School Robotics Initiative - An Outreach Initiative to Prepare Teachers and Inspire Students to Choose a Career in Engineering and Science

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Abstract

Declining enrollment in science, engineering and technology at college level is a serious problem facing this nation. Experience indicates choosing engineering as a career is made as early as in middle school. Students behind in math and lacking interest in science and technology at elementary and middle school level perform poorly in high school and are unlikely to choose careers in engineering and science. Even if they do choose engineering in college, their lack of high school preparation puts them in remedial programs thus placing them several years behind.

Through a private foundation grant, Cal Poly Pomona has developed an engaging, problem-based robotics program for K-12 students. The objective of the School Robotics Initiative is to reach the students early on at elementary and middle school level and inspire them through engagement in authentic problem-based activity. In addition, to ensure the long term sustainability of this program, K-12 teachers will be trained and supported so that they can continue to conduct the program independently.

The field of Robotics is chosen as the platform to launch this program because Robotics is increasingly being considered as the Fourth essential **R** (after the 3 Rs, **R**eading, w**R**iting and a**R**ithmetic). Robotics is a truly multi-disciplinary field which combines mechanical, electrical, electronics engineering and computer science. Even though robots are very complex machines and building robots require multidisciplinary skills, current technology makes it possible for everyone to build, program, and control their own robots. Experience indicates that learners who are immersed in the activity, acquire important skills in math and science without realizing that they are intensively engaged in the learning process.

Building robots:

- Makes learning fun, engaging, and inspiring
- Provides highly practical hands-on experience
- Gives a head-start in preparing for high school and college.
- Develops critical thinking skills and problem solving strategies
- Enables learner to develop and express creativity
- Develops the ability to work collaboratively in teams
- Helps to excel in math and science and choose a career in science and technology
- Enables learner to appreciate and realize technology

A grade-appropriate robotics program for elementary for 4th and 5th grade and middle school students has been developed and the pilot program is being conducted in two elementary schools. This paper will present various aspects of this outreach program including the design, methodology, weekly projects and learning experience.

Introduction

The School Robotics Initiative seeks to improve student and teacher learning in regional schools and prospective teacher learning at the university. It is based on the establishment and gradual expansion of a network of regional schools that will develop robotics-learning programs linked to Cal Poly Pomona technological resources and faculty in education, psychology, and engineering. The School Robotics Initiative is implemented as a problem-based curriculum approach designed to enhance cross-curricular learning (with an emphasis on mathematics, science and writing) at the levels of elementary through high school.[1] As it evolves, this effort will involve industry and academic experts in the assessment of student performance in order to improve the learning of participants (i.e., students, teachers, and prospective teachers).

First-year activity began with the establishment of the robotics programs at two elementary schools, and it will be expanded in subsequent years to include a larger network of elementary, middle, and high schools. The project includes a research component that supports project improvement and informs broad dissemination of knowledge and expertise gained through initiative activity.

This paper describes the goals, accomplishments, and future direction of the School Robotics Initiative. Formal work on this first-year phase of the project began in September 2006 and will continue through August 1, 2007.

Educational Context

This initiative seeks to make a positive impact on K-12 education in the context of growing national concerns about the ability of U.S. schools to successfully prepare students for the workplace and higher education. Issues that have received the most intense national attention are the unacceptably low high school graduation rates, the poor preparation of entering college freshman, and the inability of our schools and colleges to meet the growing demand for graduates who will help the U.S. retain its global lead in science and technology.

Nationally, only about 68% of all students who enter 9th grade will graduate "on time" with regular diplomas in 12th grade. While the graduation rate for white students is 75%, only approximately half of Black, Latino, and Native American students earn regular diplomas alongside their classmates. Graduation rates are even lower for Black, Latino and Native American males. [2]

Locally, the widely publicized, drop-out rates and failure rates in algebra in the Los Angeles Unified School District further highlight the severity of problems in large urban districts. In the fall of 2004, 48,000 ninth-graders took beginning algebra; 44% failed these courses, nearly twice the failure rate as in English. Seventeen percent finished with D's.[3]

A Harvard study reported that "only 48% of the minority students enrolled in ninth grade in the fall of 1998 successfully completed high school in the district four years later."[4]

There is also concern for students who manage to graduate.[5] A 1996 study reported that 81% of four-year colleges in the U.S. offer remedial courses and 30% of incoming freshmen require remediation.[6]

A 2006 National Academies committee report calling for improvement in K-12 science and mathematics education lists the falling rate of innovation in the U.S. and the increase in outsourcing of information technology jobs to other countries among the reasons for concern about the inadequate size of our locally developed talent pool in math, science and engineering.[7]

Goals of the School Robotics Initiative

The School Robotics Initiative seeks to develop a network of schools in communities surrounding Cal Poly Pomona that will use robotics and a diverse range of expertise from both professionals and faculty who work directly in this area of technology. This expertise will complement the learning of participants across the curriculum, but it will have a particular focus on mathematics, science and writing, weaker areas of achievement in K-12 education that often lack teacher expertise. The project is premised on (1) the availability of a full complement of experts on the given topic; (2) the recognized significance of a topic that is both relevant and engaging to students; (3) the Cal Poly Pomona's comprehensive resources as a polytechnic university; and (4) the need to produce a program that can be scientifically assessed and yet is capable of both refinement and increased difficulty as it is expanded to higher grades.

We believe that the opportunity to work collaboratively on in-depth challenges in robotics at the various grades has the potential to promote creativity and proficiency in problem solving, boost student attendance, promote academic engagement, and stimulate interest in technical careers. In addition, we contend that increased student engagement is likely to benefit graduation and college attendance rates as well as reduce discipline problems. Participating teachers will receive professional development as they work with university faculty and students. Cal Poly engineering students, who receive service learning credit for assisting us with the classroom robotics activity, learn about working with young learners in culturally diverse classrooms. Because school activity will be linked to Cal Poly Pomona's teacher education program, the initiative will afford teacher candidates greater access to innovative field practices that reflect practices endorsed by the Cal Poly Pomona Department of Teacher Education.

Implementation

In the first year of the Initiative, the robotics programs were introduced into two local elementary schools. Fourth- and fifth-grade students in two classrooms are working for two hours per week through robotics curricula tailored to the schools' specific circumstances. Using LEGO® Mindstorms NXT robotics kits, the students are progressively developing expertise in robotics design and construction as well as associated knowledge and skills in math, science, and technological literacy. Activity will culminate with an annual "Robotics Rally," hosted by the university, at which students will demonstrate their creations.

The Initiative will be expanded in subsequent years to include a larger network of elementary, middle, and high schools. The two elementary schools where activity has begun are serving as pilot programs where research and development work can be carried out. Although the programs are being flexibly implemented in order to accommodate the specific needs and challenges associated with the participating schools and their communities, our desire to tie our program into the standard school curriculum dictated that robotics activity be integrated into the regular school day, thus ruling out after-school programs or clubs.

The Initiative links to Cal Poly Pomona programs in a number of ways through the participation of faculty from the Engineering, Psychology and Education departments at Cal Poly Pomona. Collectively, this interdisciplinary team contributes expertise in engineering, working with robotics in schools, implementing effective team activity; and analyzing the learning of the participants (students, teachers, university students, and university and industry experts) and the intended skills and creativity that the program promotes.

The robotic programs are expected to become self-sustaining within a few years of their inception. However, the university will need to continue to provide the necessary expertise through faculty and undergraduate participation. Even as new schools are added, research will continue in the original schools. The effort will serve as the basis for establishing long-term, mutually beneficial relationships among a network of neighboring schools and Cal Poly Pomona professional and academic programs in such areas as teacher education, engineering, psychology, math, and science. A vital dimension of the Initiative calls for the development of relationships with participating schools that emulate the Professional Development School model (PDS).[8]

The two participating elementary schools represent opposite ends of the socioeconomic spectrum. Royal elementary is in an underperforming school district in severe need of assistance.[9] The other elementary school, University elementary, is a high-performing Cal Poly Pomona PDS (professional development school), located in a middle-class community. The decision to work with two schools with disparate socioeconomics is based on the desire to harness the learning benefits to students, both academic and social, that result from interacting in culturally and socially heterogeneous learning environments. Repeated opportunities will be created for the students from both schools to interact online and through organized robotics exhibitions and competitions at the university.

The robotics programs are to be headed by participating school teachers who receive pedagogical coordination and technical support from faculty members at Cal Poly Pomona. Ultimately, the teachers will determine if and how the program is integrated into their curriculum. The role of extramural experts—that is professors, industry scientists, and undergraduate engineering students—is central to the project. This group will supply the much-needed bridge between the early education of students and the demands of the workforce and higher education. They will introduce, demonstrate, and apply the assessment criteria and processes of applied science as they guide and assess the students' work.

Curriculum development at each school will proceed gradually, collaboratively, and in a principled manner that is free of peripheral constraints and features ongoing cycles of assessment, reflection, and revision. The curricula related to the Initiative will be developed and revised in relation to relevant California and national content standards. In the long-term, curricula will be developed at the middle- and high-school levels, based on implementation experience at the elementary level.

A long-term goal of the Initiative is to develop a network of schools that will give interested students the option to participate in robotics from elementary through high school. This will substantially broaden project-based learning opportunities for students and allow them to participate in a 7- to 8-year "apprenticeship," afforded by the network, which, in turn, is supported by a range of professional and academic experts in the field. Participating students will emerge with much-needed understanding and skills, and, we believe, they will be far better prepared to succeed in college. With this network in place, student progress could be tracked and monitored from elementary through middle and high school up until college admission.

Weekly Projects

Weekly projects have focused on developing a student foundational understanding that will prepare them to meet open-ended design challenges by year's end.

The following are the sequence of assigned tasks:

1. Construction of robot driving base with simple programming tasks
2. Programming driving base to travel two meters in a straight line at half speed, turn right 90 degrees and travel one meter at a higher speed, stop, reverse half a meter and make a noise.
3. Program driving base with light sensor to travel the interior of an elevated circular region without falling off the edge.
4. Use a programming loop to instruct robot to drive the perimeter of a two meter square.
5. Construction and programming of a robot with touch, ultrasonic and light sensors that performs a series of consecutive maneuvers: Reverse and turn at a precipice (outlined by a black line), approach an obstacle (a box), reverse when ultrasonic sensor detects proximity of box, turn, approach and bump another box, then reverse once again.
6. Construction and programming of a robot that sweeps scattered LEGO parts off elevated circular ring within 20 seconds.
7. Construction and programming of robot that mimics inchworm locomotion.

Some of the tasks have required more than one weekly session to complete.

Early Insights

The project has yielded rich insights in the brief period since implementation. These early lessons relate to governance and leadership, observed curricular ties, participant satisfaction, and orchestration of learning.

School Governance and Leadership

Identifying schools with supportive school and district administrators was essential to the successful implementation of the first phase of the project. Three months were dedicated to finding and setting the foundation for work to begin at these schools. Both schools and their districts have supported the program enthusiastically from its inception. They have facilitated our implementation by contributing resources to the effort and offering flexibility in scheduling and use of facilities.

Choosing the appropriate teachers has been beneficial. The two participating teachers are experienced, talented professionals who from the beginning demonstrated commitment and flexibility by seamlessly adjusting their schedules and classroom structure to accommodate the demands for space and time of the robotics activity. Their experience is readily apparent in their teaching practices, which emphasize student collaboration and extensive writing opportunities. Their students are enthusiastic, industrious, friendly and appreciative of our efforts.

Ties to the Math and Science Standards

Our classroom activity has already yielded considerable relevant information. For example, it immediately became evident that our program brings grade-relevant mathematical thinking to the forefront. For example, early evidence suggests that the robot-construction process demands and develops spatial-reasoning skills that address the 5^{th}-grade California Mathematics Content Standards (e.g. standard 2.3 Measurement and Geometry) essential in high school geometry. [10] Further, our observations suggest that this experience promises to be especially beneficial to our female participants given that, historically, girls encounter fewer opportunities than boys to develop their spatial reasoning through play (e.g., with TINKERTOY® or LEGO®).

We have also observed exciting evidence that students are applying inventive approaches to solving emergent mathematical problems. For example, in one of the programming challenges we provided the students, robots had to travel a distance of 2 meters. Programming options allowed students to designated the number of seconds of travel or the number of rotations (or degrees of rotation) of the robot's wheels, but not the distance. This created the need to solve a *rate* problem, which represents a linchpin concept in the K-12 math curriculum. The multiple approaches demonstrated by students were fascinating and suggest the importance of problem-based approaches, such as our robotics activity, in developing student intuition and capacity for mathematical problem solving.

Relevant science-related understandings were also immediately evident. Most notably, we witnessed how our robotics activity depends centrally on students' ability to design, test and modify their creations in order to meet specific performance demands. This feature of the program aligns well with the Investigation and Experimentation dimension of the California Science Content Standards for 5^{th} grade which directs students to develop and test scientific questions. Making mistakes is an essential element of this process, which one student recognized when she wrote to us, "I really have learned a lot from my mistakes." Another student wrote, "I can't wait for next week… last week I was prog[ramming] my robot. It was hard for me…I learned that it takes a long time to pro[gram]." These are important early insights for students in a schooling system that traditionally has reduced learning to a series of abbreviated, strictly demarcated and narrowly specified tasks. Tasks like these provide few opportunities for students to engage in the inventive, experimental processes associated with creating, solving problems, resolving situations, and achieving goals in the world beyond school.

There are many other science-related understandings embedded in robotics design related to force, energy, and systems which we anticipate will reveal themselves in a variety of ways in these classrooms. Evidence of additional curricular ties such as expository writing is also emerging. The evidence we seek of relevant cross-curricular ties such as these will support the case we are building for our curriculum approach as a valid reform effort.

Satisfaction of Participants

We are seeing tremendous student, teacher and parental satisfaction, an important dimension of this initiative if it is to develop into a sustainable and enduring curricular reform. As with most curricular reforms, which call for a substantial change in daily practices, this project has the potential to be rejected if its benefits do not far outweigh the added demands it creates.

Thus far, students have been extremely enthusiastic: the kids at one school have spoken and written exuberantly about their enjoyment; kids at both schools wave to us from across the school yard when they see us arrive on campus; and often thank us when we leave. Moreover, the teachers and parents report that the students demonstrate a high degree of anticipation between our weekly visits. One of our participating teachers quipped, “It’s like Christmas every Tuesday.”

A very encouraging sign of the viability of our reform effort is that both teachers repeatedly engage the children in robotics work in our absence. This evidence suggests that our goal – that teachers will progressively become independent as their knowledge of robotics grows – is quickly coming to fruition.

It is also important that the faculty and engineering students involved also find the experience fulfilling. The three participating faculty members have expressed satisfaction with their involvement thus far; and evidence is emerging that the engineering students are finding the experience enjoyable and satisfying.

Orchestrating Learning

We are also learning important lessons about how to organize activity so that students can accomplish complex robotics design tasks. Research in this area is in its infancy, especially with regard to efforts at the early grades (i.e., 4^{th} and 5^{th} grade). A key challenge is to demonstrate how one can orchestrate a series of classroom experiences, which feature assessment by outside experts or consultants that will result in continuous student and teacher learning of robotics design with concurrent development of capabilities for self-directed learning. We have many questions in this area and will continue to refine our inquiry.

We are witnessing the tremendous opportunities for peer learning afforded by the interactive classroom environments we are organizing in our two schools. Therefore identifying optimum classroom *participation structures* will be central to this inquiry.[11] This will require matching the needed configurations, and rights and responsibilities of participants to desired goals.

Future Direction

Research Approach

As the School Robotics Initiative is in its initial stages of implementation (Year 1), our goal will be to continue pursuing an in-depth formative evaluation of the program. Formative evaluation is typically conducted for the purpose of improving a program, and occurs while program activities are forming and/or happening. Formative evaluation focuses on the *process.*[12]

A triangulated approach of data collection will be used to obtain ongoing feedback on SRI program activities from a variety of stakeholders (teachers and school administrators, elementary school students, Cal Poly Pomona Engineering student volunteers, and parents). These measures will include: in-depth interviews with teachers and administrators, reflection journals from program participants, open-ended questionnaires from parents, and appreciative inquiry assessment reports from Cal Poly Pomona Engineering student volunteers enrolled in project's service-learning courses. Appreciative Inquiry (AI) is a process of assessment which is based on the overriding philosophy of building on what programs are already doing well, rather than trying to pinpoint problem areas and fix what is not working.[13] In essence, AI is a particular way of asking questions and envisioning the future that fosters positive relationships and builds on the basic goodness in programs and the practices within them. AI has been used extensively to foster change in businesses (a variety of sectors), health care systems, social profit organizations, educational institutions, communities, local governments, and religious institutions.

In addition to an extensive formative evaluation of the program, we will develop summative measures to track student performance in the SRI, and to document other outcomes from the program as well. In summative evaluation, the focus is on results or outcomes.[14] For this purpose, we will – (a) devise tests to assess student learning, (b) have experts review the robotic products generated by the students, (c) examine related standardized scores and grades of participants in related areas, and (d) for the long term, use a pretest posttest design before and after the students are introduced to robotics to gauge changes in student attitudes about STEM.

Questions to Pursue

We will continue to identify curricular ties to standards-based curriculum and continue to explore how to orchestrate a progressive set of curricular experiences that will lead to desired learning. This will entail continuing to identify the disciplinary principles and concepts we wish students to learn, both in the long (over a semester) and short term (2 hour session). We also need to explore the proper balance and timing of individual versus group work, and of isolated robot designs v designs that build on previous; benefits and limitations of tasks that are exploratory, open-ended design challenges, strictly specified design tasks.

Our inquiry on our classroom activity has brought many questions to the foreground. Among these several merit mentioning here. First we realize the importance of understanding the situated benefits and limitations of highly structured design tasks, direct instruction, and open-ended challenges which sustain student exploration and discovery activity. Developing principled rationales for the choice of tasks and their order is an essential piece of the program and a fundamental challenge. An associated question relates to the preconception that young students prefer concrete (building) over abstract (programming) activity seems so far to not hold up in our classrooms and merits further study. Insights in this area will affect our choice and ordering of tasks.

Expansion of Project

The project plan calls for the addition to the program of an elementary- or middle-, school classroom within the next two years with concurrent research in the participating schools. Additional classrooms, to include high school, will be added incrementally in subsequent years.

Summary

In its first year, the School Robotic Initiative has implemented robotics curriculum in two elementary-school classrooms as part of a long-term plan of affecting a larger network of schools that includes middle and high school. Early evidence suggests that the program is achieving its goals of positively affecting student and teacher learning in regional schools and prospective teacher learning at the university. Reflection on first year activity continues to inform development of our evaluation plan as we focus our research questions. The viability of this reform effort depends on our ability to orchestrate practical and effective classroom learning, and to identify the curricular ties of our robotics activity to the standard curriculum. We believe these are achievable goals.

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[1] Robotics is a multidisciplinary field that combines mechanical, electrical, electronics engineering, and computer science. Even though robots are very complex machines and building robots requires a range of skills, current technology and related, age-appropriate pedagogies make it possible for everyone to build, program, and control their own robots.

[2] Dan Losen and Johanna Wald, *Confronting the Graduation Rate Crisis in California* (Cambridge Mass.: The Civil Rights Project, Harvard University, March, 2005).

[3] Duke Helfand, "The Vanishing Class: A formula for failure in L.A. schools," *Los Angeles Times*, 30 January 2006.

[4] Dan Losen and Johanna Wald, *Confronting the Graduation Rate Crisis in California* (Cambridge Mass.: The Civil Rights Project, Harvard University, March, 2005).

[5] At Cal Poly Pomona, the proficiency in English of regularly admitted, first-time freshmen in Fall 2003 was calculated by ethnicity as follows: American Indian, 37.5%; African American, 36.1%; Mexican American, 41%; Other Latino, 37.4%; Asian American, 34.6%; Pacific Islander, 54.5%; White Non-Latino, 66.2%; Filipino, 40%; Unknown, 56.9%; Nonresident, 20.3%. In total, only 46.4% of freshmen were deemed proficient in English.

[6] Laurie Lewis and Elizabeth Farris, *Remedial Education at Higher Education Institutions in Fall 1995*, (Washington, DC: U.S. Department of Education, National Center for Education Statistics, 1996): NCES 97-584.

[7] From *Rising above the gathering storm: Energizing and employing America for a brighter economic future*, by Committee on Science, Engineering, and Public Policy (Washington, DC: The National Academies Press, 2006)

[8] "Professional Development Schools are schools that have joined with a university to accomplish common educational goals that include developing exemplary practice to maximize student outcomes, providing optimum sites for pre-service teacher training, offering connected in-service teacher professional development and implementing reflective inquiry to enhance teacher and student learning and development." (Excerpt from http://coe.winthrop.edu/pds)

[9] Names of elementary schools and students are pseudonyms.

[10] *Mathematics Framework for California Public Schools: Kindergarten Through Grade Twelve,* by California State Board of Education (Sacramento, CA: California State Board of Education, 2000)

[11] Erickson, Frederick and Jeffrey Schultz (1997). When is a context? Some issues and methods in the analysis of social competence. *In* Mind, culture, and activity: Seminal papers from the laboratory of comparative human cognition. Michael Cole, Yrjo Engeström and Olga Vasquez eds. Pp. 22-31. Cambridge: Cambridge University Press.

[12] Scriven, M. (1991). *Evaluation thesaurus*. 4th edition. Newbury Park: Sage Publications.

[13] Cooperrider, D. & Whitney, D. (2005). *Appreciative inquiry: A positive revolution in change*. San Francisco: Berrett-Kohler.

[14] Scriven, M. (1991). *Evaluation thesaurus*. 4th edition. Newbury Park: Sage Publications.