

## Using Modern Sensors in High School Science Labs to Promote Engineering Careers

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**Abstract** — A student’s first introduction to engineering and technology is typically through high school science. Unfortunately, science labs often make use of antiquated tools that fail to deliver exciting lab content. As a result, many students are turned off by science, fail to excel on standardized science exams, and do not consider engineering as a career.

This paper reports on the results of Project RAISE: *Revitalizing Achievement by using Instrumentation in Science Education*. RAISE is a partnership between Polytechnic University and several New York City (NYC) high schools that is funded by the National Science Foundation (NSF). By using sensors and computerized data acquisition in science labs, RAISE seeks to enhance students’ academic achievement; excite them about science, technology, engineering, and math (STEM); and inspire them to pursue STEM careers. A description of the project, along with some of the sensor-based experiments that are in use, are presented along with lessons learned, and assessment outcomes

### BACKGROUND

American Universities must recruit, train and graduate large numbers of scientists and engineers in order for the United States to sustain its “innovation economy” (Friedman, 2005). Education for engineering and technology careers has always been considered more rigorous than education for other careers. Over the previous 50 years, interest in STEM careers was propelled by the Cold War (AEA, 2005). However, with the end of the Cold War interest in STEM careers waned (Council on Competitiveness, 2004). As a result, American engineering colleges face stiff competition from colleges offering competing disciplines.

This problem is further exacerbated by several unique negative stereotypes of engineering held by American teenagers. First, engineering is held in lower esteem than other professions, such as medicine, law, and accounting. Secondly, society

tacitly discourages female students from becoming engineers or scientists. Finally, math and science studies are not perceived as fun by high school students.

Today's students are attracted to new gadgets, such as iPods, video games, robots and cell phones. We can leverage this as a way to interest students in technology and to motivate them to excel in STEM disciplines. Unfortunately, due to limited resources and shortage of adequately trained high school science teachers, schools often present required science courses in an unimaginative manner (AEA, 2005). They introduce basic scientific concepts in the abstract, and fail to relate these concepts to science, as encountered by students in their daily lives. That is one major reason for students' losing interest in their science studies. Additionally, uninspiring laboratory experiments contribute to a general lack of interest in studying STEM disciplines. The result is poor achievement on standardized science exams and apathy about pursuing careers in engineering and technology.

Integrating modern sensing technology into science labs makes labs more appealing to students by having them use exciting tools and by allowing students to visualize results graphically and in real time. This is beneficial for learners who rely on visualization. Modern sensors allow inductive and reflective learners to develop inquiry-based learning skills, by developing measurable recorded data. These skills are essential in an increasingly technological society (Orsak et al., 2004). In addition, those students who are most proficient in science and math, will be introduced to contemporary innovative ideas which, it is hoped, will make them more likely to be enticed by career paths that are related to science and engineering.

Instrumentation and monitoring was selected as a general theme for this project for several reasons: (1) data acquisition is an exciting application that can be understood by pre-college students; (2) data reduction presents an ideal medium to reinforce existing math skills of students and to introduce new skills, such as spreadsheets; (3) data analysis provides students with an opportunity to apply their science and math skills; (4) data visualization affords an opportunity to develop students' cognitive skills and the excitement of self-discovery; (5) through lab activities involving modern sensors, students develop inquiry-based learning skills; (6) data acquisition and reduction allows us to monitor student learning and identify areas of weakness; (7) since manual collection and recording of data is not the principal focus of the lab, students can focus on learning the underlying concepts of the lab and formulating and testing new hypotheses; and (8) the whole exercise gives students an opportunity to learn and apply state-of-the-art computerized delivery tools such as presentation graphics, document preparation, and spreadsheets. Our approach is in keeping with students' leisure-time use of state-of-the-art equipment in comparison to their use of manual equipment in traditional science labs.

## **PROJECT OVERVIEW**

High school science and math courses have historically been viewed as the "gatekeeper" to engineering education. Students who excel in these subjects succeed in high school and have the option to continue their education at college in a technical or engineering field. However, the inherent rigor of science and math, the quality that helps impart this gatekeeper function, also presents great challenges to educational

systems. A lack of fully prepared science and math teachers, coupled with a well-documented general teacher shortage (Rodriguez & Knuth 2000) limits the achievement of students in STEM disciplines in American K—12 schools. Without dramatic intervention, these dynamics do not bode well for American engineering colleges being able to fulfill the workforce needs of an innovation economy. These needs are too great to rely on schools of education alone to provide the training and human resources to accomplish this goal. At the very least, the current scenario suggests an important supporting role for engineering colleges in assisting pre-college STEM programs.

### **Project Planning**

The RAISE Program was developed through a dialog conducted over 18 months between Polytechnic University<sup>1</sup> faculty, high school principals, teachers, and school district administrators, culminating in a proposal to NSF. The dialog assessed the STEM curricula and educational, instructional, and teacher training needs of schools.

After initiating the project in summer 2004, monthly meetings were held to discuss: content/time constraints on curriculum, technology training needs of teachers, student academic preparation, opportunities for curriculum innovation, availability of time in their curriculum to integrate lab activities, etc. Our interactions have resulted in the identification of Living Environment, Marine Science, Earth Science, Active Physics and Physics as the courses that can benefit from this project, for several reasons. First, through RAISE activities in these courses, students' interest in science and math will be sparked early on and reinvigorated near the end of their high school careers. Secondly, these courses have lab components, which allow ease of RAISE activity scheduling and benefit from the use of modern sensor technology. Thirdly, the curriculum of these courses is a natural fit for integrating sensor-based activities. Finally, the project will synergistically influence performance in Math—A, since math skills will be developed, applied, and practiced in all learning activities.

### **Project Objective**

The project objectives address several common areas of need found in NYC high schools:

- Enhance student achievement in standardized exams in Living Environment, Marine Science, Physics, Active Physics, Earth Science, and Math-A.
- Expose high school students to engineering as a career option through (1) positive role models, (2) lab experiments that introduce engineering as the application of science, and (3) a recognition of the role of engineering in every day endeavors.
- Excite students about STEM disciplines through real-world science and engineering projects that make extensive use of modern sensors and provide teachers with technology proficiency, qualifications, and resources to integrate project-based learning in STEM curricula.

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<sup>1</sup> Polytechnic University merged with New York University in summer 2008 and became Polytechnic Institute of NYU

- Develop human resources by (1) inspiring students to pursue challenging academic work, meet high academic achievement standards, and acquire a passion for STEM disciplines/careers; and (2) enabling RAISE Fellows to develop communication and leadership skills, and a deeper appreciation for STEM disciplines, all of which will prepare them to be role models.
- Strengthen the ties between Polytechnic University and the New York City public school districts.

### **Project Organization and Training**

The RAISE program is supervised by two engineering faculty, and one liberal arts faculty. The main interface between Polytechnic and high schools is RAISE Fellows. During the academic year, each Fellow spends ten hours a week at their assigned high school as a science resource and five hours a week on campus preparing experiments and materials to be used in the high school classroom. During the summer, each Fellow is paired with a RAISE teacher attending a weeklong workshop to learn about modern sensing technology. The graduate RAISE Fellows are required to make satisfactory progress in thesis research. They receive tuition remission for three graduate courses and as well as a stipend, while the undergraduate RAISE Fellows receive a stipend only. An external evaluator evaluates the progress of the program.

The RAISE Fellows attend a weeklong professional development workshop conducted by an education specialist who formerly served the New York City school system as a trainer of teachers. The workshop is designed to enhance the Fellows' pedagogical, communication and presentation skills, and to help them prepare effective lessons. Many Fellows felt that this training program gave them an advantage in the classroom, especially with matters of classroom management, discipline and effective questioning techniques. Fellows learned practical approaches to anticipated challenges that may arise in the classroom and they also developed techniques of conveying academic material in an effective manner.

The RAISE teachers underwent a weeklong training session on how to implement sensors in classrooms, effectively. The teachers also received a crash course in mechatronics and engineering, in which they made their own robots. The rationale behind this training was to encourage and excite the teachers to go beyond basic implementation of sensors in the classroom, and to present an opportunity for the teachers and Fellows to bond with one another. A secondary goal was to motivate some teachers to start robotics clubs at their schools, where they could use what they learned during the training session and motivate students to joining this club.

## **IMPLEMENTATION CHALLENGES**

### **Year-1**

Initially, it was difficult to attract graduate students to join RAISE in a hot job market despite the generous stipend (\$30,000 plus tuition) because jobs and paid internships were plentiful. Out of the twelve Fellows selected for Year-I, ten were undergraduate students. Since undergraduate classes are scheduled mainly during the daytime, this limited undergraduate Fellows' availability to serve in high schools.

A second challenge encountered in Year-1 was that the NSF GK-12 program provides generous stipends but does not allow for adequate equipment funding for the high school. Polytechnic University subsidized the program by providing each school with four biology and four physics sensor kits. Schools were required to provide laptops. In Year-1, schools that were unable to provide laptops or computers used the sensors with graphing calculators. By Year-2, however, all schools were equipped with laptops or computers.

Despite receiving intensive training, problems were bound to arise during the pilot year of the RAISE program. These ranged from poor classroom discipline to students' inability to cope with new technology. For many students, it was the first time that they were being exposed to such equipment. However, eventually over the course of the year, students formed an appreciation for the sensors and were able to do the many computations that were required of them.

One dramatic contribution in Year-I was the role of Fellows at one of the schools when a teacher suffered a debilitating heart attack. The principal had enough confidence in the Fellows to have them provide instruction for the class in an effort to salvage the class although a replacement physics teacher could not be found. According to the NYC Board of Education rules, a certified teacher must be present in the classroom at all times. A substitute teacher was hired to meet this requirement, but he did not play an active role in teaching the material. This was a noble effort, and although the class eventually had to be disbanded, the Fellows had proven their value through this rescue effort.

### **Year-2**

New York City was in the midst of a major school reform effort, which frequently breaks up large schools into several small ones occupying the same building. One of the RAISE schools was broken up, and the principal and the assistant principal for science, as well as some science teachers, left to pursue a variety of professional and personal interests. It was difficult, therefore, to maintain the relationship, and a different school was substituted.

In the second year, the benefit of RAISE to the Fellows was evident. Five of the ten undergraduate Fellows applied to continue as graduate RAISE Fellows and pursue their studies towards the master's degree. Thus, in Year-II there were eight graduate and five undergraduate Fellows, which made in-school scheduling considerably easier.

Over the course of the second summer, the Fellows and teachers started planning for the upcoming school year in terms of scheduling, lab experiments, tutoring, and various other activities. The Fellows underwent a second summer workshop similar to the first in order to train them effectively for working in their classrooms. Since most of the Fellows were experienced, they enjoyed a comfort level with their cooperating teachers. This familiarity promoted communication that led to more improvements in the program's infrastructure.

### **Year-3**

The program faced similar challenges to those encountered in years I and II. First, many graduated seniors were attracted by the hot job market and chose not to

apply for graduate study or to the program. As a result, only three new graduate Fellows joined the program, of which one was returning undergraduate Fellow from year I and two were returning undergraduate Fellows from year II. Only a few senior undergraduate students applied to the program due to plentiful opportunities in engineering firms.

A second difficulty is that one school sub-divided into two schools as a result of NYC school reform initiative. Although both schools exist in the same building, there are significant difficulties in moving, storing and sharing equipment.

Finally some high schools are in need of additional computers for data acquisition since the computers originally used for this task were reassigned. Consequently, Polytechnic donated several used computers to maintain the function of the program.

#### **Year- 4&5**

The program continued in one school with one or two Fellows using a no cost extension. Students in that school continued to derive the Full RAISE benefits. RAISE teachers in other schools continued to use the provided sensor kits to provide a technology enriched program, but without the benefit of RAISE Fellows.

### **TYPICAL SENSOR-BASED EXPERIMENTS**

Twenty five sensor based experiments were developed by the RAISE Fellows (RAISE 2009) to support learning in Living Environment, Physics, Active Physics, and Marine Biology classes. The developed experiments were modeled after the New York City curriculum (NYC 1999). The developed experiments incorporating sensors, demonstrating concepts that originally seemed difficult to visualize and comprehend. The sensors helped students more interactively experience important concepts for the living environment.

Some of the experiments designed went beyond merely a demonstration of key concepts; many related everyday life to the content of lab. In one living environment experiment, students were asked to analyze water quality by carrying out four tests: temperature, pH, total dissolved solids, and dissolved oxygen. The students use the corresponding sensors, a dissolved oxygen sensor, a temperature sensor, a conductivity sensor and a pH probe, to perform the tests. Results from each test are multiplied with different weighting factors to obtain a water quality index. Use of sensors enables students to visualize the relationship among the parameters involved the instant results are recorded. Thought-provoking questions are posed to reinforce the concept of water quality testing, such as: How do you account for each of the measurements? What, if any, is the relationship among them? or, What can be done to improve the water quality of your sample?

Students investigate their hypothesis and discuss the results with their classmates. Such experiments excite students about the subject, motivate them, and satisfy their curiosity. Next, students are engaged in a discussion of natural resources and laws passed to protect them, such as the Clean Water Act of 1972 and the Safe Drinking Water Act of 1974. This relates science to everyday concerns. The students

compare their water quality index to the conventional National Sanitation Foundation Water Quality Index (WQI), which includes nine tests: Temperature, pH, Turbidity, Total dissolved solids, Dissolved oxygen, Biochemical oxygen demand, Phosphates, Nitrates and Fecal Coli-form. This helps students learn how to sort through complex scientific issues and focus on the key parameters.

Some experiments were designed to illustrate some engineering applications while reinforcing basic concepts taught in physics, such as Newton's laws of motion, friction, and momentum. For example, in the stability experiment, examples of landslides, retaining wall failures, and toppling of cranes and excavators are presented. Next, students perform an experiment using a force sensor by pulling on a wooden block until the block tips or slides. Use of the force sensor, real-time data acquisition hardware, and real-time data acquisition software running on a laptop computer, allows students to visualize the instance when the applied force exceeds the resisting force, thus initiating sliding or overturning. Students are then assigned to compute critical forces and compare them with the sensor measurements. This allows students to validate Newton's laws of motion and friction effects. This activity is followed by thought-provoking questions; such as, which face of the block will require the least amount of force to be overturned? Students can formulate and investigate their hypothesis by conducting the experiment again by changing the position where load is applied

### **CLASSROOM IMPLEMENTATION**

Usually before performing an experiment, a Fellow will give a demonstration to allow the class a chance to gain familiarity with the lab. Then the students are split into groups of three to five to perform the laboratory activity. Since labs by their nature are interactive, each student is assigned a specific task, such as setting up the experiment, controlling the pace of the experiment, recording data or performing calculations.

Starting in year-2, Fellows set up tutoring sessions to expand their assistance to students who require extra help. Students' receptivity to the Fellows is based on the positive interaction they have experienced, which gives the student an opportunity for a one-on-one learning experience with the Fellow. The presence of another science resource in the class helps alleviate the pressure on the teacher and encourages the students to ask more questions.

### **BROADER IMPACTS OF PROJECT RAISE**

A change in students' attitudes was observed over the course of the year. Students generally looked forward to performing lab experiments. The tasks that they may have found daunting in the beginning of the year became second nature. Furthermore, students devised extensions to the lab experiments for a fuller learning experience. Some students started expressing interest in careers in science and engineering to Fellows, whom they looked up to as a source of inspiration, and for career advice.

The RAISE program affected the Fellows as well. Fellows displayed an improvement in their communication and presentation skills. Additionally, many indicated that their own comprehension of scientific principles has improved as a result of having to teach. However, the impact of RAISE extended beyond the classroom, as well. Many events were organized to support program goals. These included:

### **Career Days**

Polytechnic hosted two RAISE Career Days. Students from the participating high schools were exposed to various disciplines of engineering via presentations and tours made by faculty and recent Polytechnic graduates. The purpose of these events was to arouse students' interest in science, engineering, and technology that may lead them to consider engineering as a possible career option.

### **NYC NSF GK-12 Grant Holders Meeting**

Polytechnic hosted The NYC NSF GK-12 Grant Holders Meeting that took place in May 2005. Participants included representatives from the four GK-12 projects in NYC: Columbia University (two programs), CUNY Graduate Center and Polytechnic University. The NYC Department of Education played a vital role in ensuring the success of this program. This meeting provided an opportunity for participants to discuss major challenges that are faced within collaborative programs, which seek to enhance K-12 learning in science and technology. In addition, it gave a chance for the participants of the different GK-12 projects to network and explore new methods of tackling similar problems. The GK-12 program team from NSF also attended this event.

### **Annual GK-12 Meeting**

The Association for the Advancement of Science (AAAS) and the NSF hosted an annual meeting for the GK-12 project teams in Arlington, Virginia. Various GK-12 projects throughout the nation displayed their work, using poster boards and PowerPoint presentations, and gave participants a chance to network and exchange ideas. Polytechnic Fellows were actively involved as presenters, and benefited greatly from interaction with other GK12 Fellows from across the United States.

### **Third Annual Convergence on Inquiry**

RAISE was invited to the Third Annual Convergence on Inquiry at the American Museum of Natural History and gave a presentation to a group of teachers and other educators on how sensors and instrumentation can help students "ask more questions" related to science and technology. The goal of this conference was to discuss different means of getting the students to "inquire."

## **ASSESSMENT**

### **Impact on High School Students**

It is difficult to assess the impact of RAISE on student achievement since many of the objectives need time to determine their impact (Victor & Iskander 2007).



Nevertheless, most students were excited at the opportunity to use the new instrumentation available in the lab. More students felt that the laboratory component was their favorite aspect of the science course. Teachers believed that concepts learned in sensor-based labs were more memorable to students than those encountered in a traditional lab. Control classes are not available for subjects in most high schools. However, the impact of RAISE is evident where control classes are available. For example comparing Living Environment at George Westinghouse High School, the Mean Regents scores for the RAISE classes was 61.69 compared to 52.92 for non-RAISE classes. Moreover, while 39 of 54 (72%) of the RAISE students took the Regents only 24 of 47 (barely over 50%) took the Regents from the non-RAISE classes. Grades showed similar results: Mean grade for the RAISE students was 66.83 as compared to only 59.56 for the non-RAISE students.

One of the goals of Project RAISE is to encourage high school students to continue their education at a college level in areas related to STEM. There are two problems with assessing this objective. First, it is difficult to track students after they leave high school without dedicated resources. Secondly, it is difficult to determine if those students who are expressing interest in a STEM career would have chosen to study STEM anyway, even without RAISE. Finally, with the many changes associated with NYC school reform, it is difficult to verify the relative contribution of many experiences and initiatives.

All things considered, the project team believes that sensors have had a positive impact on the students' academic experiences. The team also believes that the opportunity for high school students to interact closely with goal-oriented role models who are studying engineering, a rigorous discipline, will help them, to develop academic goals for themselves.

### **Impact on Fellows**

The effect of the program on RAISE Fellows was found to be positive, as evinced by the fact that seven out of twelve Fellows chose to continue the program. Fellows clearly improved their communication and technical skills as a result of frequent presentation of their work. Through classroom management techniques, Fellows polished their leadership and management skills. These elements have served the Fellows well once they graduated, as they seek to become leaders in their fields.

### **SUSTAINABILITY**

RAISE teachers are continuing the sensor based curriculum in their classes. Additionally, the project directors obtained Funding from New York State and conducted a workshop to train 20 school teachers in Instrumentation, Sensors, and Engineering (Iskander et al 2010)

### **CONCLUSIONS**

Integrating modern technology into the science lab is an answer to the fading interest in STEM disciplines among American high school students. Students found the labs interesting. Early indications are that students are succeeding on

standardized exams in greater numbers than before, and some students are motivated to pursue STEM careers as a result of their exposure to RAISE. The Fellows have improved their technical and pedagogical skills.

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