Kindergarten Robotics: Using Robotics to Motivate Math, Science, and Engineering Literacy in Elementary School*

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Robotics naturally lends itself to teaching math, science, technology and engineering in the K–12 classroom. LEGO Mindstorms makes it easy for students even in kindergarten to design and build their own robotic creations. However, the key to bringing engineering into K–12 through robotics is educating teachers on the content, how to use the materials, and how open-ended design problems can be effective in the classroom. This paper details the Tufts University Center for Engineering Educational Outreach's theoretical framework, motivations, and efforts involved in bringing engineering via LEGO robotics into every kindergarten through fifth-grade classroom in one school through the Systemic School Change in Engineering Project. Preliminary results and recommendations are presented.

Keywords: elementary schools; systemic change; professional development; educational technology; LEGO robotics

INTRODUCTION

THE AIM OF the Tufts University Center for Engineering Educational Outreach (CEEO) is to bring engineering education into the K–12 classroom and extend the general population's familiarity with engineering. One of the primary ways this goal is addressed is by integrating the teaching and learning of math, science, technology and engineering (MSTE) through robotics. Robotics provides a unique learning opportunity for students to design, build, and program a meaningful creation. In addition, it gives students opportunities for hands-on learning and the development of metacognitive and higher-order thinking skills [1], both of which have been shown to have significant impact on students' performance on math and science assessments [2]. By using LEGO Mindstorms robotics kits and ROBOLAB programming software, this can be done at a variety of skill levels (from kindergarten to the graduate level) for relatively low cost.

Children naturally latch onto LEGO robotics. Their teachers, however, may be more apprehensive. Young children have not yet developed conceptions about what is involved in engineering and robotics and who can participate meaningfully in these fields. Many adults, including teachers, have grown to think of themselves as fitting into categories, such as "I am not a math person", that may hinder their ability to engage in robotic design (regardless of any actual limitations). Without convincing teachers about the rewards of robotics, it will never enter into the classroom and its potential benefit to students will not be realized.

The CEEO has taken several initiatives in robotics teacher education and aims to act as a supporting institution, providing expertise and materials for teachers to draw from. To involve teachers in robotics, the CEEO takes a unique approach by having teachers participate in workshops geared towards classroom implementation, providing them with classroom support, and developing curricular materials in conjunction with the teachers. Additionally, the workshops adopt a hands-on, learning-by-doing philosophy so that classroom teaching practices are essentially modeled during professional development. Following a discussion of the previous work and related research in this area, the results of one system-wide implementation—the Systemic School Change in Engineering (SSCE) Project—are presented with recommendations.

BACKGROUND

Theoretical framework

Teaching engineering through robotics allows students to learn the content of a subject area, such as mathematics, by applying the content in a real-world context. Learning-by-doing is an educational approach with its roots in the theory of Jean Piaget, who claimed that knowledge is not transmitted to children, but is constructed in the children's minds [3]. This theory, known as constructivism, is extended by the work of Seymour Papert of the Massachusetts Institute of Technology's Media Laboratory. Constructionism, Papert's theory, purports that not only do we learn by doing, but we learn best when we are engaged in building some type of external artifact,

be it a robot, a theory, or a story [4]. He breaks with Piaget by ascribing a larger role to the surrounding culture in providing the student with materials with which he or she constructs.

In the late 1970s Papert saw the development of a new element in society that he believed would revolutionize learning—the computer. Papert believed that by programming the computer a child "establishes an intimate contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model building" [5]. Programming allows, or compels, children to think about their own thinking. They must make processes explicit in order to teach the computer how to perform a given task. In doing so, they come to know a lot about learning. The computer is powerful in its universal application; it allows for experiences that can be personalized to each student. By combining programming and designing, both aided by the use of computers, as well as building in robotics we can provide a student of any age with a rich and meaningful learning experience.

Posing open-ended problems as the focus of a K–12 class is an idea born from this constructionist philosophy. Open-ended engineering design problems are outlets for creativity as well as ways for students to uniquely convey their knowledge and understanding of the concepts presented in the classroom. Open-ended design is personal, as it "allows students to frame their own problems and construct their own solutions" within limited constraints [6]. Because the design process involves the proposal of multiple solutions and the testing and evaluation of each, open-ended design problems also provide insight into students' thinking and can highlight some of their preconceptions about how things work. With the proper scaffolding, this can lead to the creation of powerful ideas on the part of the learner and a deep understanding of the content being addressed [7]. If we can interest our students—children, teachers, or Ph.D. candidates—in a problem, they will have a much more valuable learning experience by engaging in the designing, building, and programming of a robot to solve it than they would if they listened to a lecture or followed a step-by-step lab.

Technology and teacher education

Many K–12 teachers have little or no prior experience with engineering and robotics. In addition, teachers often do not take advanced math and science courses during the course of their teacher education program, especially teachers at the elementary level. The National Center for Education Statistics (NCES) reports that 58 percent of elementary-level teachers hold a degree in general education [8], which generally demands fewer content courses than degrees in science or math education. For example, pre-kindergarten through sixth-grade pre-service teachers have minimal math and science requirements and no required coursework in design, engineering, or technology [9]. This creates a large need for professional development for teachers regarding content knowledge in these areas.

Additionally, the constructionist methods advocated and employed by the CEEO to engage students in robotics engineering design challenges can make teachers nervous. Often these methods are new and unfamiliar to many teachers. Teachers may not want to try methods that differ from their own educational experiences [10]. This may frighten teachers away from teaching engineering and robotics before they even begin. However, carefully planned teacher education and professional development programs can influence both these concerns about the content of engineering [11, 12] and theories of learning and teaching [13].

Still, teachers have many reasons for questioning the inclusion of robotics and other technologies in their classroom. First, robotics lessons can take up a lot of time, both during class (building, designing, testing, and clean-up) and in preparation outside the classroom (creating new lesson plans, collecting materials, setting up challenges, and preparing computers). Additionally, teachers face pressure brought on by the No Child Left Behind Act and the high-stakes testing that has resulted. They wonder where robotics can fit into an already over-stuffed curriculum [11]. Cost of materials, limited classroom space, and short class periods also limit even the most motivated teachers. Without support from their administration, teachers may feel overwhelmed about bringing robotics into their classroom [14]. These factors must all be taken into consideration by any institution or organization promoting robotics education in the K–12 classroom and have played a strong role in the development of the CEEO's teacher-education programs and choice of robotics tool set.

Students and robotics education

Curriculum standards of national organizations and the Massachusetts curriculum frameworks place an emphasis on the importance of design for students [15, 16]. The design process encourages students to explore and apply their knowledge while gaining skills such as systematic testing, evaluation, and redesign. Often design problems provide students with a rich and engaging context for their knowledge [9]. Robotic design can explore subject areas such as simple machines, sequence and order, and control [17]. Additionally, these elements can easily be integrated into interesting contexts like exploring our environment, creating inventions, or building an artifact from a favorite story.

There are several important reasons for exposing young students to robotics. As our world becomes increasingly technological, students need experiences at an early age that enable them to become comfortable with and knowledgeable about technology. Robotics can often do this within a context students care about. This is especially critical for female and minority students,

as positive early exposure may contribute to persistence in MSTE courses and possibly careers [18, 19]. Additionally, including robotics throughout the K–12 curriculum will help prepare students to enter the workforce as technologically literate [20]. Robotics is an attractive approach to technology education because of its interdisciplinary nature, requiring expertise in a range of fields from mathematics to aesthetics. This can make MSTE subjects engaging for students who are not reached by traditional classroom lessons.

Work in the area of K–12 robotics began with Seymour Papert's Logo project [6] and continued at the Massachusetts Institute of Technology's Media Lab with LEGO/Logo projects [17, 21] and the development of a programmable brick [22]. The work continued at Tufts University through the CEEO and the LEGO RCX [23]. These projects explored what could be done with the developing technology, but did not systematically research learning or implement large school change. Projects at these institutions are now aimed at researching children's learning and thinking [24] as well as teacher education and classroom implementation.

Children learning about and through robotics is an area of research that is beginning to develop. One area of interest is what skills children develop using robotics that they would not gain otherwise. For example, Wagner found increases in the areas of science achievement and problem-solving skills with elementary students using robotics as compared to those in a traditionally taught science class [25]. Another area of interest is the design process undertaken by students during robotics activities. These processes can provide insight into what and how students learn. Studies such as those by Stein et al. and McRobbie et al. are providing the foundations of children's design processes. Students may not be learning explicit science or robotics content during these activities, but rather they are gaining an understanding and appreciation of the process of robotic design [26, 27].

While there have been many efforts to bring robotics into schools, there is little knowledge about projects making sustainable systemic changes to introduce an entire school's population to the subject.

The tool set

To teach engineering through robotics, a toolset is needed that is robust, powerful, and easy to use.

LEGO Mindstorm construction kits and the ROBOLAB software form the major components of the toolset utilized in the CEEO's efforts to teach math, science, technology and engineering. This toolset was selected for several reasons. The robotics kit is easily available for teachers to order and contains all the necessary pieces to take on significant projects (which eliminates piecemeal ordering). Despite being a self-contained "kit", the components are flexible enough to allow for open-ended design. While the materials are costly for some schools beginning robotics programs, they are reusable and durable, making them a worthwhile investment. The toolset has a low entry point and a high ceiling, allowing it to be used over a wide span of ages (kindergarten through college) and applications, thus preventing students and teachers from constantly having to adjust to new tools.

Comprised of three main components—LEGO pieces, the LEGO RCX, and the ROBOLAB software—the toolset allows users to create their designs relatively quickly and easily, thus allowing for more time to be spent learning the content being addressed. The LEGO pieces in the LEGO Mindstorms for Schools are from the LEGO technic line. This line includes the standard LEGO pieces most people are familiar with, including bricks, beams, and plates. In addition, it has a range of engineering elements including motors, sensors, gears, cams, pulleys, and axles (Fig. 1).

The LEGO RCX is a LEGO brick with an embedded microprocessor (Fig. 2). The RCX has three outputs for controlling motors and lights and three inputs for gathering information via sensors. It basically serves as "the brain" for robotic creations. The RCX communicates with a computer via infrared signals. It can store multiple programs and collect data from sensors.

To use the RCX in a robotic creation it must be programmed as to when to turn motors on and off, when to collect information, etc. Multiple environments for programming the RCX have emerged. The one used in courses at Tufts is entitled ROBOLAB and was developed via a partnership between Tufts University, National Instruments, and LEGO Education. ROBOLAB provides a graphical way to program the RCX on both PC and Mac platforms. Powered by National Instruments' LabVIEW, ROBOLAB allows users to program by connecting icons that represent
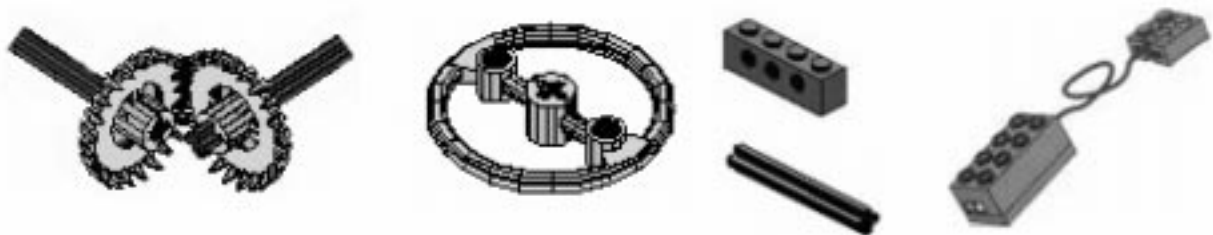

Fig. 1. LEGO technic pieces.

Fig. 2. The RCX.

commands. ROBOLAB has a tiered interface with multiple levels to allow different entry points for students of different ages and abilities [28]. The lower level, entitled *Pilot* (Fig. 3), allows children as young as four to program, while the higher level, entitled *Inventor*, has been used in fourth grade through college.

As users progress, they can develop more and more sophisticated algorithms by advancing to higher levels in the software. At the Inventor level (Fig. 4), users have access to all the capabilities of the RCX along with standard control and programming structures.

The toolset allows for a wide range of projects, from a basic solar system explorer (Fig. 5) to an orbiting planet car (Fig. 6) to a LEGO piano (Fig. 7).

The SSCE project

The CEEO has worked with hundreds of teachers around the globe through workshops
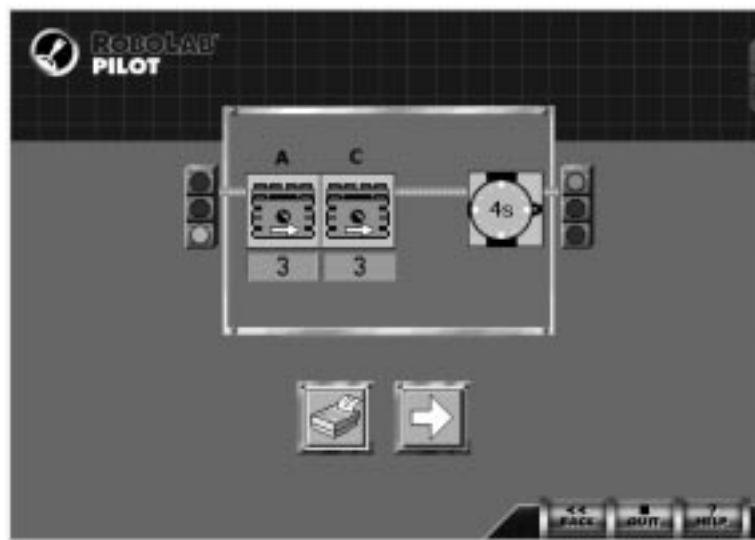

Fig. 3. At the Pilot level, users modify a basic template. This program turns motors on A and C at power level 3 for 4 seconds.
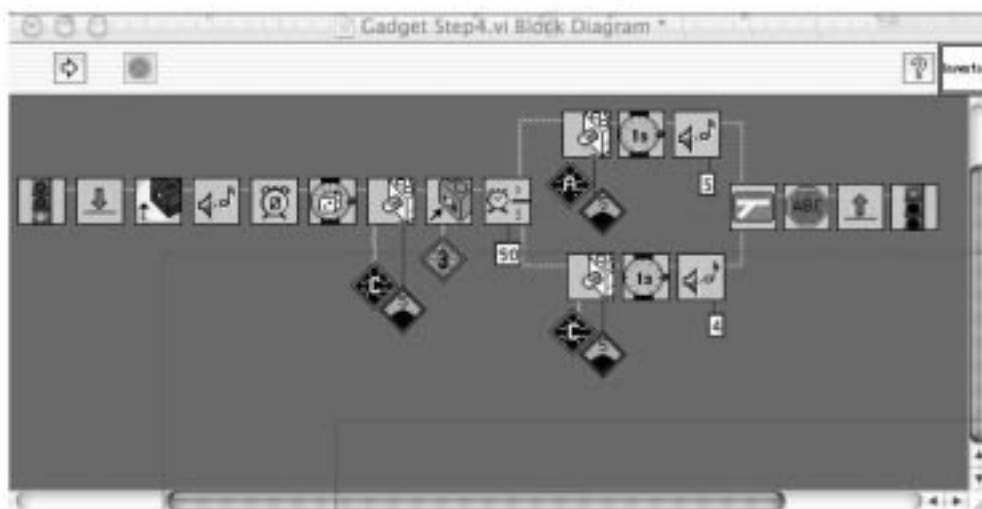

Fig. 4. Inventor-level programs allow users to connect icons in any order they wish in order to develop algorithms (that mimic the form of a flowchart).
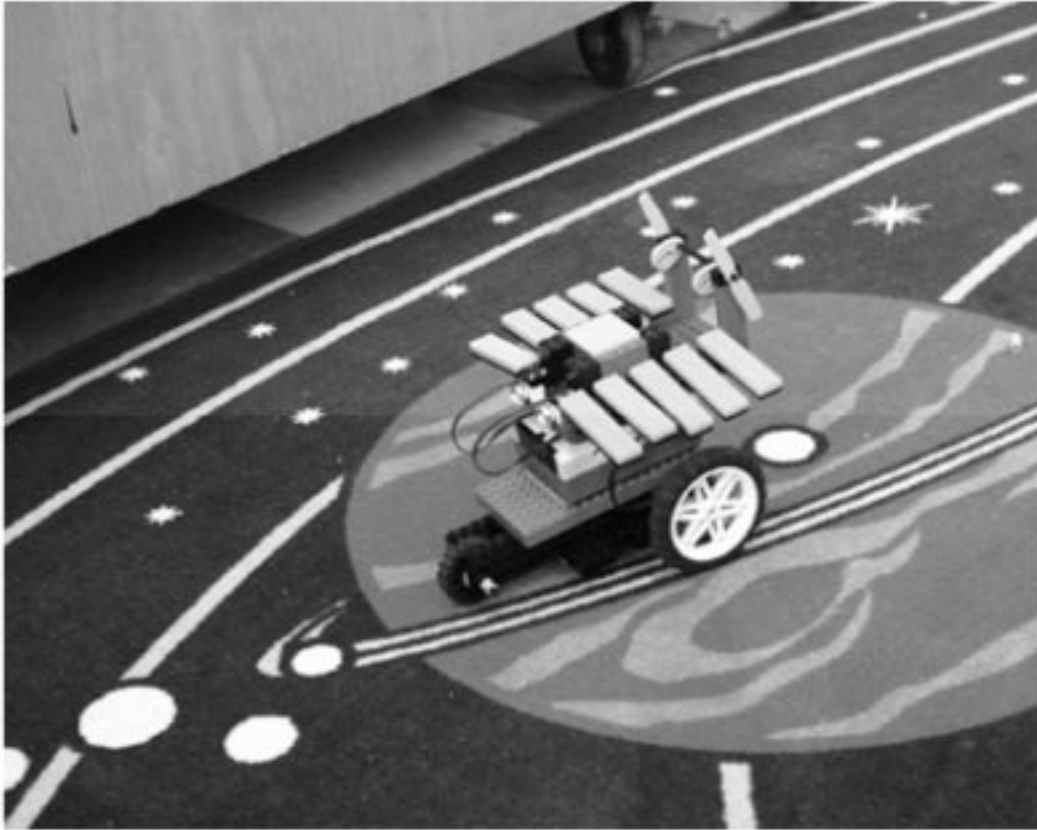
Fig. 5. A simple ROV that drives to a planet and aligns its "solar" panels with a light source during an activity in an SSCE classroom.
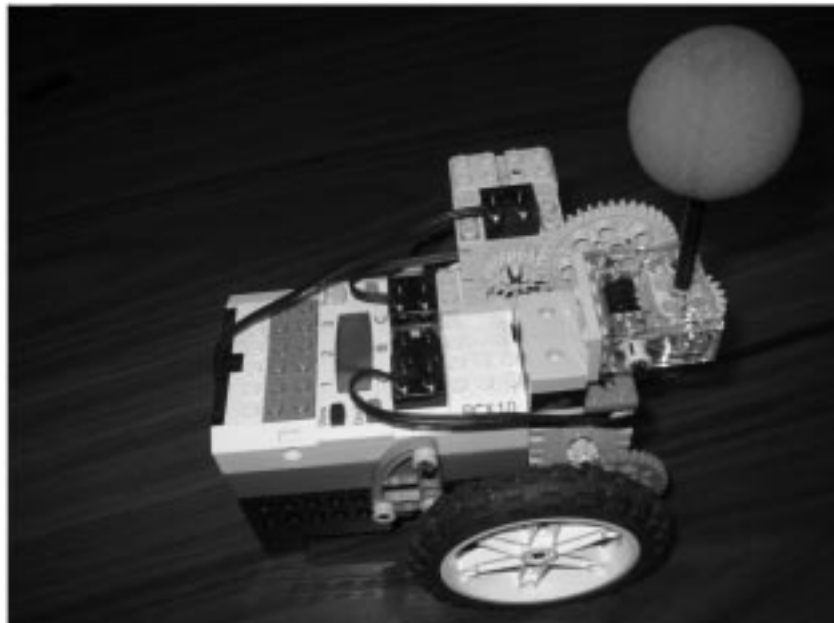

Fig. 6. A Lego planet car created by an SSCE advocate teacher.

and seminars. However, one of the center's most focused efforts is the Systemic School Change in Engineering (SSCE) project, which has worked to effect a systematic implementation of engineering and robotics in one school system in the American northeast. The SSCE project was developed to create an example school that would illustrate what engineering looks like in K–5 education and how students' understanding of robotics and engineering would develop if they were exposed to engineering concepts in every grade level. The CEEO worked with the SSCE school district to
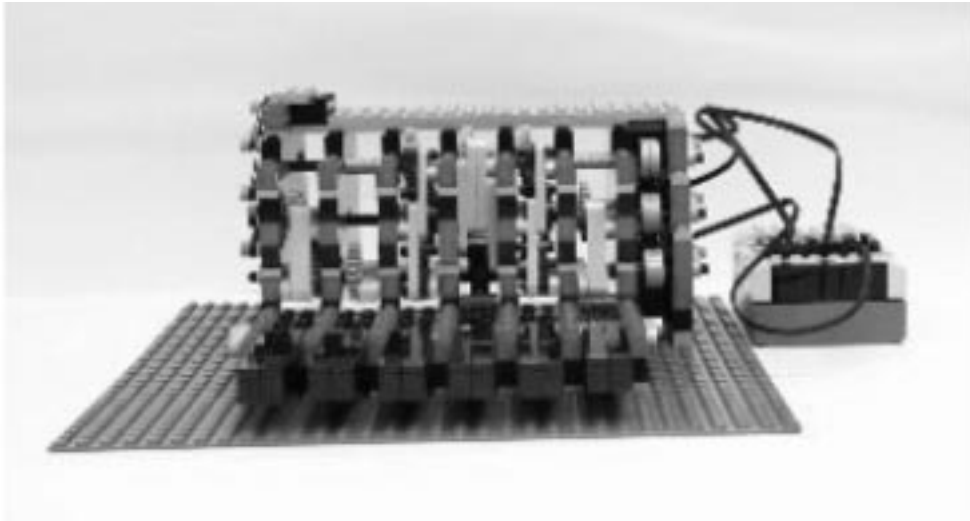
Fig. 7. A LEGO RCX piano created by a CEEO graduate student.

provide teacher education, materials, classroom support, and funding to implement engineering in the classroom through LEGO robotics.

Professional development

Each summer for four years, the CEEO has hosted a week-long workshop exclusively for teachers and administrators from the SSCE school district. The workshops, entitled "Lego Engineering", focused on teaching basic concepts of science and engineering (such as friction, gearing, and torque), the engineering design process, LEGO building techniques, and ROBOLAB programming. The workshops were organized around semi-structured and open-ended design challenges intended to model the types of projects and interactions the teachers would use with their own students. Challenges ranged from building "A Chair For Mr. Bear," a simple non-motorized LEGO structure, to creating a music box (Fig. 8), to designing a robot that would pick up chocolate from multiple locations in a room. The workshops do not prescribe a set curriculum for teachers to follow; instead, the teachers were given time to develop activities that would integrate with content they already needed to teach. The final day of each workshop culminated with teachers and administrators presenting their plan of how they would use the materials to integrate engineering and robotics into their classrooms for the upcoming year.

Teachers who attended the workshops received a computer and a set of LEGO materials for their classroom, as well as a personal stipend and points or units toward maintaining their teaching certification (graduate credit is not available). The stipend compensates teachers for attending the workshop in the summer, for attendance at monthly meetings during the school year, and for the development and documentation of one activity using the LEGO materials that they test in their classroom. The project, funded by federal and
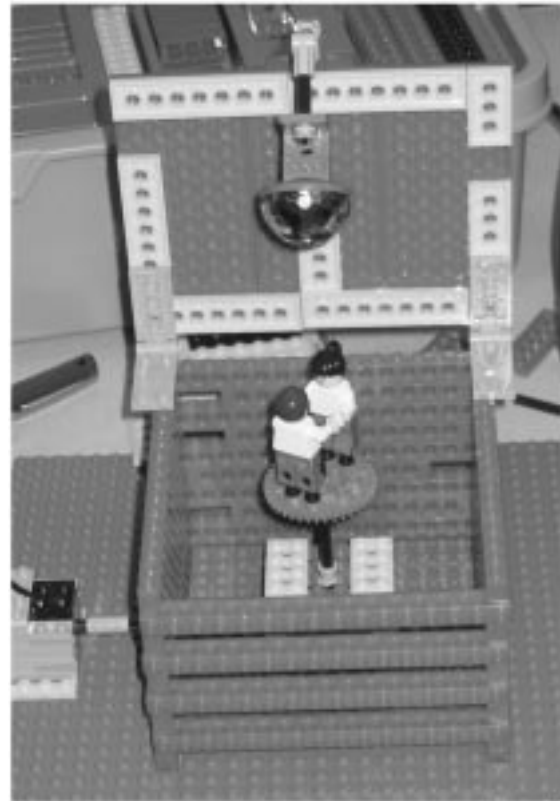

Fig. 8. Music box created by SSCE teachers during the summer workshop.

private foundation grants, aimed to fully support the teachers so they would easily be able to implement the project in their classroom.

Support

The CEEO planned monthly teachers' meetings (one hour after school) to discuss issues with the teachers and hold short refresher courses. Project managers and a selection of graduate students were available to help out in the classroom throughout the year. The teachers' demands for

Table 1. Explanation of implementation points

Point Value	Level	Definition
2 points	High level of implementation	Used LEGO for 10 or more class periods per year for multiple years
1 point	Medium level of implementation	Used LEGO for less than 10 class periods in a year
0 points	Low level of implementation	Reported one or more years of not using the LEGO at all or used it for less than five class periods a year

in-class help quickly outpaced the number of available graduate students, and it became necessary to establish a program at the CEEO to place undergraduate and graduate engineering students into the classroom. In addition, as demand continued to increase, a program was started to recruit parents from the district to volunteer in the classroom.

Teachers also began to request supplemental funding in order to develop formal activity sequences and curriculums in addition to what had been developed during the workshops. In collaboration with the teachers, undergraduate engineering students and graduate students in education developed these activities and curriculums at the CEEO. These were developed at the CEEO in cooperation with undergraduate engineering students and graduate students in education. The resulting documents contained worksheets and sequences that could be used by new teachers joining the program. Discussions with teachers indicate that having a structured curriculum to refer to is one of the most significant forms of support for classroom success outside of having additional support from university students or from parents. Thus, curriculum units were developed for first through third grades and activity units have been created for fourth and fifth grades. At first and second grades, which had some of the highest turn-over of teachers, these curriculum units enabled teachers to get started with the SSCE prior to attending a workshop.

Results

As the SSCE project progressed the participating teachers filled out surveys, held discussions with the CEEO staff, and were observed in their classrooms during robotics lessons. Evaluation of the project and the teachers' participation was conducted to gauge the project's success and inform future system-wide implementation efforts.

Enrollment in SSCE project

The workshop and the SSCE project were not conducted by the school administration; hence, participation in the workshops was strictly voluntary. Each year the workshop was advertised amongst the teachers, and any who wished to enroll was afforded the opportunity. In the first year of the SSCE project, the workshop attendees were primarily composed of classic "early adopters"—teachers who are always eager to try new ideas and technologies. These initial teachers started doing LEGO engineering in their classroom and the students loved it, eagerly anticipating "LEGO time" during the week. In subsequent years of the project, teachers who felt pressure from the students and other teachers to be involved in the program attended the workshop alongside the "early adopters".

Teachers' participation in the workshops and perception of the usefulness of what they were learning varied greatly. A rating system was devised to categorize teachers' participation and attitudes in the program. Three categories were examined and rated: *participation*, *implementation*, and *value*.

Participation: Records as to the year each teacher at a grade level participated in the workshop were analyzed and weighted:

- 2 points: First teacher at grade level
- 1 point: Second teacher at grade level
- 0 points: Third teacher at grade level or later

This aspect is important to determine whether teachers were leaders or followers in terms of trying new ideas in their classroom.

Implementation: Surveys and observations of teachers' use of the LEGO robotics activities were used to determine and rate the degree to which teachers made use of the materials, as explained in Table 1.

Value: Surveys and discussions with the teachers were used to determine the value that teachers believed the materials and curriculum added to the classroom. The point values assigned for this variable are explained in Table 2.

Table 2. Explanation of value points

Point Value	Level	Definition
2 points	Significant value	Teachers reported that the LEGO helped them to address previously neglected concepts and helped them to reach multiple types of learners
1 point	Standard value	Teachers reported that the LEGO was of similar value to other curriculum tools that they used
0 points	Less value	Teachers reported that the LEGO did not enhance their classroom teaching

Table 3. Teacher participation in SSCE classifications

Classification	Score
Advocate	6
Adopt	5
Accept	4
Abuse	3 or below

For each teacher, participation, value, and implementation scores were added, and then each score was used to assign teachers to a category.

1. *Advocate* – teachers who fell into the "advocate" category encompassed approximately 20 percent of the attendees. They liked the concept and thought it sounded "cool." These teachers were generally comfortable with technology and were successful at building with LEGOs and programming in ROBOLAB. These same teachers also indicated that they felt the materials addressed needs in their classroom with respect to students' learning styles and thinking styles. Comments like "This will really help me engage students like Josh who can never stay on task" and "This will really challenge the way some kids learn" were heard from these teachers.
2. *Adopt*—the teachers in the "adopt" category comprised the largest portion (roughly 55 percent) of the attendees. They generally became interested in the program after seeing it in action in their own grade or having someone come in and demonstrate the concept in their classroom. Success in building and programming varied tremendously within this group.
3. *Accept*—teachers in the "accept" category made up approximately 20 percent of the teachers. These teachers became involved because of pressure from other teachers, students, or parents ("The rest of forth grade does LEGO engineering, why doesn't your class do it?"). Success in building and programming varied within the group, though a considerable number tended to be less comfortable with the technology.
4. *Abuse* – only a small percentage (5 percent) of teachers were in the "abuse" category. These teachers participated in the workshop strictly to receive the stipend and the computer for their classroom. They participated in the workshop but had little interest in the project as a whole.

Implementation

Having attended the workshop during the summer, the teachers returned to their classroom each fall to implement the project. How the teachers proceeded with this implementation varied greatly. Generally each year 10 to 20 percent felt unable to implement it that year due to time or support constraints. The large majority of the teachers (60 to 85 percent) did between one

to three stand-alone projects (for two to four weeks). The last group (5 to 10 percent) established LEGO engineering as a weekly or bi-weekly activity for a majority of the school year. Implementation was not necessarily correlated to teachers' workshop participation.

Those who were unable to implement the project at all often had scheduling, time, or support difficulties. Those who successfully implemented the project (often in the "adopt" or "accept" category) generally had either strong classroom support or another teacher in the "advocate" category at their grade level. The correlation between participation in the workshop and success in the classroom is an area that needs to undergo further research.

In the classroom

At first, activities were sporadic and varied widely in the content and level of difficulty. This was to be expected, as initially all students, regardless of grade level, had to be introduced to the pieces and basic concepts as it was new material. However, as the project continued, a progression of topics evolved that spiraled and revisited topics in subsequent years to reinforce concepts—supporting Bruner's notion of a spiral curriculum which allows students to gain deeper understandings as they revisit a topic or concept [29].

Students in the early grades gain fundamental concepts of construction, force, and programming and gradually reach advanced topics of algorithm development and project management. In the elementary school, children can learn about robotics and engineering through math and science and vice versa. Students learn about the design and construction of robots, intelligence, and control through programming, as well as the process of testing and refining. While some areas of robotics, such as sensor design, are not reached at such an early age, the foundations of working with sensors and robotics are laid so that students are more prepared to conquer these topics in the future. Table 4 shows the concepts that are targeted at each grade level and a sample project used to address those concepts.

Per the requirements of the program, each teacher participant had to generate and test an engineering activity in their classroom. These activities are posted at the CEEO's ROBOLAB@-CEEO website (http://www.ceeo.tufts.edu/robolabatceeo). The curriculum units developed by teachers through supplemental SSCE funding are also posted (in PDF form) on this site. The SSCE has generated a majority of the content on this site which during the 2003–2004 school year received over 140,000 visits (with individual curriculum units being downloaded by up to 14,000 visitors). The site is the most successful and most visited section of the CEEO's overall website.

Ramp climbers in first grade

One of the successes of the SSCE program is a full curriculum for the first grade that was devel-

Table 4. Basic outline of topics and sequence

Grade	Engineering concepts	Science and math concepts	Sample Project
Kindergarten	– Sturdy structures – Elementary programming	– Forces	Build a sturdy wall
1st grade	– Sturdy structures – Gearing and motion – What is an engineer? – Testing and redesigning	– Forces and torques – Prediction and estimation	Build a vehicle that can survive the drop test
2nd grade	– Sturdy structures – Gearing and motion – Levers and pulleys	– Decimal numbers – Mechanical advantage – Graph generation	Build and program an amusement park ride that uses pulleys
3rd grade	– Sturdy structures – Gearing and motion – Modeling and calibration	– Graph interpolation and extrapolation – Multiplication applications	Build a car and program it to travel exactly two meters
4th grade	– Advanced programming (algorithms) and automation – Hypothesis testing	– Scientific method – Design of experiments	Design a vehicle to rescue an astronaut from a space station
5th grade	– Problem definition – Redesign and optimization – Competition and collaboration	– Heat transfer – Acids and bases – Scientific method	– Design a voting booth

oped by SSCE teachers in conjunction with the CEEO. The students are first introduced to engineering and the LEGO pieces. They then learn about sturdy building techniques and simple machines. Next, students begin to program their robotic creations, with the year culminating in a final project. In one of the lessons for the first grade, which illustrates what robotics can look like in the primary grades, students build and program a robot to climb a ramp.

During this lesson the students learned about gearing and sturdy building, making tradeoffs (speed versus torque), and controlling a robot (Fig. 9). They had to test their cars on flat surfaces, smooth ramps, and a carpeted ramp (Fig. 10).

When the robots did not perform as they would like, the students had to redesign their cars.

Student outcomes

Data collection on student outcomes and interactions was not the initial focus of the SSCE project, though it is planned for future years once the instruction has stabilized across grade levels. However, preliminary qualitative observations of students indicate that students are capable of understanding science and engineering concepts at a young age when they are engaged in relevant robotics projects. In first grade, for example, students will often examine each others vehicles and provide recommendations for improvements:

Fig. 9. Students working on their ramp climber.

Fig. 10. Testing the ramp climbers.

"Your car is slow because your wheels are touching the side and you have too much friction."

Informal year-to-year discussions with students seem to suggest that students retain a significant proportion of content, process, and tool knowledge. Teachers have noted that they can tell the difference between students who have participated in the project for multiple years and those who have not (by virtue of transferring into the school system or placement with non-participating teachers). They point to skill level as well as persistence in and approach to designing as differentiating factors.

Summary of results

As of spring 2004, 43 teachers and two administrators from the SSCE school district had attended workshops with the intent to participate in the program. Fifteen percent (7) of those teachers are no longer with the school district, having moved on to other locations. The remaining 36 teachers represent approximately 80 percent of the K–5 teachers in the SSCE district. Of the remaining teachers, an estimated 85 percent use LEGO in their classroom and plan to continue doing so in the future. Spring 2004 surveys and discussions with teachers indicated a high level of satisfaction with and commitment to the program. One teacher commented, "If the school wouldn't let me use LEGOs in my classroom, I think I would have to find another job." This attitude demonstrates the value and importance of the LEGO education program to these teachers. However, teachers still report low confidence in their building and programming abilities. Issues of support and time ranked highest among teachers as continued difficulties in implementing the project in their classroom. The school administration and the CEEO are currently working together to phase in more school administrative support and management (with great success and enthusiasm) in preparation for less financial and classroom support from the CEEO.

FUTURE DIRECTIONS

The SSCE project has led to a number of research initiatives that are now being pursued at the CEEO. In addition to data collection on student outcomes, researchers at the CEEO are particularly interested in finding ways to increase teacher confidence in their building and programming abilities in order to improve levels of classroom implementation. To do so, projects are aimed at gaining an understanding of the learning and design processes employed by inservice teachers while they are participants in professional development workshops. Specifically, research is beginning to explore the nature of modeling classroom teaching practices during professional development robotics workshops. While the CEEO still maintains a constructionist philosophy in both classroom and workshop situations, the research is beginning to indicate, as Deborah Ball has said, that "the simple adage that teachers should be taught as they would teach students, is likely *too* simple" [31]. This research is comparing current practices and exploring new practices in order to improve the quality of teacher-education programs. Efforts are also being made to extend the evaluation of the effects of robotics education longitudinally and across disciplines. Projects are looking at how female students approach robotics from kindergarten to college, how supporting robotics in the K–12 classroom affects college

students, how robotics learning is impacted by different learning styles, and the differences between robotics in classrooms and in after-school settings.

CONCLUSIONS

Bringing robotics into the K–12 classroom continues to be a challenge. However, the results of the SSCE project helped to illuminate issues that will help other organizations or institutions interested in attempting systemic adoption of robotics and engineering education by a school or school system. The CEEO offers three main recommendations for such a project:

1. To reduce the number of teachers who fall into the "abuse" category (or fail to implement the program), the incentives should be restructured in a way that ties them more directly to deliverables. The stipend, for example, should be awarded in smaller increments throughout the year as activities are developed, tested, and submitted.
2. SSCE was initiated from the bottom up, with teachers electing to participate in the program and integrate it into their classroom. This method had several benefits in terms of the teachers being very excited and maintaining ownership of the program. Teachers in the "advocate" category managed the program and worked to maintain and expand it. This was an effective recruitment and advertising tool, as other teachers could easily see how it might be used in their classroom. However, as the program progressed needs arose that required administrative decisions and support. Greater involvement of the administration from the outset would make sustaining the program and transferring the management of the program to the school easier.
3. Data collection for the purposes of understanding the students' participation in the program was not part of the original design of the SSCE project. This should be incorporated as early as possible in a future project in order to collect baseline data on the students affected. This data can be used to analyze the effects of incorporating robotics into a school program and the methods through which this can be done.

The SSCE project has demonstrated to the CEEO that systemic change in a school is possible with a great deal of commitment and support. The preliminary qualitative data gathered from students and teachers are encouraging. The unique opportunities for learning and research provided by the SSCE project continue to inspire efforts amongst SSCE teachers and administrators as well as CEEO staff and researchers to increase the breadth of our knowledge of and abilities in robotics education.

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