2006-1622: USING REAL-TIME SENSORS IN HIGH SCHOOL LIVING ENVIRONMENT LABS: A GK-12 PROJECT

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Using Real-Time Sensors in High School Living Environment Labs: A GK-12 Project

1. Introduction

In a series of recent op-ed pieces in *The New York Times* and in his latest book *The World Is Flat*,[1] Thomas Friedman points to an urgent need to develop a strong and technologically trained workforce to ensure the American leadership in scientific discovery and technological innovation. This call to action has been joined by business and government advisory groups such as the American Electronics Association,[2] the National Innovation Initiative,[3] and the National Academy of Engineering;[4] and reflected in the remarks delivered by industry captains such as Bill Gates at the 2005 National Education Summit on High Schools.[5] In a recent letter[6] to the editor of *The New York Times*, titled *"Scientific Competition,"* Debra W. Stewart, the President of the American Council of Graduate Schools, noted that "the last time the United States carried out a national strategy to improve our scientific competitiveness was in response to another nation surpassing us technologically." She referred of course to the launch of Sputnik by the U.S.S.R., which led the United States government to pass a series of immediate measures that enabled students to pursue doctoral study in scientific and technical fields, thus propelling the nation to accelerate its technological advancement and regain its leadership.

In a similar vein, today's global economy and our growing trade deficits demand bold new programs to produce the highly trained work force needed to maintain the U.S. leadership in science and technology. The foundation of scientific and technological leadership of a nation is built upon a deep understanding and appreciation of the basic sciences and math[7] by its young scholars. Unfortunately, today's youth exhibit a lack of interest in pursuing careers in scientific and technical fields. A shortage of well-trained science and math teachers, uninspiring and antiquated science labs, and the failure of school systems to provide competitive salaries to those who teach in these shortage areas lead students to perform poorly in science disciplines. This ultimately contributes to young people losing interest in studying science. This state of affairs persists despite the fact that today's youth are increasingly drawn to modern technological wonders such as video games, mp3 players, and instant messaging. Students' interest in state-of-the-art technologies can be used to deliver innovative educational curricula in science, technology, engineering, and math (STEM) disciplines.[8] At the very least, high school science labs can be revitalized by a systematic integration of sensing and computing technologies to support hands-on experiments.

Under a GK—12 Fellows project titled, "Revitalizing Achievement by using Instrumentation in Science Education[9] (RAISE)," Polytechnic University and four inner city schools in New York City have partnered to enhance students' academic achievement. This project seeks to ensure that a high-quality education is available at public schools attended largely by students who are economically disadvantaged and come from groups that have been traditionally underrepresented in advanced science and math study and careers. The project allows high school students to conduct exciting, hands-on learning activities to advance their scientific understanding. Through lab activities students visualize and practice science and math concepts that they otherwise find difficult to comprehend. Moreover, students learn sensing and computing technology and graphing and analysis tools that are used by practicing scientists and engineers in real-world.

A principal objective of science lab experiments is to promote learning in math and science. By integrating modern sensor technology into traditional labs, students can be introduced to lab experiments which are not only informative but are also exciting. For example, a typical high school level Living Environment (another name for a typical Biology course) experiment concretely demonstrates that plants generate energy from photosynthesis with carbon dioxide. To perform this experiment, the students use an oxygen sensor and a carbon dioxide sensor. The sensors are hooked up to real-time data acquisition hardware and software. The students see the increase in the concentration of oxygen on a computer monitor as the plant absorbs carbon dioxide during the process of photosynthesis. Real-time data acquisition hardware and software allow 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 experimental parameters and see results. For instance, by changing the location of the light source or the numbers of plant leaves, students can study the varied results of the experiment.

Under this GK—12 Fellows project, integration of modern sensing technology into hands-on science experiments is increasing the appeal of lab activities for high school students. It is anticipated that these students, having being introduced to contemporary technical concepts and tools used in the study of science, will understand these concepts at a higher level and will be sufficiently interested to consider pursuing careers in science and engineering.

2. Overview

The RAISE project is funded by a GK—12 Fellows grant from the National Science Foundation (NSF). Two engineering and one humanities faculty are guiding 13 undergraduate and graduate students (RAISE Fellows) to integrate modern sensing technology in science labs by partnering with nine teachers at four high schools. An external evaluator assesses the progress of the program.

This GK—12 Fellows project aspires to stimulate interest in high school students toward STEM related fields by incorporating sensing, instrumentation, and modern computing technologies into Active Physics, Marine Biology, Regents Physics, and Living Environment curricula. The project also aims to enhance student achievement on standardized exams. The goal is to have the students form a deep appreciation of STEM disciplines so that they can consider career options in STEM-related disciplines.

To achieve the goals of the program, 13 RAISE Fellows are deployed in four inner-city high schools to serve as teaching assistants in the classrooms and labs and as science resources to the teachers. Each RAISE Fellow is paired with one of the nine teacher-participants in the project. The RAISE Fellows spend a minimum of ten hours a week at their assigned high school and at least five hours a week on campus preparing educational materials and lab experiments to be used in the classroom, performing research, and interacting with one another.

The teacher-participants of the RAISE project attend a week-long workshop during the summer to learn about modern sensing technology. This workshop, conducted by the RAISE Fellows under faculty guidance, trains teachers to become proficient with sensing and computing technologies. Hands-on experiments and reflective group discussions enable the teachers to consider different ways of integrating sensor-based activities in their classrooms and labs. The teachers also conduct several hands-on activities in mechatronics (involving integration of sensors, actuators, and microcontrollers) and mobile robotics (a prototype wheeled robot that explores its environment using a variety of on-board sensors). Thus the workshop equips the teachers with sufficient skills so that they can introduce their students to fundamentals and applications of engineering and can establish robotics clubs at their schools. Finally, the workshop provides an opportunity for the teachers and the RAISE Fellows to bond with one another.

The RAISE Fellows also attend a week-long summer workshop on pedagogical skills and techniques that is conducted by an education specialist who formerly served the NYC school system as a trainer of teachers and as an instructional supervisor. The workshop is designed to improve the Fellows' pedagogical, communication, and presentation skills. They learn to plan effective lessons and different questioning techniques that challenge students to utilize higher-order thinking skills. The Fellows consider this training program to be beneficial because they learn practical approaches to anticipated challenges found in the classroom. The Fellows also develop a repertoire of techniques for transmitting academic material and to determine the level of students' comprehension. These are skills which engineering students who lack pedagogical training customarily do not develop, but they are the very skills that are essential if a classroom teacher is to be effective so students can learn.

This GK—12 Fellows project has been active outside the high school classrooms and labs as well. Specifically, throughout the first year of the program many events were conducted to engage various stakeholders in the project and to disseminate positive aspects of the program. For example, the project team hosted a Career Day for the high school students and a city-wide GK—12 Grantee's meeting. In addition, an undergraduate RAISE Fellow and a high school teacher gave a cooperative presentation at the NYC American Museum of Natural History.

3. Illustrative Sensor-Based Living Environment Experiments

Students attending public high schools in NYC school districts are required to pass one state-wide Regents exam in science to graduate. However, to earn a Regents-endorsed diploma, which is the minimum admission requirement for most undergraduate programs in science and engineering, a student must pass at least three Regents exams in science. Living Environment tends to be a student's first exposure to "Regents science" in high school and thus serves to lead the way to a solid college-preparatory record.

The Living Environment RAISE Fellows developed sensor-based experiments that model New York state's Regents Living Environment curriculum. The new sensor-based experiments illustrate concepts that originally may have been difficult to grasp by the students. Incorporating sensing technology into the lab experiments allows the students to be more interactive and be exposed concretely to sophisticated abstract concepts. Table 1 shows the Living Environment experiments that have been created.

3.1. Sample Lab Modules

3.1.1. *A Crime Scene Investigation (C.S.I.) Lab*

To set the scene for this experiment: Mr. Ramon Menendez, a young patient at Belleview Hospital, died following what should have been a fairly routine surgery. His appendix burst early in the afternoon, and he was scheduled for surgery within a few hours. His death, however, has been questioned, as it was clearly not related to the condition which necessitated the surgery. The patient's appendix was safely removed, but he expired shortly after the procedure was completed. Suspicion swiftly shifted to the amount of anesthesia that was given to the patient. Anesthesia can only be used safely in concentration of 0.02M or less, and questions have arisen as to the exact concentration of the anesthesia administered to Mr. Menendez.

It is the student's job to determine if the anesthesiologist should be charged with Mr. Menendez's negligent homicide. The class is asked to use quantitative analysis to determine the concentration of anesthesia administered. Spectrophometry, using a colorimeter, is used to determine the sample concentrations in this investigation. If the concentration is less than 0.02M, another investigative team will have to continue its analysis of the situation. However, if the students find that the concentration exceeds 0.02M, then the patient was administered a deadly dose and the anesthesiologist will be charged with the crime.

The experimental setup of this lab consists of colorimeter and cuvettes with different concentration of food coloring to represent various concentrations of anesthesia administered. The students plot a graph of absorbance versus the different concentration of the food coloring. Next, the students take the cuvette which contains unknown concentration of food coloring (to represent the unknown amount of anesthesia that was delivered to Mr. Menendez) and record its absorbance and determine by using the graph (see Figure 1) whether or not the amount of anesthesia delivered violated the safe limit.

In recent years, several C.S.I. television dramas have become popular and have led to increasing student enrollments in academic programs in forensic science. This lab uses a contemporary theme to mimic a real-life scenario to engage and excite students' interest and enables them to appreciate the curriculum content as well. Students are exposed to the colorimeter sensor and its operation and their graphing skills are reinforced.

Applications of concepts covered in this lab are relevant to engineering fields such as biomedical engineering. To prevent scenarios such as the one described above, many engineers are working toward the design and development of effective means to deliver anesthesia and other drugs accurately. We anticipate that this lab exercise will inspire the students to pursue careers in engineering (e.g., bioengineering, biomedical engineering, etc.).

3.1.2. *Acid Rain*

Factories continuously release many different gases, such as carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_2) into the atmosphere. When such gases react with the water in the atmosphere, acid rain is formed as seen below.

1. CO_2 reacts with water to form carbonic acid: $CO_2(g)+H_2O(l)\rightarrow H_2CO_3(aq)$
2. SO_2 reacts with water to form sulfuric acid: $SO_2(g)+H_2O(l)\rightarrow H_2SO_3(aq)$
3. NO_2 reacts with water to form nitric acid: $2NO_2(g)+H_2O(l)\rightarrow HNO_2(aq)+HNO_3(aq)$

The normal acidity level of rainfall has a pH of about 5.6 due to the presence of CO_2 in the atmosphere. However, if the rain reacts with a high concentration of SO_2 and NO_2 its pH can drop down to 2, which is very harmful to the living environment.

In this experiment the students are asked to create acid rain themselves by blowing into distilled water using a straw for approximately 60 seconds. When students blow into water they emit CO_2 which reacts with water to form carbonic acid. The students use a pH sensor to compare the pH of pure distilled water and the "acid rain" that they created. The students see a drop in the pH level which demonstrates the concept of acid rain.

Once again, a contemporary environmental problem such as acid rain is used to expose the students to the phenomenon of acid rain itself and they learn to use the pH sensor in this experiment. Following the acid rain experiment, through discussions, students are exposed to other factors that may affect the environment. Next, the students take on a role of environmental engineers and suggest experimental designs incorporating different sensors to monitor how various factors may impact the environment and how to lower such impact. One RAISE Fellow engaged his class in a semester long project where the students monitor pH, dissolved oxygen, conductivity, temperature, etc., over a period of time, in a fish tank and study optimal conditions for the fish and other organisms to survive.

4. Classroom Implementation

A series of activities has enhanced technical proficiency of in-service teachers. For example, through a week-long summer workshop, teachers received a hands-on introduction to and experience in modern sensing technology, mechatronics, and robotics. Furthermore, 13 RAISE Fellows serve as science resources in partnership with nine teachers to facilitate the integration of modern sensing technology in the science curriculum and labs. Finally, through the generous support of NSF, equipment vendors, Polytechnic University, and the participating high schools, the living environment lab at each of the four schools is equipped with four sets of sensor kits, data acquisition hardware, and appropriate computer hardware/software. The enhanced technological literacy, availability of RAISE Fellows as science resources in the class, and modern lab resources are allowing the teachers to conduct in-class demonstrations and hands-on lab experiments with the state-of-the-art tools.

The presence of RAISE Fellows in the classroom is proving beneficial in several ways. First, the Fellows provide the students an opportunity to receive a "one-on-one" learning experience. Second, the RAISE Fellows work with the teachers to integrate modern sensing technology in the science lab curriculum while making connections between the science content and its applicability in our daily lives. For example, in one living environment experiment, aerobic and anaerobic respiration lab, students were asked to identify which drink would give the most surge of energy to athletes. To make the experiment analogous to the experience by a human athlete, students used yeast and drinks like Coca-Cola, orange juice, Gatorade, milk, and water to observe the directly proportional relationship between the amount of released energy and the carbon dioxide concentration in the drink. Third, the Fellows engage the students through demonstrations of robotics, fiber optics, and other technologies to inspire their curiosity and drive for studying advance material.

The lab experiment sessions are conducted as follows. A RAISE Fellow begins by demonstrating the day's experiment and its key features to familiarize the students with the lab. Next, the students are split into groups of three to four students per setup. Each student group sub-divides the tasks involved in completing the experiment: setting up, managing, and monitoring the experiment; controlling the pace of the experiment; recording data; and performing calculation. The students have opportunities to switch roles for different runs of the same experiment. This method of organizing lab groups engages every student in the lab. The students have been typically receptive of the sensor-based lab activities. They appreciate the ability to acquire, observe, display, and manipulate real-time experimental data since it enables them to visualize science concepts quickly.

5. Assessment

5.1. Impact on RAISE Fellows

Having seen the value of the program during the first year, more than half of the RAISE Fellows (seven out of twelve) applied to continue with the program for the second year. In fact, 5 undergraduate Fellows from the first year of the program are now pursuing graduate education and are serving as graduate Fellows. The Fellows are receiving ample opportunities to convey technical concepts in an effective manner to a non-technical audience which is sharpening their communication and presentation skills. The improved communication skills are not only enriching Fellows' academic careers now, but will also serve them in their future academic and professional endeavors. Many Fellows report that they are able to convey to the students the relevance of science taught in high school to real-world problems. In addition, Fellows overwhelmingly feel that their experience with the project is helping them to enhance their own understanding of science. Finally, by serving as role models to youngsters, the Fellows are developing skills that will aid them to become leaders in their respective fields and better informed citizens in the future.

5.2. Impact on Students

This project aims to provide opportunities to high school students to develop, apply, and enhance their STEM related skills. Although it is early to assess the impact of the program on student achievement, the following observations are noteworthy. A majority of the students see two components of the GK—12 Fellows project *viz.*, the sensor-based labs and the presence of Fellows as the areas expected to yield the greatest educational value *vis-à-vis* other aspects of the courses (e.g., readings, lectures, discussions, group work, etc.). The high school students are receptive and appreciative of the new sensor-based activities in their classrooms and have reported that the lab component is their favorite aspect of the science course. Many students report that the sensor-based labs are more helpful in understanding science concepts than the traditional labs. Finally, many students have expressed interest in continuing their education at the college level in STEM disciplines.

5.3. Impact on High School Teachers

This project provides opportunities for professional development of teachers and the expansion of their technological literacy. In addition, RAISE Fellows team with the teachers to serve as science resources in the teachers' classrooms and labs. The project has allowed all teacher participants to integrate sensor-based demonstrations in their classroom lessons and modernize the hands-on lab experiments. Many teachers have rated the program highly for: helping to explain science concepts to students; providing useful lab exercises; presenting positive role models for their students; helping to improve lab attendance; engaging students' attention; and providing information on what is involved in working in science/engineering professions. They treat the Fellows as equals, as visiting engineering professionals, and as collaborators in finding ways to improve student learning

6. Broader Outreach

As evidenced from the following, this GK—12 Fellows project has reached out beyond the classroom and lab to engage various constituencies by participating in and holding several events.

Career Day: Over 100 students from the participating high schools attended this event that was held at Polytechnic University to expose students to various engineering disciplines in a professional conference-like setting. Students were introduced to various engineering disciplines by the university faculty. In addition, several recent engineering graduates presented their experiences and perspective on engineering careers. Students toured several labs at the university where the RAISE Fellows conduct their research. The event enabled the high school students to gain a better understanding of the potential professional advancement and personal development that can be accomplished through a career in science and engineering.

Citywide NSF GK-12 Fellows Grant Holders Meeting: Polytechnic University, in partnership with three other NYC-based GK—12 Fellows projects, organized a citywide NSF GK—12 Fellows grant holders conference in May 2005. Polytechnic University hosted this meeting which included representatives from the four NYC-based GK—12 Fellows projects and representatives from the city's Department of Education. During this meeting the participants discussed challenges faced by the universities, schools, Fellows, and teachers in their collaborative effort to enhance primary/secondary school STEM programs. The event also provided an opportunity for the personnel from the different GK—12 Fellows projects to network and share their experiences in tackling similar issues.

Annual GK-12 Meeting: The Association for the Advancement of Science (AAAS) and the NSF hosted an annual meeting of the GK—12 Fellows project teams in Arlington, VA, on March 4-6, 2005. GK—12 Fellows project teams from throughout the nation displayed their work and interacted with one another. Our project was represented by two faculty participants, one high school teacher, and one Fellow.

Third Annual Convergence on Inquiry: The project team was invited to attend the Third Annual Convergence on Inquiry, held on June 11, 2005, at the NYC American Museum of Natural History. A team consisting of one undergraduate Fellow and a high school teacher gave a presentation to a group of educators on how sensor-based lab experiments can draw students to "ask more questions" related to science and technology. The goal of this conference was to discuss the different ways to utilize inquiry to promote deeper understanding.

RET Program: Polytechnic University also hosts an intensive summer research and training experience in mechatronics for 10 teachers/year under an NSF funded Research Experience for Teachers (RET) program. The RAISE Fellows supported the RET project as follows: during the first two weeks of guided training of teachers, the undergraduate RAISE Fellows served as lab assistants and during the final two weeks of the independent research experience phase, the graduate RAISE Fellows served as project advisors to the teachers, assisting them with their research planning and implementation.

7. Conclusion

The RAISE Fellows have created a series of modern sensor-based activities for classroom demonstrations and lab experiments to support the Living Environment curriculum at four high schools. Having participated in a week-long pedagogical training and after bonding with their teacher-partner during a week-long summer workshop for the teachers, the RAISE Fellows were deployed in the four high schools. The Fellows are successfully supporting classroom instruction and labs to aid students to visualize complex science concepts concretely and to motivate them to excel in STEM disciplines. In addition, the Fellows are sharpening their own technical, communication, leadership, and pedagogical skills. The high school students are enthusiastic about the presence of Fellows in their classrooms. Qualitative assessment of the project reveals that it is having a positive impact on the academic development of high school students and the RAISE Fellows. Furthermore, the teachers have accepted the Fellows as legitimate teaching resources and partners in educational efforts.

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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 and Base	A pH sensor is used to measure the pH of different liquids that are acidic and basic and help understand the pH scale.
3. Aerobic Respiration	A CO_2 gas sensor is used to measure the rate of respiration. Students compare different rates of respiration for different energy drinks which helps them to conclude which energy drink is the most effective.
4.Anaerobic Respiration	A gas pressure sensor is used to measure the rate of respiration. Students compare 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 are studied.
8. Enzymes	A colorimeter sensor is used to study the functions of an enzyme present in various detergents.
9. Greenhouse Effect	A temperature probe is used to measure the temperature changes within an environment to understand the greenhouse effect as a physical phenomenon
10. Heart Rate Monitoring	An EKG sensor is 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 are used to calculate the rate of photosynthesis and compare the affects of light on the rate of photosynthesis
12. Population Dynamics	A colorimeter is 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.

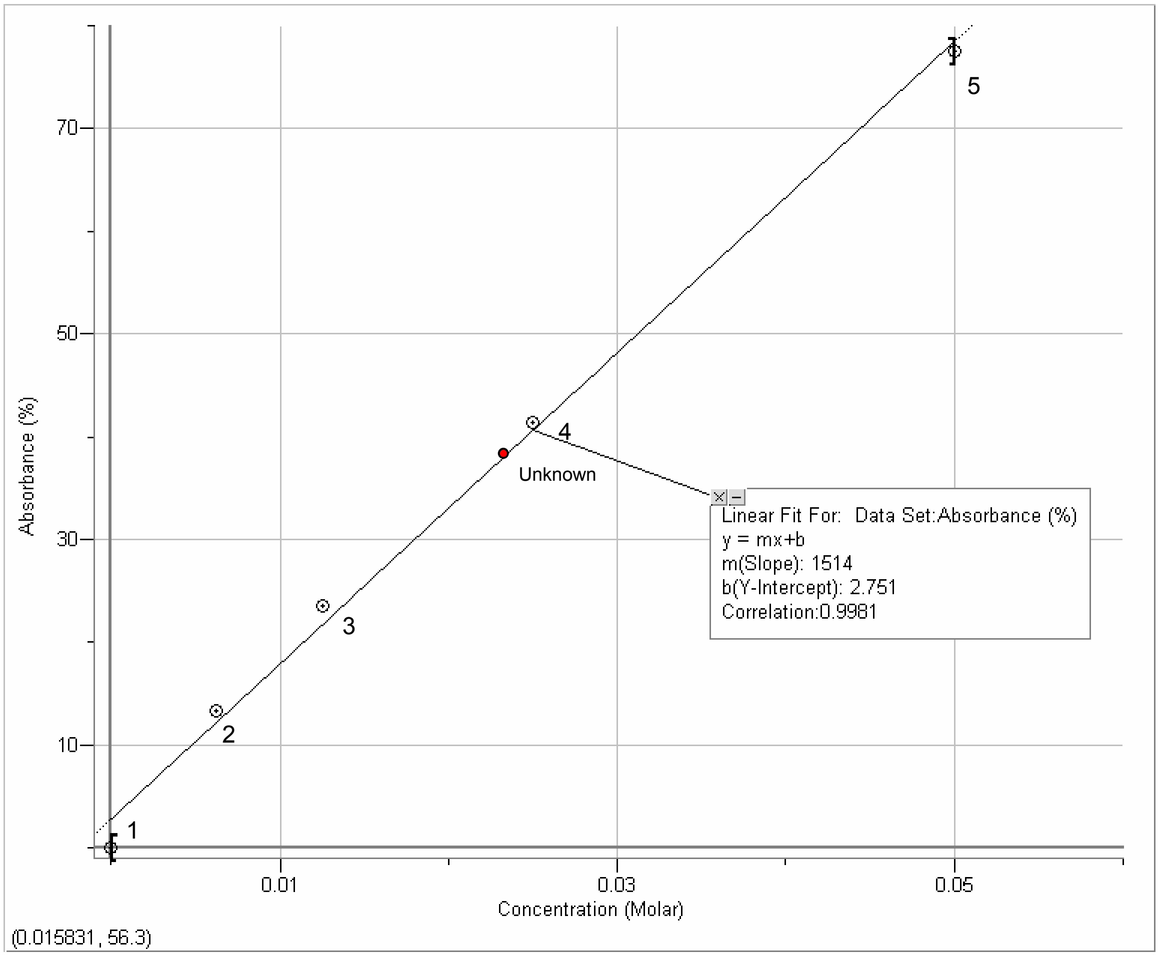

Figure 1: Calibration Curve of Colorimeter and Unknown Data Point (Concentration Values used to draw the Calibration Curve— Point 1: 0, Point 2: 0.00625, Point 3: 0.0125, Point 4: 0.025, Point 5: 0.05)