Lessons Learned from Conducting a K-12 Project to Revitalize Achievement by using Instrumentation in Science Education

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Abstract

A student's first introduction to engineering and technology is typically through high school science labs. Unfortunately, in many high schools, 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 option. By using sensors and computerized data acquisition in science labs, project RAISE (Revitalizing Achievement by using Instrumentation in Science Education) sought to enhance students' academic achievement; excite them about science, technology, engineering, and math (STEM); and inspire them to pursue STEM careers. This paper gives an overview of the project along with lessons learned and suggestions for best practices.

Key Words: Best practices, engineering education, high schools, instrumentation, lessons learned, outreach, sensors, teacher training.

I. Introduction

American universities have been called upon to recruit, train and graduate large numbers of scientists and engineers in order for the United States to sustain its "innovation economy" (Friedman 2005, CSEP 2006). Over the last 50 years, interest in STEM careers was propelled by the Cold War (Clowse 1981). However, with the end of the Cold War interest in STEM careers waned (CC 2004). This problem is further exacerbated by several unique negative stereotypes of engineering held by American teenagers (NSB 2002). First, engineering is held in lower esteem than other professions, such as medicine, law, and business (Hauser and Warren 1996, NAE 2008). Second, society tacitly discourages female students from becoming engineers or scientists (Etzkowitz 1994). Finally, students who excel in math and science are viewed as nerds by their peers.

High school science and math courses have historically been viewed as a "gatekeeper" to higher education. The inherent rigor of science and math, the quality that helps impart the gatekeeper function, also presents great challenges to the U.S. educational system. Notably a shortage of adequately prepared science and math teachers limits the achievement of American K-12 students in STEM disciplines (Rodriguez and Knuth 2000). Unless measures are taken to encourage students' and teachers' interests in math and science, and assist them to learn, many students fall by the wayside and are de facto denied academic and professional achievement opportunities (Ingersol and Perda 2009, Jeffers et al 2004).

Against this backdrop, Project RAISE conducted an array of activities to create an exciting and engaging outreach program that enriched the educational experience of high school students. These activities included: (1) recruiting, training, and deploying engineering "Fellows" in five high schools; (2) addressing workforce diversity issues by encouraging inner city students to pursue challenging academic work, meet high achievement standards, and acquire a passion for STEM disciplines; (3) imparting technology literacy to teachers; (4) developing modern sensor-based activities relevant for grades 9-12; (5) mentoring of Fellows by faculty and teachers; (6) conducting an annual summer workshop on pedagogy for Fellows; (7) conducting an annual summer technical training workshop for teachers; and (8) conducting project assessment. This paper provides an overview of the project along with lessons learned and suggestions for best practices. A recent paper contains assessment results (Iskander and Kapila 2012).

II. Project Rationale

In the last 50 years, even as the United States has witnessed a tremendous interest and expenditure in school reform, a vast majority of these efforts have been futile. According to the National Center for Education Statistics (2010) only 29 percent of fourth graders are proficient in science and an alarmingly low 18 percent of 12th graders are proficient in science. Performance in math also deteriorates as students advance in the K-12 system (Snyder and Dillow 2010). Only 60 percent of 17-year-olds are able to conduct moderately complex math procedures and reasoning, while a distressingly low 6.2 percent are able to perform multistep problem solving and algebra. According to Samuelsson (2010) "The larger cause of failure is almost unmentionable: shrunken student motivation." Motivation is weak because a vast majority of students across all socio-economic classes find school disconnected from the real-world and school work boring, causing them to not to work hard and not to do well in school.

Today's students are immersed in and benefit from widespread usage of modern technology (iPods, video games, robots, and mobile phones) in their everyday lives. Students' interest in technology can be leveraged to motivate them to excel in STEM disciplines. Yet, obsolete school labs and inadequate training cause teachers to continue to present required science courses in an unimaginative manner (Lewis et al., 2000; AEA, 2005). A critical problem with conventional high school science labs is requiring manual collection of experimental data, despite the availability of opportunities to engage students in real-time sensing and data acquisition. These outdated labs may seem confusing, redundant and unappealing to students. The drudgery associated with manual data collection makes students lose focus on the purpose of the task at hand. Uninspiring lab experiments do not cater to the learning styles of today's students and result in their loss of interest in pursuing STEM education and careers.

Integration of modern sensors and instrumentation into science labs enables students to experience greater engagement with science through practical tools. For example, visual learners benefit by obtaining and visualizing graphical results of experiments in real time. Moreover, computerized data acquisition technology affords the students capability to record, store, display and analyze data, thereby allowing inductive and reflective learners to develop inquiry-based learning skills which are essential to effectively function and succeed in an increasingly technological society (Orsak 2004). Sensor-based labs allow students to focus on understanding the underlying scientific concepts by conducting a variety of experiments and interpreting their results.

III. Project Overview

The RAISE project was developed through a dialog conducted over 18 months among NYU-Poly faculty, high school principals, teachers, and school district administrators prior to its start date. The partner high schools (Table 1) have several areas of academic need that are common to many New York City (NYC) 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 the curriculum to integrate lab activities, etc. These discussions resulted in the identification of Living Environment, Marine Science, Earth Science, Active Physics, and Physics as the courses to be included in the project for several reasons. First, through RAISE activities in these courses, students' interest in science and math could be sparked early on and reinvigorated near the end of their high school careers. Second, these courses have lab components, which allowed ease of RAISE activity scheduling and benefit from the use of modern sensor technology. Third, the curriculum of these courses provided a natural fit for integrating sensor-based activities.

The RAISE program was supervised by two engineering faculty and one liberal arts faculty, who served as the principal investigators (PIs) of the project. During the summer, each Fellow was paired with a RAISE teacher. During the academic year, each Fellow spent 10 hours a week at an assigned high school serving as a science resource and five hours a week at NYU-Poly campus preparing experiments and materials to be used in the high school classroom. Each summer, the Fellows attended a weeklong professional development workshop conducted by an education specialist. The workshop was designed to enhance Fellows' pedagogical, communication and presentation skills, and to help them prepare effective lessons. The workshops also equipped the Fellows with the necessary literacy skills and pedagogical practices including essential elements of active learning techniques, project-based learning, and evaluation methods. The Fellows and teachers attended a weeklong summer workshop to learn about modern sensing technology and how to integrate sensors-based lessons in classrooms, effectively.

A. Typical Sensor-Based Experiments

A key element of the RAISE project was the development of sensor-based lab experiments that demonstrate scientific concepts from an engineering perspective. Forty experiments were developed by the Fellows, for use in a variety of classes, to complement NYC curriculum and to demonstrate concepts that students originally found difficult to comprehend (RAISE, 2011; BOE, 1999). While some of the experiments were developed during the summer workshops, many were developed during the Fellows' deployment in schools to address perceived learning needs of students. All experiments use one or two sensors, an analog-to-digital interface, and a computer running data acquisition and visualization software, all sourced from Vernier, Inc. A few of the experiments were adapted from Vernier manuals, while many others were developed by the Fellows to address a variety of science concepts. Through philanthropic and other funds, the university provided financial support for the acquisition of 13 sets each of LabPro Biology Deluxe Package and LabPro Physics Deluxe Package from Vernier that were distributed among the partner schools (approximately three to four per school). Several of our partner schools acquired additional sensor lab set up from their own funds. Moreover, all schools had computer labs equipped with desktop or laptop computers to allow for the use of computerized lab setups. At a minimum, each school had at least four setups of Biology and four setups of Physics sensors, which allow for groups of four to five students per setup. Fellows participated in science classes twice a week, however not all science lab activities involved the use of a sensor. Sensor-based activities were conducted approximately two to three times a month.

The sensor-based labs allowed students to interactively experience important science concepts. Some experiments developed under RAISE are similar to the ones typically performed in the NYC high schools, except that they make use of sensors. Other experiments are entirely new and demonstrate connections between real-world applications and high school science. In some cases, the developed sensor-based experiments illustrate concepts that would be difficult to demonstrate manually. The following are two example experiments. The project website and some other examples hold more details (RAISE, 2011; Sobhan et al., 2006, 2007; Walia et al., 2006, 2007; Iskander et al., 2010).

1) Monitoring EKG Experiment: One of the most entertaining and interactive experiments conducted involved an Electrocardiogram (EKG) sensor. Many students were already exposed to what an EKG diagram looks like from television shows such as ER. In the EKG lab, students determine heart rate based on the EKG diagram produced using the sensor, which is hooked up to three electrode patches placed on a volunteer's arms. The students collected data while the volunteer rested and after performing fifteen jumping jacks. A video

High School Name	Average SAT		% Graduating	No. of Students	Attendance Rate (%)	Suspensions (%)	Free Lunch (%)	Ethnicity (%)			
	Verbal	Math						Black	Hispanic	Asian	White
George Westinghouse	389	418	51	1054	75.7	7.3	63	85	10	0	5
Paul Robeson	384	418	55	1537	83.8	7.2	81	95	4	0	1
Seaward Park	345	505	31	657	81.4	16.6	83	19	44	35	1
Marta Valle	377	440	60	583	87.5	5.1	82.5	13	68	15	4
Telecommunications, Art & Technology	446	470	75	1244	…	…	56	16	53.4	11.2	19.3

"…" denotes data not available

Table 1. Demographics of the participating high schools

of students conducting the experiment in a classroom setting is available in Iskander (2010). The students found this lab to be interesting because they were able to visualize what their EKG looks like in comparison to that of other classmates'. Students came up with many questions to investigate, such as (1) How would age, gender, and weight affect the EKG diagram? (2) Why are the peaks of my EKG smaller or larger than those of my classmate's? (3) How can we use an EKG to diagnose various ailments of the heart? (4) Why don't we get electrocuted if the EKG sensor measures the electrical impulses? The lab opened up a riveting discussion about various heart ailments and how useful an EKG is in diagnosing such illnesses.

2) Experiment on Electromagnetism: Electricity and magnetism are ubiquitous. Common human interactions with such phenomenon arise through static shocks and permanent magnets. When manipulating the orientation of two permanent magnets one quickly observes that they either attract or repel. Students also discover that a magnet can pick up ordinary pieces of metal. This experiment investigates magnetic fields created by current carrying wires. By winding an electric wire in the form of a helix, a uniform and measurable magnetic field is created in the space surrounded by the wire. This structure is known as a solenoid and the space surrounded by the wire is referred to as the core. Using a magnetic field sensor allows for the exploration and verification of the following basic concepts: uniform field within the core, negligible field strength along the outer surface of the solenoid, direction of pseudopoles as predicted by the right-hand rule, and field attenuation inversely proportional to the cube of the distance measured axially. Given the equation that governs the intensity of the magnetic field in a solenoid, students compete to build an electromagnet that picks up the largest number of paper clips.

B. Classroom Implementation

Usually before performing an experiment, a Fellow gave a demonstration to allow the class an opportunity to gain familiarity with the lab. Then the students were split into groups of three to five to perform the lab activity. Since labs by their nature are interactive, each student was assigned a specific task, such as setting up the experiment, controlling the pace of the experiment, operating the data acquisition software to record and display experimental data, or performing calculations.

Fellows also offered tutoring to students who required extra help. The presence of another science resource in the class helped alleviate the pressure on the teacher and encouraged the students to ask more questions. Finally, as engineering students, Fellows brought an in-depth knowledge about sensors and their applications, thus allowing them to become effective partners with their teachers. A change in students' attitudes was observed over the course of their participation in the RAISE supported courses. Students generally looked forward to performing lab experiments. 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. The project also affected the Fellows and teachers. Fellows gained an improvement in their communication skills and their own comprehension of scientific principles. Many teachers rated the program highly for: helping to explain science concepts to students; providing useful lab exercises; helping to improve lab attendance; and engaging students' attention.

C. Project Assessment

An evaluation was conducted to provide data on the impact of Project RAISE (Iskander and Kapila 2012). According to project's external evaluator, the project impacted the Fellows, students, and teachers as follows. Fellows indicated that: participation in the project increased their own understanding of science (90 percent); their students respected them and found them helpful (75 percent); pedagogy workshops were effective (82 percent); and they had been helpful in teaching science concepts, introducing lab exercises, and working with students in groups (80 percent). The most convincing evidence of the positive effect of the RAISE project on students is that when data from all classes is averaged, a higher percentage of RAISE students (more than 60 percent) passed the Regents Living Environment exam than did non-RAISE students (less than 40 percent). In addition, a third of the RAISE students expressed definite interest in continuing their education at college in STEM disciplines. Teachers reported that Fellows explained concepts to students (100 percent); provided useful lab exercises (100%); provided information on science and engineering (87 percent); improved lab attendance (75 percent); and helped to keep students more attentive (88 percent). More than 90 percent of teachers found summer workshops to be effective. All teachers treated the Fellows as equals and as collaborators in finding ways to improve student learning.

IV. Lessons Learned

The following are important lessons that can contribute to the success of any STEM education outreach project modeled after the GK-12 Fellows program of the National Science Foundation (NSF).

1. A GK-12 Fellows project must balance two competing objectives: (i) allowing Fellows to pursue their academic and research activities and (ii) improving STEM education in K-12 classrooms through Fellows' participation. To make efficient use of Fellows' time, it is important to provide them with meaningful technical and pedagogy training prior to the start of the school year. Moreover, the project PIs must explicitly communicate time commitment for K-12 activities to Fellows and their research mentors. Project teachers must also be informed regarding Fellows' time commitment to the schools and their responsibility to their academic work. Periodic review of Fellows' progress in developing K-12 learning activities and meeting their academic requirements ensures that they develop good time management skills. Finally, the school activities should be designed to enrich the STEM curriculum in full consultation with teachers and with the explicit support of principals.

2. A GK-12 Fellows project benefits tremendously by having faculty PIs of diverse educational and professional backgrounds. For example, in the RAISE project, the two engineering faculty designed, supported, and conducted technical training and provided technical mentoring to Fellows. An education faculty drew upon his vast knowledge of local school system and network of K-12 contacts to develop teaming arrangements, recruit qualified education experts to staff pedagogy workshops, and design a protocol to resolve problems with the direct intervention and support of school principals.

3. It is essential to develop a spirit of camaraderie in order to build a strong project team. RAISE Fellows came from several different departments and were interested in different facets of engineering. Thus, it was essential to design activities and events to provide the Fellows with ample opportunities for contact, interactions, and interdisciplinary learning experiences. For example, initial interaction between the Fellows took place during summer training and continued through sharing of a common office space, attending bi-weekly project meetings, and travelling as a cohort to regional and national GK-12 Fellows project meetings.

4. A key contribution of the RAISE project is integration of modern sensing, instrumentation, and monitoring technologies in the lab curriculum of science courses in several NYC high schools. This has been done by the development and implementation of a series of sensor-based lab experiments that illustrate typical high school level science concepts. The

experiments are designed in a way that each member in the student-team has an active role in the experiment. Moreover, team members must have constant interaction among each other to complete the lab assignments properly. For example, one student holds the sensor, another operates the computer, a third works with the equipment, and the fourth acts as a manager and monitors the project to ensure that everyone is synchronized. The students have the opportunity to switch roles as most experiments have multiple trial runs. This method of running the labs keeps the students engaged and prevents negative behavior. Moreover, incorporating automatic data-logging software allows the instructor to convey the material through a wide range of learning styles: (i) the graphical user interface displays sensor measurements through which visual learners easily pick up the concept; (ii) the team-based tasks require group effort which benefits auditory/verbal learners; and (iii) the hands-on lab activities aid the tactile/kinesthetic learners, who grasp the concept by doing the experiment. Teachers have commented that the sensor-based science labs (1) keep student interest focused on the outcomes rather than the means of doing the assigned task and (2) provide a valuable diversion from the normal sequence of instruction and a way to illustrate phenomena that would have to be accepted as truth, without any hard evidence.

5. Integration of authentic, hands-on learning activities, which introduce students to tools and techniques used by practicing scientists and engineers in real-world, necessitates significant upfront investment in hardware and software. The $10,000 equipment budget allowed by the GK-12 Fellows program solicitation can serve only as a seed fund in this regard. Thus, it is imperative that the project team seeks out support of university, schools, foundations, and equipment vendors to acquire required equipment.

V. Suggested Best Practices

1. Recruitment of Fellows requires a multi-faceted approach. For example, every spring semester, project team prepared a poster to advertise the Fellowship opportunity. The poster was used for campus-wide advertisement; mailed to more than 100 universities and e-mailed to professional contacts at other universities, federal labs, private corporations, and minority programs such as NACME and GEM. The project team also held RAISE Information Days where the project PIs and RAISE Fellows met with prospective candidates to inform them about the opportunity. Moreover, the graduate student office sent direct e-mails to qualified students to inform them about the fellowship. Finally, the project team held meetings with members of various engineering clubs and the student newspaper to spread information about the program. All the aforementioned interactions were planned to cast a wide net to attract a diverse applicant pool. Nevertheless, the majority of Fellows were recruited through one-on-one interactions with the project PIs and other Fellows because such interactions often revealed personal growth benefits of participation in the project that were not self-evident to potential applicants.
2. It is essential to include teachers on the selection committee of Fellows. Teachers provide useful feedback on candidates' (i) communication skills; (ii) ability to explain complex concepts by breaking it down into simpler, easy to comprehend building blocks; (iii) attitude towards teamwork; etc. More importantly, having a role in the selection of Fellows empowers the teachers to be a key professional member of the project team. For each selection cycle, four to six teachers volunteered to be on the selection panel. The interviews were held on two weekdays, in the late afternoon, to allow teacher participation. Two to three teacher volunteers attended each selection session.
3. Education/pedagogy training of Fellows must consist of (i) a summer workshop to introduce Fellows to the theory of teaching and learning and (ii) follow-up sessions in fall and spring semesters allowing Fellows to share their classroom experiences with the pedagogy expert and plan new pedagogical strategies.
4. Technical training and preparation of Fellows via on-going synergistic projects is quite productive. For example, RAISE Fellows were engaged in an NSF-funded Research Experience for Teachers (RET) Site in Mechatronics project, where they attended a two-week series of introductory lectures on mechatronics and corresponding structured, hands-on learning activities (Kapila & Lee, 2004). The Fellows also interacted with the RET teachers and even provided mentoring for the RET teachers' research projects. Fellows attended these workshops in 2005, 2006, and 2007 (second and third week of July). Finally, having acquired significant background in mechatronics, the Fellows learned to use sensing and data acquisition tools and began developing high school relevant sensor-based science labs, with useful input from RET teachers. Participation in the RET project allowed the Fellows to interact with and expand their pedagogical relationship to teachers unaffiliated with the RAISE project and further learn about the high school environment.
5. Involving Fellows in the technical training of teachers is very useful. The RAISE PIs and Fellows conducted weeklong technical workshop (in mid to late August) on modern sensor technology to provide teachers with insights for sensor-based classroom activities and to prepare them to become technology resources in their schools. As a byproduct of this training, the teachers and Fellows became acquainted with and bonded with one another as they began planning for the upcoming year. Further, teachers immediately perceived the Fellows to possess valuable expertise.
6. Periodic planning and review meetings with Fellows (bi-weekly) and teachers (monthly) are paramount to the success of the project. Pre-project and summer planning meetings allow the project team to finalize the project scope (courses, labs, etc.), develop contents of education/pedagogy workshop for Fellows, address data collection and school observation visit needs of the external evaluator, select teachers to replace teachers who leave their schools, recruit and select Fellow, etc. Fall and spring review meetings are essential to keep the project on track and address questions/problems raised by Fellows, teachers, evaluator, and PIs. The summer workshops allow some preliminary planning between Fellow-teacher partners for the academic year. However, Fellows spend five hours/week during the academic year on planning and designing lab lessons and activities.
7. Taking advantage of Fellows' presence and expertise, and student respect for them in school can be harnessed to achieve various ancillary benefits. For example, the Fellows perform numerous other useful functions in their schools, such as: (i) help students with their assignments inside and outside class; (ii) tutor and review for Regents exam preparation; (iii) help students and teachers with sensor-based science projects; (iv) act as science and math resources in schools; (v) share their exciting STEM research activities with students; and (vi) counsel students about opportunities in STEM education and careers.

VI. Conclusions

As technology continues to profoundly impact our daily lives, it is essential that all students receive comprehensive, high quality education in STEM subjects because K-12 students must achieve high scores on standardized STEM courses to advance in society. Unfortunately, many science labs often make use of antiquated technology that fails to tap the potential of modern technology in order to create and deliver exciting lab content. As a result, students are turned off by science, fail to excel on standardized science exams and do not consider STEM as a career option. Integrating modern sensing technology into science labs presents one answer to the declining interest in STEM disciplines among American high school students. Project RAISE worked to enhance students' academic achievement and interest in STEM by using computerized data acquisition and sensor-based equipment in science labs. This paper presented an overview of the RAISE project together with lessons learned and best practices gleaned from the project.

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