Session 1510

Integration of Real-Time Sensor Based Experiments in High School Science Labs: a GK-12 Project

Nerik Yakubov, Sookram Sobhan, Magued Iskander, Vikram Kapila, Noel Kriftcher, and Alon Kadashev

Polytechnic University, Brooklyn, NY 11201
Email: [nyakub01@utopia, ssobha01@utopia, iskander@duke, vkapila@duke, nkrift@duke, akadas01@utopia].poly.edu

Abstract

Polytechnic University and four public high schools in New York City (NYC) are partners in a project focused on enhancing the educational experience of students through the integration of modern sensing and data acquisition technologies into science labs. Computerized data acquisition and sensor-based science labs are believed to excite students' hidden curiosity for science, impart technology literacy, allow for exploring scientific concepts, and interest students to strive for achievement in science and math courses. This paper presents some of the developed sensor-based physics experiments along with the motivation and preliminary observations.

1. Introduction

The prevalence of computer technology in all facets of human life is rendering conventional high school science labs obsolete. Traditional labs are often outdated since they necessitate manual operation and allow only limited data collection, thus constraining students and inhibiting opportunities for them to excel in a technologically advanced society. Furthermore, the uninspiring nature of such labs fails to capture the imagination of students, which leads to their losing interest in studying science [1]. Experience with obsolete and unappealing science labs causes too many students to develop a negative view of science and what scientists do, and they never develop an understanding of how scientists address problems.

A critical problem with conventional high school science labs is the primitive manner in which students are required to collect data. The prevailing practice is to require manual collection of experimental data, despite the availability of opportunities to engage students in real-time sensing and data acquisition technology. These outdated labs may seem confusing, redundant, and unappealing to students, particularly when these same students are immersed in widespread usage of modern technology in their everyday lives (iPod, PlayStation, mobile computing and communication, 24-7 Internet, etc.). As an example, a conventional physics lab on graphical analysis of motion may consist of a mass and a timing tape apparatus. One way for this experiment to proceed would be for the teacher to attach the mass to the timing tape and drop the mass from an arbitrary height. Holes punched through the timing tape with uniform temporal separation can be used to illustrate, after some calculations, that the acceleration of the mass is constant and that the velocity of the mass increases with time. The intricacy of space-time relationship may not be grasped by many students. In addition, the tedious data collection chore may bore students and prevent them from understanding the basic concept behind this experiment, that one may measure velocity, and from such measurements one may determine the acceleration of the mass.

A related problem that arises in science classrooms and labs is that many students lack the ability to utilize math to gain an understanding of physics. This is exasperated by the drudgery associated with manual data collection, making students lose focus of the purpose of task at hand. To overcome this problem, computer software, which can easily collect, process, and presents data graphically, can be used as an aid to save time and allow students to focus on understanding the underlying physical concepts by conducting a variety of experiments and interpreting their results.

2. Overview

"Revitalizing Achievement by using Instrumentation in Science Education (RAISE)" project was conceived under a National Science Foundation (NSF) GK-12 grant [2]. Under the guidance of two engineering faculty and a faculty member with extensive experience in educational leadership, the RAISE project aims to enhance science, technology, engineering, and math (STEM) skills of high school students. Undergraduate and graduate students (RAISE fellows) have been placed in four NYC public high schools—George Westinghouse, Marta Valle, Paul Robeson, and Seward Park—to implement the project's goals.

The primary objective of the project is to enhance student achievement in science in general and prepare them to succeed on standardized exams, such as the Regents Exams of Physics and Living Environment [3]. The project is founded upon the philosophy that the development and delivery of an inspiring and engaging STEM curriculum, which integrates sensing, instrumentation, and monitoring technologies in the lab curriculum of Active Physics, Living Environment, and Physics, by the RAISE fellows and well-prepared technology-savvy teachers, will naturally entice students to strive for achievement in science and math courses. This paper discusses curriculum innovation related to physics labs, yet math skills are indirectly and positively impacted. Specifically, in order to perform the required lab exercises, students have to apply their math knowledge, which synergistically influences them to learn, develop, apply, and practice math skills to achieve successful mastery of science [4].

Before being deployed in the four schools, in the summer of 2004, the RAISE fellows received intensive training in modern sensing technology and mechatronics [5, 6]. They quickly became familiar with topics such as sensors and signal conditioning, actuators and power electronics, hardware interfacing, and embedded computing. They also received a 4-day professional development workshop designed and conducted by an education specialist who serves with the United Federation of Teachers' Center program in NYC. This educational workshop exposed the fellows to topics such as: pedagogical skills—lesson planning and effective questioning techniques, student behavior and cognition, learning theory and styles, classroom/group management skills, and effective communication/presentation skills. The workshops equipped the fellows with the necessary literacy skills and pedagogical practices including essential elements of active learning techniques, project-based learning, and evaluation methods. Parallel to the education workshop, teachers from the RAISE supported schools attended a 4-day technical professional development course in modern sensing technologies conducted by the engineering faculty and some RAISE fellows. The timing of both events allowed the teachers and fellows to become well acquainted with one another before the beginning of classroom activities. The teachers were able to comment and suggest changes to the labs being developed by the fellows. Finally, it is during this period that the teachers and fellows began a bonding process which is of vital importance for the success of a project of this nature.

The structure of the RAISE team at Polytechnic is as follows: the three faculty provide guidance and empower graduate students, who provide leadership for the undergraduate students in the project. Each fellow is required to spend 10 hours per week at a high school as a science resource and an additional five hours on campus preparing for the high school classroom activities. Graduate fellows are required to be full-time students in the mechanical or civil engineering departments and are also required to make progress towards their thesis research. Undergraduate fellows have a similar time responsibility to the program but may be majoring in any engineering, science, or computing discipline.

Each RAISE fellow is paired with a teacher at one of the four participating high schools. The participating teachers facilitate the work of the RAISE fellows with support from the schools' administration. In addition to receiving a stipend to offset the additional work load, the teachers benefit by gaining proficiency in modern sensing technology. This provides the teachers with insight for activities in future classes and in the long term allows them to become technology resources in their schools.

Graduate fellows receive tuition remission, as well as a stipend, while undergraduate fellows receive a stipend. The fellows benefit by acquiring valuable teaching experience, improve their communication skills, and apply their knowledge and explore their creativity by being able to design lab experiments and demonstrations.

3. Illustrative Sensor-Based Physics Experiments

A key element of the RAISE project is the development of sensor-based lab experiments that demonstrate concepts in physics from an engineering perspective. Before the development of experiments can begin, sensors which are rugged enough for a high school environment, along with a user-friendly software interface, must be selected. Given these requirements, numerous vendors were examined and Vernier Software and Technology [7] was selected as the primary source of sensing and data logging equipment.

A wide range of experiments complementing New York States Regents Physics curriculum has been developed by the RAISE fellows (Table 1). All experiments use one or two sensors, an analog-to-digital interface, and a desktop/laptop that runs Logger Pro 3.3 software [8].

Some experiments developed under the RAISE project are similar to the ones typically performed in the NYC public high schools, except that they make use of sensors and real-time data acquisition hardware and software. This alleviates the drudgery of manual data collection and allows students to focus on the concept at hand. Other experiments are entirely new and demonstrate connections between real-world applications and high school physics.

In some cases, the developed sensor-based experiments illustrate concepts that would be difficult, if not impossible, to demonstrate manually. In one example, to illustrate the concept of conservation of energy, a ball is tossed directly above an ultrasonic sensor that precisely detects the position and velocity of the ball throughout its path [9]. Using this data, the potential and kinetic energy of the tossed ball can be calculated at any two or more locations to verify that the total mechanical energy is conserved. It would be difficult, if not impossible, to illustrate this concept without modern sensing technology. Moreover, by using computerized data collection, experimental data is instantaneously presented in graphical form, thus allowing visual learners to witness the concept instantly, even before any analysis is performed.

Table 1: Sensor-based physics activities developed under the RAISE project

Experiment	Description
Air resistance	An ultrasonic sensor is used to measure the velocity of one or more free falling coffee filter(s) and to show that the filter reaches a terminal velocity due to air resistance.
Buoyancy	A force sensor is used to measure the buoyant force of an object immersed in liquid. By knowing the submerged volume of the object the density of the liquid is obtained.
Conservation of mechanical energy	An ultrasonic sensor is used to determine the position and velocity of a tossed ball. Using the position and velocity at various locations, conservation of total energy is verified.
Electromagnetism	A magnetic field sensor is used to verify properties of a solenoid such as uniform field strength within the core, negligible field outside the core, direction of poles formed due to current direction, and attenuation of field as measured axially.
Freefall acceleration	Using a photogate, the acceleration due to gravity of a free falling object is measured.
Heat transfer	Using a temperature probe, the rate of cooling and heating of water is measured. Insulating properties of different materials are also investigated.
Projectile motion	Two photogates are used to measure the horizontal component of the initial velocity of a ball being rolled off a table. Using this value, the range of the horizontal landing is calculated.
Simple harmonic motion	An ultrasonic sensor is used to measure the amplitude and frequency of a mass-spring oscillator. From this, maximum velocity and acceleration are calculated and the mathematical model of harmonic motion is verified.
Stability	A force sensor is used to pull a block until the block tips or slides. The critical forces are then computed theoretically and compared with the sensor measurements.
Static and kinetic friction	A force sensor is used to pull on a wooden block, sliding over a frictional surface, to determine the coefficient of static friction. Kinetic friction is determined using an ultrasonic sensor that measures the deceleration of a sliding block coming to rest.
Vector addition	Force sensors are used to find the tension in two strings attached to a mass. The resultant force is then computed.

3.1 Sample Modules

3.1.1. *Experiment on Stability—Sliding and Overturning*

This experiment is designed to illustrate some civil engineering applications in the classroom while reinforcing basic concepts taught in physics, such as Newton's laws of motion, friction, and moment. Students are first familiarized with the notion of instability in civil engineering structures, in the form of sliding and overturning. Examples of land slides, 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 (Figure 1). Use of force sensor, real-time data acquisition hardware, and real-time data acquisition software running on a desktop computer, allows students to visualize the time 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 with changed position of the hooks and by applying the force on each face of the block with the force sensor. Such experimentation allows students to discover on their own that the shorter the resisting lever arm from the point of rotation the lesser the force required to overturn it.

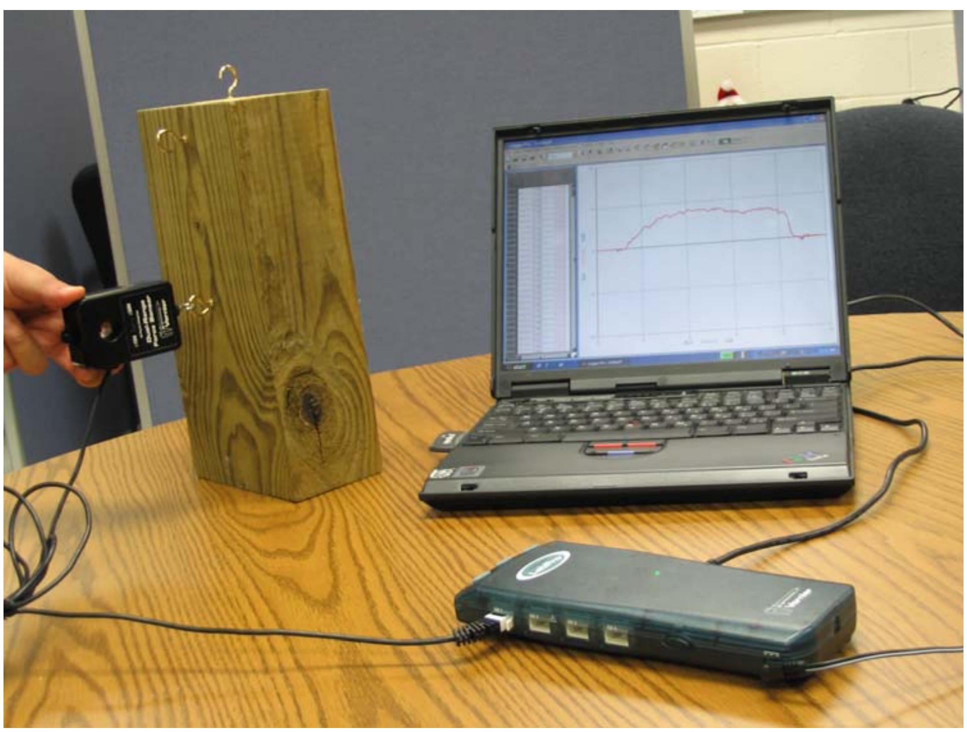

Figure 1—Stability test: finding the force required to slide or overturn the block

3.1.2. *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. We also discover that a magnet can pick up ordinary pieces of metal, which may become temporarily magnetized. Students who do not learn the science driving the magnet's operation may view such phenomena as magic. Therefore, this lab is constructed to explore a subset of the laws of magnetism. Specifically, 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 largest number of paper clips.

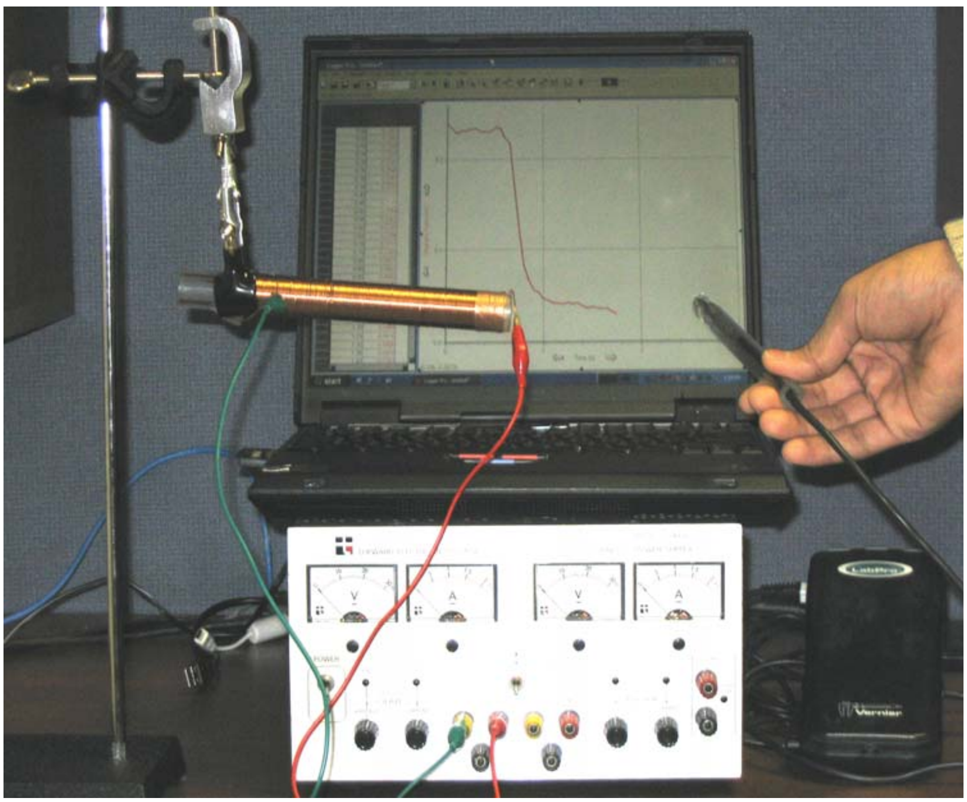

Figure 2—Electromagnetism test: finding the magnetic field intensity attenuation with distance from the pole

4. Classroom Implementation

It is commonly viewed that high school students who excel in math and science courses succeed in high school and continue their education at college. The difficulty involved in mastering these subjects presents great challenges for students and for the educational system. A lack of fully prepared and effective teachers is limiting the achievement of students in STEM disciplines in American K-12 schools. Teachers lack adequate professional preparation, budgets are limited, and science and math are areas suffering from acute teacher shortages. In addition, the sheer shortage of teachers [1] has led to overcrowded classrooms, further hindering the student achievement in these disciplines.

Motivated by the recognition of these needs, RAISE fellows have been mobilized to implement a partnership between Polytechnic University and four New York City public high schools, to *i)* introduce technology to in-service teachers to enhance their technical proficiency, *ii)* serve as an additional resource in the classrooms and labs to provide individual attention to students, *iii)* interact with students as their mentors and coaches to stimulate their interest in math and science, and *vi)* serve as role models to motivate students to pursue careers in STEM disciplines.

Sensor-based experiments in physics have been developed and are now being implemented in the lab sections of physics classes. Each school is equipped with four computerized setups which allow for groups of four or five students per setup. The modules are designed in a way that every member of the group has an active role in the experiment. Furthermore, team members must have constant interaction among each other to complete the lab assignment properly. For example, one student holds the sensor, another operates the computer, the third works with the equipment, and the fourth acts as a manager and monitors that everyone is synchronized. The students have the opportunity to switch roles as most modules have multiple trials. This method of running the labs keeps students engaged and prevents negative behavior before it starts.

Incorporating the LoggerPro 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, *iii)* the hands-on lab activities aid the tactile/kinesthetic learners, who grasp the concept by doing the experiment.

Lab activities are exciting students about STEM disciplines. Students tend to appreciate the need for a solid foundation in science and math in order to function in an increasingly technology driven world. Some students are pursuing challenging academic work, meeting high academic achievement standards, acquiring a passion for STEM disciplines, and are considering pursuing STEM careers. Collaborative efforts between the RAISE fellows and high school teachers allow the fellows to make presentations and demonstrations during class time, thus aiding in the transformation of students.

5. Assessment

The project has an ambitious set of objectives. For high school students, we aim to develop, apply, and enhance their STEM skills through the project activities. We hope to revitalize student performance on the Regents Exams of Physics and Living Environment. Effective oral and written communication and opportunities to work in culturally diverse groups are also emphasized. Finally, we aim for students to have a positive experience that will interest them enough to pursue STEM careers.

For the RAISE fellows, our goal is to sharpen their communication, leadership, and STEM skills through curriculum planning, lab development, and instructional delivery.

For the high school teachers, our objective is that they attain adequate technology proficiency to integrate sensor-based demonstrations in their lesson plans and classroom activities. Moreover, we believe that teachers improve their pedagogical skills by collaborating and exchanging ideas with engineers. Finally, they are afforded an opportunity to teach ideas developed through these collaborations to an audience that has a heightened interest in STEM discipline.

An independent program evaluator has been retained to assess the degree to which the RAISE project is meeting its stated objectives. Thus far, the independent evaluator has: observed the educational workshop offered during summer 2004, attended many project meetings, and observed all RAISE fellows in classroom. At the time of this writing, the classroom implantation phase of this project has been in effect for four months. It is somewhat early to provide a definitive assessment of the project success in meeting its objectives. Nevertheless, the following are the evaluator’s preliminary observations:

- Teachers at the schools seem, in general, to feel that the presence of the RAISE fellows is helpful in enriching their courses.
- There have been no significant cultural problems in having the fellows interrelate readily with students at the four inner city schools.
- The relationships formed between the fellows and the high school teachers seem to be positive and the teachers seem comfortable in working with the fellows.
- Students at the high schools generally accept the RAISE fellows as legitimate learning resources and seek answers from them to clarify concepts that they are trying to master.

- In some cases, the RAISE fellows have shown instructional skills that suggest that they can be successful teachers with similar populations of students, should they choose to do so.

- Students' improvement in STEM disciplines can not be evaluated until the first semester is over.

We close this section by offering quotes from the administrators of four partner schools on the impact of RAISE project at their schools.

George Westinghouse: "The students in RAISE project classes enjoy the change of pace of working with lab equipment. Students tend to grasp scientific concepts much quicker. RAISE project classes reinforce scientific methodology on a regular basis, and this has impacted on the quality of lab reports. Teachers associated with RAISE project at Westinghouse benefited from the training workshops that were given at Polytechnic University. RAISE Fellows and teachers have motivated the students to develop an interest and curiosity for science and science research."

Marta Valle: "The hands-on experience of using probes, laptops and software, coupled with the collaboration between Marta Valle and Polytechnic students, has enabled our youngsters to gain a deeper understanding of the scientific concepts being presented. As a result, students are motivated to pursue science as a possible area for college study and later career choice. Without this exposure, we do not believe that our students would pursue this path."

Paul Robeson: "RAISE has succeeded in improving student attendance and motivation. Previously, many students tried to cancel physics when it appeared on their programs, but they are now showing greater effort, confidence and growth."

Seward Park: "The two Fellows have been a tremendous asset to the students in the Regents physics class. They have allowed the students to participate in interesting sensor-based labs and they have provided the two teachers (i.e., Mr. Qian, the classroom teacher and Mr. Aubrey, the lab teacher) with additional support in the classroom. Also, due to the innovative technique of splitting the class into two groups (i.e., sensor-based lab with group A while teacher does traditional lab with group B; then they switch), students are able to experience collecting data both manually and via sensors."

6. Conclusion

Within the first few months of its existence, the RAISE program has begun to revitalize science education through implementation of advanced sensing technology in physics classrooms. The RAISE fellows have designed sensor and instrumentation-based labs that convey physics concepts through use of modern data acquisition tools. The new lab experiments will either replace or co-exist with the previously used labs in science classrooms. A sudden integration of these tools is difficult, but it is necessary to equip students with technology tools that will benefit them in an increasingly technological society. In addition to student improvement, the fellows develop their leadership and communication skills which are essential for their career success.

Acknowledgements

This work is supported by the GK-12 Fellows Program of National Science Foundation under grant DGE–0337668: *RAISE: Revitalizing Achievement by using Instrumentation in Science Education*. Polytechnic University provided significant financial support for the acquisition of 13 sets each of LabPro Biology Deluxe Package and LabPro Physics Deluxe Package from Vernier. Finally, the authors acknowledge the support of Vernier Software and Technology, which provided equipment at a significantly discounted rate as support for this project.

References

1. W. S. Bacon (Ed.), Bringing the Excitement of Science to the Classroom: Using Summer Research Programs to Invigorate High School Science, *Research Corporation*, Tucson, AZ, 2000.
2. Online: http://raise.poly.edu, website of the RAISE project.
3. Online: http://www.nycenet.edu/teachlearn/standards/nycstandards.html, website of NYC Department of Education Public High Schools Math and Science Performance Standards.
4. G. C. Orsak *et al.*, "High-Tech Engineering for High School: It's Time!," *IEEE Signal Processing Magazine*, January 2004, 103—108.
5. Online: http://mechatronics.poly.edu, website of Mechatronics @ Poly.
6. Online: http://www.parallax.com/html_pages/edu/curriculum/sic_curriculum.asp, website of Parallax Inc.'s "Stamps in Class" educator's program.
7. Online: http://www.vernier.com/, website of Vernier Software and Technology.
8. Online: http://www.vernier.com/soft/lp.html, website of Vernier's Logger Pro software.
9. K, Appel, J, Gastineau, C. Bakken, and D. Vernier, "Physics with Computers" *Vernier Software and Technology*, Beaverton, OR, 2003

NERIK YAKUBOV received the B.S. degree in Civil Engineering and a minor in Mathematics from Polytechnic University, Brooklyn, NY, in 2004. Upon graduation he joined Poly's GK-12 fellowship program funded by NSF. As part of his fellowship commitment, he is pursuing the M.S. degree in Geotechnical Engineering at Polytechnic and serves on site at George Westinghouse High School as a science resource to both, teachers and students. In the summer of 2003 he held a geotechnical internship position with Arup Associates working on the Second Avenue Subway project in New York, NY. In the summer of 2002 he held an internship position with John Picone

Incorporated working at the Jamaica Water Pollution Control Plant in Queens, NY. His proposed research is an education-based thesis concentrating on civil engineering instrumentation, such as, strain gages, load cells, earth pressure cells, groundwater pressure cells, tiltmeters and inclinometers, seismic load monitors, and fiber optic sensing technology.

SOOKRAM SOBHAN received the B.S. degree in Electrical and Computer Engineering from Polytechnic University, Brooklyn, NY, in 2004. He is currently pursuing the M.S. degree in Mechanical Engineering, with emphasis on Control Systems, at Polytechnic. From 2003-2004, he served as a research assistant in the Power Laboratory at Polytechnic investigating dynamically reconfigurable energy aware multimedia information terminals and is currently guiding two undergraduates in this topic. He is currently a teaching fellow under Poly's GK-12 fellowship program funded by NSF. His interests include sensor networks, integrated circuits for power processing and control, electromagnetic, microwave, and mechatronics.

MAGUED ISKANDER is Associate Professor and Graduate Adviser of the Civil Engineering Department at Polytechnic University, Brooklyn, NY. Dr. Iskander is a recipient of NSF CAREER award, Chi Epsilon (Civil Engineering Honor Society) Metropolitan District James M. Robbins Excellence in Teaching Award, and Polytechnic University Distinguished Teacher Award. Dr. Iskander's research interests include Geotechnical modeling with transparent soils, foundation engineering, and urban geotechnology. He makes extenive uses of sensors and measurement systems in his research studies. Dr. Iskander has published 50 papers and supervised 6 doctoral students, 14 masters students, 6 undergraduate students, and 7 high school students.

VIKRAM KAPILA is an Associate Professor of Mechanical Engineering at Polytechnic University, Brooklyn, NY, where he directs an NSF funded Web-Enabled Mechatronics and Process Control Remote Laboratory, an NSF funded Research Experience for Teachers Site in Mechatronics that has been featured on WABC-TV and NY1 News, and an NSF funded GK-12 Fellows project. He has held visiting positions with the Air Force Research Laboratories in Dayton, OH. His research interests are in cooperative control; distributed spacecraft formation control; linear/nonlinear control with applications to robust control, saturation control, and time-delay systems; closed-loop input shaping; spacecraft attitude control; mechatronics; and DSP/PC/microcontroller-based real-time control. He received Polytechnic's 2002 Jacob's Excellence in Education Award and 2003 Distinguished Teacher Award. In 2004, he was selected for a three-year term as a Senior Faculty Fellow of Polytechnic University's Othmer Institute for Interdisciplinary Studies. He has edited one book and published four chapters in edited books, 37 journal articles, and 73 conference papers. He has mentored 54 high school students, 21 high school teachers, ten undergraduate summer interns, and seven undergraduate capstone-design teams. In addition, he has supervised two M.S. projects, two M.S. thesis, and two Ph.D. dissertations.

NOEL KRIFTCHER is Executive Director of the Packard Center for Technology and Educational Alliances at Polytechnic University, where he also holds an appointment as Industry Professor of Humanities. At the Packard Center, he coordinates an extensive array of faculty development services, directs a consortium of colleges known as the Knowledge Workers Educational Alliance, and organizes varied hands-on scientific experiences and competitions for students in middle and high schools. He works closely with NSF-funded projects to connect them with the pre-college community and has won grants from the U.S. Dept. of Education, the NY State Education Department, and private foundations to improve access and opportunity for women and minorities for advanced study in science, mathematics, and technology. Before coming to Polytechnic, Dr. Kriftcher served as a teacher and administrator, then as principal of Seward Park High School in New York City, and as superintendent of the high schools in Brooklyn and Staten Island. He is a co-PI for Project RAISE—Revitalizing Achievement using Instrumentation in Science Education.

ALON KADASHEV began pursuing a B.S./M.S. degree in mathematics and electrical engineering, respectively, in Fall 2002. He is expected to receive these degrees in June 2006. He is currently working on Poly's GK-12 fellowship program funded by NSF. His current research interests are in functional analysis, differential equations, signal systems and DSP.