating during summer and after school. The project addresses the urgent need to enhance student interest and performance in STEM courses, while fostering skills that are important prerequisites for IT careers. In the near term, the project is helping Massachusetts schools and students meet statewide academic standards. Over the long term, the project will help inspire and prepare a new generation of IT professionals.

The project utilizes hands-on robotics projects innovatively as its delivery platform of its professional development program for teachers and hands-on activities for students. To serve schools and teachers effectively, the robotics curriculum is aligned with both state and national technology education standards. Throughout the project activities, special emphasis is placed on female and minority students. Pedagogical methods are tailored to the student learning patterns, and strategies are provided to help middle school STEM teachers engage all students, regardless of gender or race. This paper presents the robotics model, how it works, how it is implemented, and its results. The paper also presents data and analysis from the project.

Introduction

The NSF-funded project described in this paper addresses four needs: (1) placing middle school students on a path to meet state and national workforce demands; 2) providing professional development for middle school teachers; 3) helping Massachusetts schools and students meet statewide academic standards; and 4) preparing more female and minority students for careers in IT.

The demand for workers with IT skills is expected to remain strong into the next decade. In a November 2001 report, the Bureau of Labor Statistics identified IT as the U.S. economy‘s fastest growing industry, and the second largest overall in terms of employment[1] —Reflecting businesses‘ need to integrate new technologies, capitalize on software enhancements, expand Internet usage and electronic commerce, and maintain network security, this industry is projected to gain 1.8 million jobs over the 2000-10 period, the result of 6.4% annual average growth. This compares to an overall estimated employment growth rate across all industries of 22.2 million jobs, or about 2.2%. Furthermore, with the growing reliance on IT across all industries, IT fluency will increasingly be a required competency for all workers.

Preparing students to succeed in an IT-driven economy requires educational reform at all levels, starting with middle schools. In its 2001 report, *Building a Workforce for the Information Economy*, the National Research Council‘s (NRC‘s) Committee on Workforce Needs in Information Technology noted that —it is important to the future of the IT workforce that the curriculum of secondary school mathematics and science provide a strong foundation for later study and training in IT and IT-related subjects. While a substantial amount of money is allotted in the United States to technology education each year, a relatively small percentage of that money is earmarked for teacher training needs. During the 1999-2000 school year, only about 17 percent of the more than $5 billion spent on educational technology nationwide was devoted to teacher training, with most of the remainder spent on computer hardware and software.[2]

In 2001, Massachusetts became one of the first states in the nation to formally require all students to receive technology and engineering instruction as part of the regular curriculum, with the adoption of the 2001 Massachusetts Science and Technology/Engineering Curriculum Framework. The framework articulates ambitious statewide guidelines for teaching, learning, and assessment in science and technology/engineering, and states as one of its 10 guiding principles that: —Investigation, experimentation, and problem solving are central to science and technology/engineering education.

There is a pressing need within Massachusetts and across the country to prepare more female and underrepresented minority students for careers in IT. In *Building a Workforce for the Information Economy,* NRC characterized the current IT workforce as —predominantly white, male, young, educated, and U.S. born.“ According to the report, in 1999, white employees represented 77 percent of the IT workforce, Asian and Pacific Islanders represented 9.9 percent, and underrepresented minorities (Blacks, Hispanics, and Native Americans) represented 12.4 percent. In 1999, about 77 percent of IT positions were held by men, compared to an average of 53 percent men in all professions.

The loss of interest in STEM courses among middle school girls results from a range of factors, including gender bias in the classroom, the tendency of middle school boys to monopolize computer and lab equipment, subtle pressures from teachers and parents, sexual harassment in the classroom, and male-oriented marketing of educational software and games.[2,3]

In NSF's 2003 research compendium titled *New Formulas for America's Workforce: Girls in Science and Engineering,* the agency identified a range of proven strategies for engaging girls in STEM courses (NSF, 2003). According to the report, girls respond positively to hands-on activities. With respect to minority students, research has shown that traditional classroom instruction methods likewise may fail to engage African-American and Hispanic-American students (Guild, 2001). To a greater degree than their classmates, minority students respond to learning experiences that emphasize oral skills, physical activity, and strong personal relationships.[4,5] As a result, collaboration, discussion, and active projects in the classroom tend to be more engaging for minority students than work involving independent study and competition.[6]

Partners

The partnering institutions on the NSF project have a thorough understanding of the preparation that middle school students need for further training in IT at the high school and university level. Furthermore, the project partners have extensive experience serving the needs of Boston's racially and ethnically diverse urban populations. The partners are Northeastern University (NU), TechBoston, and Argosy Foundation. NU brings its expertise in robotics, and STEM education of school children. NU received national recognition for achievement in robotics in 2001, when NU engineering undergraduates teamed with students from Boston Latin School, Brookline High School, and Milton Academy succeeded to field the winning entry in that year's FIRST Robotics Competition. Two NU-based projects, originally funded by NSF–Project SEED and RE-SEED–are actively engaged in offering assistance to schools.

TechBoston is a BPS department whose mission is to provide high-level technology education to BPS students in preparation for careers and post-secondary opportunities in high-tech fields. Established in 1998, with funding from the Massachusetts Department of Education, TechBoston has provided high-tech skills training to over 5,000 students and 150 teachers. The Private Industry Council works closely with TechBoston to place high school students in industry internships with area companies.

The Argosy Foundation has generously agreed to fund the purchase of the LEGO robot kits needed for this project. Established in 1995 by Boston Scientific co-founder John Abele, the Argosy Foundation supports the diverse charitable interests of its trustees, with a focus on science literacy for children, education, and technology.

Focus

An innovative, hands-on robotics curriculum forms the foundation for all workshop and classroom materials. The curriculum has been carefully aligned with state and national academic standards, as well as a set of prerequisite skills for IT careers identified by the U.S.

Department of Labor. In addition, the curriculum has been designed specifically to appeal to an audience of middle school girls and minority students.

In order to ensure replicability throughout Massachusetts, the project's robotics curriculum has been carefully aligned with the relevant learning standards in the Massachusetts Science and Technology/Engineering Curriculum Framework. These include the following, among others:

- *Standard 2.1*. Identify and explain the steps of the engineering design process, i.e., identify problem, research the problem, develop possible solutions, select the best possible solution, construct a prototype, test and evaluate, communicate the solution, and redesign.
- *Standards 2.2 and 2.3*. Demonstrate methods of representing solutions to a design problem. Describe and explain the purpose of a given prototype.
- *Standard 2.6*. Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.

Since the Massachusetts standards are consistent with national standards issued by the International Society for Technology in Education (ISTE), the robotics curriculum will also be replicable nationally. The project team predicts that school districts in other states could adopt the curriculum with only minor modifications.

The project's robotics curriculum has been designed specifically to appeal to female and minority students. The project approach is supported by the academic literature, which suggests that many female and minority students respond better to classroom work that emphasizes collaboration, discussion, and hands-on projects, as opposed to competition, pressure, and independent activity.

Description

The project employs an innovative framework to prepare middle school teachers to integrate robotics activities with their classroom teaching methods, and to make these activities inclusive and engaging for female and minority students. Teachers receive all of the professional development, tools, and support that they need to lead year-long after-school robotics programs, which will serve as incubators for changes in course content and classroom activities. The advantage of this approach is a more natural evolution of teaching methods–teachers have the opportunity to practice new strategies in a relatively informal setting before deploying them in the classroom.

A. Teacher Workshops

The project provides an intensive, two-week workshop for 30 teachers every summer, providing 80 hours of professional development for each participant. At the summer workshops, teachers will learn to implement robotics curriculum. Personnel from NU and TechBoston collaborate to develop the curriculum and conduct the workshops, using NU's computer facilities and robotics labs.

In week one, teachers learn the fundamentals of LEGO robot design and engineering. Topics will include the construction of simple stationary structures, the dynamics of locomotion, the use of motors and gears, and mechanisms of sensor input and feedback. Teachers then learn how to program their robots, combining control of locomotion with sensory input to complete goal-oriented projects. At every opportunity, teachers will apply their knowledge to solve practice-oriented engineering problems.

In week two, each teacher is joined by five students, forming a total of 30 six-member teams. An engineering challenge–involving the design, construction, and programming of a LEGO robot–is issued to all of the workshop participants. The teacher-students teams work on the challenge from 8AM to 12PM, Monday through Thursday, in preparation for presenting a solution to the challenge at week's end. In addition, teachers receive professional development in how to structure a successful after-school program and how to manage a team as it prepares for a STEM competition. On the last day of week two, the teams will present their solutions to one of six panels of IT/engineering professionals, who determine which team devised the best solution. A —playoff" is then held for the top six teams. Table 1 shows the structure of the professional development of teachers.

Table 1. Teachers' Professional Development

Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Welcome, Introductions and Conference Overview	Creating an Inclusive Classroom	Recruiting Females and Students of Color	STEM competitions available: How to prepare for it, How to perform successful fundraising	Classroom/Kit Management. Tie in with After School Logistics and strategies
Team/Relationship Building Exercise	Lesson 3	Lesson 5	Lesson 7	Lesson 9
Lesson 1	Problem solving exercise	Parental/Community Involvement	Student presentations from the past, Botball teams and Robotics Olympics	Lesson 9 Lesson 10
Why IT and Engineering?	Lesson 4	Lesson 6	Lesson 8	Lesson 10
Lesson 2	After School Logistics: Classroom/kit management	Q&A w/ panel of robotics teachers	Fundraising ideas	Final presentations by teachers

B. The Robotics Method

Our overall goal in the course is to provide teachers with materials to help them engage their middle-school students in thinking about engineering problems, and to integrate engineering and technology into after-school programs and eventually in-school curriculum. This program addresses a number of the MA State Curriculum Frameworks for Technology/Engineering in Grades 6-8. Students are required to pursue engineering questions and technological solutions that emphasize research and problem solving as a way of meeting their goals. Throughout, this program uses the Engineering Design Process (EDP) as a basic organizing principle. This general process, which can be seen as analogous to the scientific method for understanding and carrying out scientific studies, is a logical, step-wise approach to solving a problem. The material used in this program involves having students actively learn and successfully apply the EDP, and therefore become better problem-solvers.

C. Robotics Project

Each teacher who attends the summer professional development runs a yearlong after-school robotics program at his or her school. These programs meet at least once a week for two hours, totaling at least 10 weeks of each semester. The project provides teachers with the necessary equipment for their after-school programs, through the robotics kit loan program. Each participating teacher receives five kits, which is shared among 10 students.

Students work in collaborative groups to complete a design project. The project theme is *Robotics: Assistive Design for the Future*. The theme is designed to excite middle-school students about engineering topics, and to integrate engineering and technology into their curriculum. The curriculum will engage the students in designing, building and programming a LEGO robot, and challenge them to work cooperatively and think creatively. The students will form teams or "companies" that work together to create a LEGO robot prototype of an assistive device for some physically challenged population. The students' activities culminate in a final presentation where student teams present their products to a panel of judges.

D. Judging Robotics Project

Students are required to demonstrate their finished robotics assistive devices to a Judges Panel. The judges are given the following instructions:

During the ten sessions of this program, we emphasize the following Massachusetts framework standards:

2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.
2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.
2.3 Describe and explain the purpose of a given prototype.
2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.
3.1 Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.
7.1 Explain examples of adaptive or assistive devices, e.g. prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces.

More specifically, we want to ensure that the students demonstrate:

- Their knowledge of the engineering design process (EDP),
- How they applied the EDP to their project,
- That their prototype is a model and not the final version of what would be produced for people in the future.
- They understand how the robot can be programmed and communicates (computer-to-RCX, sensor-to-RCX, etc)

Please fill out the evaluation forms for each group. If their presentation doesn't demonstrate one of the above points, please feel free to ask them questions. However, they may be unable to "think on their feet". The purpose of the panel is to assess the effectiveness of the robotics-based instruction program. Possible questions to ask:

What things did you think of before you built your prototype?
If this were going to be produced for people, how would it change?
How does that light/touch sensor control your prototype?
Who will use your device?
Are there existing devices that are similar to your idea?
How would you improve your design for the future?

Please use the following form to evaluate the effectiveness of the robotics program:

Group 1 (fill in name)___________________________

The students demonstrated they understood the EDP.

1	2	3	4	5
Not at all	Very little	Somewhat	Pretty well	Very well

The students were able to explain their prototype (including its features, usability, and drawbacks/limitations)

1	2	3	4	5
Not at all	Very little	Somewhat	Pretty well	Very well

The students demonstrated they knew how the ROBOLAB program, the RCX, and the sensors and motors interacted.

1	2	3	4	5
Not at all	Very little	Somewhat	Pretty well	Very well

E. Robotics Olympics

In addition to the robotics projects, the students participate in a fun Robotics Olympics competition. Student teams are comprised of 1-4 students. Entries are limited to one event per student. In addition, students can enter "Become an Inventor!" competition as an individual or as a team. Sample events are Uphill Climb, Busy City Sidewalk, Smart Cars, Robotic Retriever, All-Terrain Vehicle, Personal elevator, and Become an Inventor!.

Assessment

Although this program is developed as an after-school program, assessment is critical for teachers to be able to (1) provide feedback to their students, and (2) modify their plans based on the students' understanding and progress. In general, the assessments provided consider three basic program goals: EDP principles and processes, teamwork and communication skills, and affect (interest and excitement).

Suggestions for assessment are provided; teachers may choose which to do at particular points during the program. The assessment methods include recording anecdotal observations, using a checklist during class, looking at in-class work, and assessing final projects. With the exception of the final presentation, most are informal and formative assessments done with the goal of gauging progress and determining next steps.

Professional Development Evaluation

We evaluate the teachers' professional development component of the project in three categories: Evaluation of Course, Evaluation of Training Activities, and Personal Reflection. The total number of evaluation questions is 10. Here are sample questions; on a scale of 1 – 4, with 1 being the lowest scale value, teachers gave he following scores:

Rate your knowledge of course content prior to taking it: 1.8
Rate your understanding of content after taking it: 2.7
Training was well-organized: 3.5
Pace of training: 3.4
Training activity was helpful to master content: 3.5
Likelihood of sharing your new knowledge with a colleague: 3.6
Encourage your colleague to take future offerings of the course: 3.7

Recruiting female and minority students

In addition to the Teachers' Professional Development (PD) component listed in Table 1, the teachers also participate in a week-long summer practicum program where they work with middle school students on robotics projects. The theme of the project is to design and build an assistive device using the LEGO kits. Together with TechBoston, the project team advertises through local community centers and other youth organizations to recruit students to attend the summer practicum. The summer practicum affords the teachers the opportunity to practice what they have learned during the PD component of their training program. When the trained teachers return back to their schools in the fall, they are expected to recruit students for after-school program that uses the LEGO kits.

The recruiting for both the summer practicum and the after-school program has focused on attracting female and minority students. Two of the successful techniques we have employed are: *(1) we reached the children parents through teachers; and (2) We crafted the language of our marketing material to appeal to female and minority students and their parents by stressing the Assistive Devices theme*. We sent the summer practicum fliers and announcements to the community centers for distribution to parents. In addition, we crafted the fliers to entice parents to encourage their female and minority students to participate less they miss an exciting opportunity for learning. For example, Figure 1 shows the image included in a flier. This image sends our intended message effectively to the parents.

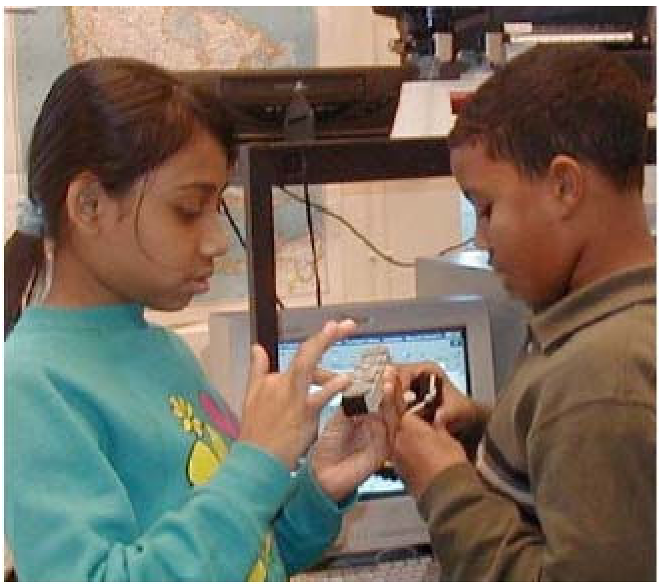

Figure 1. Flier content for Summer recruiting

Moreover, some of the flier text also emphasized the same point. Here are two of the program goals of the flier:

"Inspire students, particularly females and members of minority groups, to take a stronger interest in STEM subjects."

Increase participation by middle school students, especially female and minority students, in STEM competitions."

Additional activities are supported through individual school/teacher participation including the FIRST Lego League and a local Robotics Olympics sponsored by Boston Public Schools. Two first time participating student teams were sponsored in the 2005 FIRST Lego League competition. In 2006 four additional first time teams entered as well as the return of the two teams from the prior year.

The Robotics Olympics sponsored by Boston Public Schools and coordinated by TechBoston established a theme of Assistive Devices to draw upon the interest among the female and minority students to help out people who are physically disabled such as the elderly and older family members. Here is an example of the Olympics flier text:

> Getting around the neighborhood and completing everyday tasks such as cleaning your room is a little more difficult for people who are physically disabled. Engineers, scientists, and doctors are hard at work trying to develop assistive devices to help solve some of the problems that people with disabilities may encounter. Join the team to come up with innovative solutions to the following challenges! Design your own ROCkin' Robot!

Participating students were offered 7 competitive challenges where it was necessary to design a robotics solution. These challenges included tasks to overcome obstacles in mobility and dexterity commonly faced by the physically disabled.

The above efforts and activities have enhanced the robotics program performance in recruiting female and minority students. Table 2 shows the demographics of the students who participated in the program so far.

Table 2. Demographics of middle school students participating in the Robotics program

Activity	Period	Participating Students		
		Female (% of total)	**Minority (% of total)**	**Total**
Summer practicum	2005	30 (46%)	55 (85%)	65
	2006	65 (57%)	85 (75%)	113
After-school prog.	2005	81 (52%)	108 (70%)	154
	2006	In progress	In progress	
Robotics Olympics	2006	N/A	N/A	

Analysis

The response to the robotics project has been positive and the demand for the LEGO robotics kits is high. Teachers and students alike love the program. Some teachers are using the kits during the school day. Other teachers call in asking for more kits. Some other school districts expressed interest in participating in the project. Some community centers suggest extending the project to adult education, as a way to getting them involved in STEM activities.

Conclusion

The robotics project described in this paper targets STEM teachers and their students in grades 7 and 8. The delivery platform, robotics kits with programming coupled with hands-on projects, is based on the best and proven-by-research pedagogical practices. The projects use collaboration and hands-on activities, two important concepts to engage, excite, and motivate girls and underrepresented to participate in STEM activities in hope of pursuing IT careers in the future.

Acknowledgement
This work has been supported by NSF ITEST grant# 0423059.

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