THE MODERN SCIENCE LAB: INTEGRATING TECHNOLOGY INTO THE CLASSROOM IS THE SOLUTION

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Abstract— Technology continues to profoundly impact daily lives. It is therefore imperative that all students receive comprehensive, high quality education in STEM subjects (Science, Technology, Engineering and Math) from adequately trained teachers. In order for students to pursue STEM career, achieving high scores on standardized science and math exams is critical. Unfortunately, science labs often make use of antiquated technology that fails to tap the potential of modern technology 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

"Revitalizing Achievement by using Instrumentation in Science Education (RAISE)" project is a partnership between Polytechnic University and four New York City (NYC) high schools. Project RAISE seeks to enhance students' academic achievement by using computerized data acquisition and sensor-based equipment in science labs. RAISE seeks to excite students about STEM and help them comprehend challenging scientific concepts.

The authors argue that the modern science lab must integrate technology into the curriculum. This paper presents a description of the RAISE project, together with some of the sensor-based experiments which are currently in use in the "living environment" science lab. Lessons learned from year-one of the program as well as improvements made for the second year are also presented.

I. INTRODUCTION

Today's students are attracted to new gadgets, such as iPods, video games and cell phones. To them, gadgets are *cool*, and this can be leveraged as a way to interest students in technology and to motivate them to excel in STEM disciplines. Unfortunately, for reasons of limited resources and a well-documented shortage of adequately trained high school science teachers, schools often present required science and math courses in an unimaginative manner [1]. They introduce basic scientific concepts as before, but fail to relate these concepts to science, as encountered by students in their daily lives. That is a 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. This results in poor achievement on standardized science and math exams and apathy about pursuing careers in engineering and technology.

Laboratory experiments commonly support learning in math and science in high school. By integrating modern sensor technology, into traditional labs, students can be introduced to lab experiments, which are not only informative, but also very exciting [2]. For example, in a living environment laboratory, a demonstration may involve measuring how plants generate energy by photosynthesis. To perform this experiment in a traditional lab, students use a lamp, a plant and a bicarbonate indicator, which serves as a traditional sensor. It would take at least one day to detect the change in concentration of carbon dioxide qualitatively as its color changes from purple to yellow. Students would have to wait for the color to change, but by then the average student's attention would be lost. In a sensor-based lab, as will be explained in greater detail later in this article, a few spinach leaves, a light source, an oxygen sensor and a carbon dioxide sensor are used. Real-time data acquisition hardware and software allows groups of students to monitor and compare the process of photosynthesis through changes in the concentration of carbon dioxide and oxygen. The measurements are easily accomplished in a 55-minute class period. Furthermore, students are able to control the experiment by changing the parameters that affect photosynthesis and monitor the consequences. For instance, they could alter the results of the experiment merely by changing the location of the light source or the numbers of plant leaves.

Integrating modern sensing technology into science labs makes labs more appealing to students by having them use gadgets that are *cool* 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 [3, 4]. 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.

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II. PROJECT OVERVIEW

The "Revitalizing Achievement by using Instrumentation in Science Education (RAISE)" project is a partnership between Polytechnic University and four New York City high schools [5]. Its mission is to enhance student's academic achievement in STEM disciplines. This program is funded by a National Science Foundation (NSF) GK-12 grant. The high schools participating in Year-1 of this program were George Westinghouse, Marta Valle, Seward Park, and Paul Robeson. For Year-2, Seward Park High School was replaced by The High School of Telecommunications, Arts, and Technology.

The main purpose of RAISE is to increase students' achievement in science, as measured in part by their achievement on standardized exams. The project seeks to stimulate students by integrating sensing, instrumentation, and modern data acquisition and computing technologies into the curriculum used in Active Physics, Regents Physics, and Living Environment courses. Marine Science was added to the program in Year-2. Additionally, the RAISE Fellows serve as teaching assistants in the classroom, and as science resources to teachers and also make themselves available for extra tutoring.

The RAISE program is supervised by two engineering faculty, and one liberal arts faculty. Each Fellow is paired with a RAISE teacher who receives a stipend and attends a weeklong workshop during the summer to learn about modern sensing technology. Each Fellow spends a minimum of ten hours a week at his/her assigned high school as a science resource and at least five hours a week on campus preparing experiments and materials to be used in the high school classroom. The graduate RAISE Fellows are full time students and are required to make satisfactory progress in thesis research. They receive tuition remission as well as a stipend. The undergraduate RAISE Fellows receive a stipend only. An external evaluator evaluates the progress of the program.

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 was 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 a more 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 on mechatronics and engineering, where they made their own robots [6]. 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 for some teachers to be motivated to start a robotics club at their schools, where they could use what they learned during the training session and to motivate the students into joining the club.

III. DIFFICULTIES ENCOUNTERED IN YEAR-1

The program got off to a slow start in Year-I because of scheduling conflicts and a lack of appropriate equipment. Initially, it was difficult to attract graduate students to join RAISE in a hot job market despite the generous stipend ($30,000+ tuition). 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. In the second year, the benefits of RAISE to the Fellows were evident: five of the ten undergraduate Fellows applied to continue as graduate RAISE Fellows and pursue their studies towards the master's degree. In Year-II of the program, there are eight graduate and five undergraduate Fellows, which makes scheduling considerably easier.

A second difficulty encountered in Year-1 was that the NSF GK-12 program provides generous stipends but does not allow for adequate equipment funding. Polytechnic University subsidized the program by providing each school with four biology and four physics sensor kits [7]. However, when Marta Valle was added to the program at the last minute, it had to share kits with Seward Park High School.

Schools were required to provide laptops. It was difficult for many schools to find funding to meet this requirement, at least in a timely manner. In Year-1, schools that were unable to provide laptops or computers used the sensors with graphing calculators. By Year-2, 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 problems 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 many computations that were required of them.

By the start of Year-II, all of these problems had been successfully addressed and the RAISE program was ready to make a long-term impact on student learning. One dramatic contribution in Year-I, however, was the role of the 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 that requirement, even though they did not play an active role in teaching. This was a noble effort, and although the class eventually had to be disbanded, the Fellows had proven their merit in this rescue effort.

New York City is in the middle of a school reform, which involves among other things breaking up large schools into several small ones occupying the same building. Seward Park is one of the schools being phased out. 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 continue to maintain Seward Park in the program under the circumstances.

In the second year of the RAISE program, the mistakes that were made during the pilot year were corrected. 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 previous year in order to train them effectively for the classroom. During this 5-day workshop the fellows created a database of presentations and labs to be delivered in the classroom for instruction. Each Fellow has access to this database. Since most of the Fellows are experienced returning fellows, they enjoy a comfort level with their respective teachers. This familiarity promotes communication that can lead to more improvements in the program's infrastructure.

IV. BROADER IMPACTS OF PROJECT RAISE

A change in the students' attitude was observed over the course of the year. Many students looked forward to doing lab experiments. The tasks that they may have found daunting in the beginning of the year later became second nature. Furthermore, students were devising 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 career advice.

The RAISE program affected the Fellows as well. Fellows displayed an improvement in their communication and presentation skills. Additionally, many expressed that their comprehension of scientific principles has improved as a result of having to teach.

The impact of RAISE extended beyond the classroom. There were many events that took place during the first year of the program, which supported its goals and objectives:

1- Career Day

Polytechnic University hosted RAISE Career Day on April 20, 2005. Students from the four participating high schools were exposed to various disciplines of engineering via presentations and tours made by faculty and recent Polytechnic graduates. The purpose of this event was to arouse students' interest in science, engineering, and technology that may lead them to consider engineering as a possible career option.

2- NYC NSF GK-12 Grant Holders Meeting

The NYC NSF GK-12 Grant Holders Meeting took place on May 20, 2005. This meeting was hosted at Polytechnic University. Participants included representatives from the four GK-12 projects in NYC (Columbia University--two programs), CUNY Graduate Center, and Polytechnic University), as well as the NYC Department of Education. 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 the event.

3- 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 on March 4-6, 2005. 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.

4- Third Annual Convergence on Inquiry

On June 11, 2003, RAISE was invited to the Third Annual Convergence on Inquiry at the American Museum of Natural History to give 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."

5- SMART Program

RAISE fellows also participated as science resources for Polytechnic's SMART program at which ten teachers from New York City schools were chosen to undergo intensive training in mechatronics for four weeks during the summer. The Fellows themselves sharpened their skills in mechatronics and were made available to assist the teachers in building their respective projects.

V. SENSOR-BASED LIVING ENVIRONMENT EXPERIMENTS

Living Environment is a class typically taken by freshmen in high school. Students take an exam organized by the state called the Regents exam. Each student must pass one Regents examination in science before graduating high school [8]. To earn a Regents-endorsed diploma, which is recommended as a minimum achievement for a student entering a college such as Polytechnic University, a student must pass three Regents exams in science. In NYC Living Environment tends to be the student's first exposure to "Regents science" in a high school.

The sensor-based experiments that were developed by the RAISE fellows modeled the New York States Regents Living Environment curriculum. The developed experiments incorporated sensors, which demonstrated concepts that originally would seem difficult to visualize and comprehend. The sensors helped students get a more interactive illustration of important concepts of living environment. Table 1 shows the Regents Living Environment experiments developed by the RAISE Fellows.

VI. Examples Of Living Environment Experiments

1. Aerobic & Anaerobic Respiration

Some of the experiments designed went beyond just demonstrating key concepts of living environment. Many of the experiments related everyday life to the content of lab. In one living environment experiment, students were asked to identify which drink would give the most surge of energy. Some of the choices given were: Coca Cola, orange juice, Gatorade, milk, and water. The students tested each drink using a carbon dioxide sensor to measure the rate of aerobic respiration. To make the experiment analogous to the human body, yeast was used to consume and break down the sugar molecules of each drink and release energy. Energy is directly proportional to the amount of carbon dioxide released. Hence, the greater the amount of carbon dioxide released, the more energy is released, thus the greater the rate of respiration.

Based on their findings, students were required to compare the rates of respiration and conclude which drink would be the best option right before an athletic event. A similar process was done for anaerobic respiration except for two main differences.

- The mixture of the yeast and drink was sealed air tight, not allowing any contact with outside oxygen.
- A gas pressure sensor was used to measure the rate of respiration based on the concept that gas pressure increases as more gas is released.

Normally in a lab similar to this, the drinks would have been substituted with different sugars for example: Sucrose, Fructose, Lactose, and Glucose. These are the same sugars that are found in the drinks that were used in the experiment. Students don't fully understand why respiration is so important and how does it affect our bodies. However, by substituting the sugars with what students drink everyday allows them to fully appreciate the importance of respiration.

TABLE 1- Living Environment Experiments

Experiment	Description
1. Acid Rain	A pH sensor is used to understand the relationship between pH and CO_2 concentration of distilled water and how different pH level affects living organisms.
2. Acid & Base	A pH sensor is used to measure the pH of different liquid that are acidic and basic and help understand the pH scale.
3. Aerobic Respiration	A CO_2 gas sensor is used to measure to measure the rate of respiration. Students compare the different rates of respiration for different energy drinks which help them conclude which drink is the most effective energy drink.
4. Anaerobic Respiration	A gas pressure sensor is used to measure the rate of respiration. Students compare the different rate of respiration for various energy drinks which help them conclude which energy drink is the most effective
5. Calorie Content in Food	A temperature probe is used to determine the energy content of a small sample of food. Students learn how energy is given off by food as it burns. They determine and compare the energy contents of different foods.
6. Conducting Solutions	A conductivity probe is used to measure the conductivity level of different solutions. Students have to understand how the number of ions of solutions relates to conductivity level.
7. Diffusion	A conductivity probe is used to measure the change in ionic concentrations in a solution over a period of time. Different factors affecting the rate of diffusion were studied.
8. Enzymes	A colorimeter sensor was used to study the functions of an enzyme present in various detergents.
9. Greenhouse effect	A temperature probe was used to measure the temperature changes within an environment to understand the greenhouse effect as a physical phenomenon
10. Monitoring Heart Rate	An EKG sensor was used to graph one's heart's electrical activity. Based on the EKG recording the heart rate can be calculated.
11. Photosynthesis	A carbon dioxide and an oxygen sensor was used to calculate the rate of photosynthesis and compare the affects of light on the rate of photosynthesis
12. Population Dynamics	A colorimeter was used to monitor a closed population growth of yeast by measuring the turbidity or cloudiness. Photons of light strike the yeast cell and reflect away from the photocell. The colorimeter monitors the light reflected by the photocells as absorbance which is proportional to the yeast present in the medium.

2. Monitoring EKG

One of the most entertaining and interactive experiments conducted during the year involved an Electrocardiogram (EKG) sensor. Many of the students were already exposed to what an EKG diagram looks like from television shows such as ER. Taking advantage of this the EKG lab was designed to have students determine their heart rate based on the EKG diagram produced using the sensor. The EKG sensor is hooked up to three electrode patches that are placed on a volunteer's arms. The students collected data while at rest and after performing fifteen jumping jacks. They were also required to determine their heart rate by measuring their pulse and then compared their results with what was calculated using the EKG sensor.

The students found this lab to be the most interesting experiment partially because the sensor was directly hooked up to their bodies. They were able to visualize what their EKG looks like in comparison to one of their classmates. Branching off from this experiment, students came up with many questions, such as:

- How would age, gender, and weight affect the EKG diagram?
- Why are the peaks of my EKG smaller, larger than my classmates?
- How can we use an EKG to diagnose various ailment of the heart?
- Why don't we get electrocuted if the EKG sensor measures the electrical impulses?
- How does the EKG sensor work?

This lab opened up a riveting discussion about different heart ailments and how useful an EKG is in diagnosing such illnesses, which brought lots of excitement to the classroom [9]. Not only did they form an appreciation for an EKG, but this experiment helped the students better understand the hearts functions.

3. Photosynthesis

Life requires energy to go on. Plants generate energy from photosynthesis with carbon dioxide. During the process of photosynthesis, carbon dioxide is consumed, while the plant generates oxygen and energy. In this experiment, students illustrate the process of photosynthesis by detecting the concentration of oxygen and carbon dioxide in a plant. To perform this experiment, students use a lamp, few spinach leaves, an oxygen gas sensor, a carbon dioxide sensor, and real-time data acquisition hardware and software. Use of sensors allows students to visualize the concentration of oxygen and carbon dioxide when observing the phenomenon. Thought-provoking questions are asked to reinforce the concept of photosynthesis; such as:

- What evidences do we have to conclude that the plants experience photosynthesis?
- What is the ultimate concentration of gases if the experiment would be continuously running without touching the setup?

Students investigate their hypothesis and discuss the results with their classmates. Such experiment excites students about the subject, motivates students, and fulfills their curiosity.

VII. CLASSROOM IMPLEMENTATION

Many of the teachers have limited resources available to them to support their classrooms. In addition, overcrowded classrooms limit the personal attention that is given to students. Thanks to funding from the U.S. Congress, NSF recognizes these shortcomings and has created the GK-12 fellowship program. What distinguishes raise from other GK-12 fellowships is the integration of technology into classroom activities. The designed experiments had to be implemented within the science curriculum in order to achieve the program's objectives and gain the support of high school teachers and administrators. Therefore, the developed experiments tended to be more sophisticated than the ones already in existence.

Usually before performing an experiment, the fellow would 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 lab. 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 further assist 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.

VIII. ASSESSMENT

1. 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 pan out. 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 science course. Teachers believe that concepts learned in sensors based lab were more memorable to students than in a traditional lab. However, it is impossible to verify this observation because a control group was lacking.

One of the goals 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, none of the students is college bound yet. Second, it is difficult to determine if those students who are presently expressing interest in a STEM career would have chosen to study STEM anyway without RAISE. Finally, with the many changes associated with NYC school reform, it is difficult to verify the relative contribution of many initiatives.

All things considered the project team believes that sensor have made a positive impact on the students academic experience. The team also believes that the opportunity for high school students to interact closely with goal-oriented, engineering college students will help them, to develop academic goals for themselves.

2. Impact On Fellows

The effect of the program on RAISE fellows was found to be positive, as evidence 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 will serve the Fellows well in the future as they seek to become leaders in their fields, once they graduate and are employed.

IX. Pedagogical Lessons Learned

After working with students in Year-1, several lessons were learned and adopted to improve classroom management and teaching strategies:

Classroom Management

- Check and test the availability and condition of equipments (outlets, computers and projectors) before beginning the lab.
- Divide students into small groups.
- Students behave better when visitors are in the classroom, in addition to the teacher. Invite guests, including the principal/assistant principal to visit the class.
- Don't stop the entire class if a student comes late. Ask another student to explain what the class is doing.

Teaching Strategy

- Keep students engaged.
- Find the common ground between what the students are interested in and the curriculum.
- Don't assume students recall material from past courses. Keep reminding them what of what they have learned.
- Create rules to make students work effectively and systemically. For example, prepare lectures with built in exercises.
- Always encourage students, give positive reinforcement and build up their confidence.
- Hand out extra responsibilities for energetic students.

X. Conclusion

This paper argues that integrating modern technology into science lab is the answer to the fading interest in STEM disciplines among American high school students. Students found the labs interesting. It is however too early to determine if (1) students will do better on standardized exams, and (2) if they will be motivated to pursue STEM careers, as a result of RAISE. The Fellows have improved their technical and pedagogical skills. The RAISE project team strongly believes that, given time, the goals and objectives of the program will materialize.

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