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Research Experience for Teachers Site: A Work-in Progress Report

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1. Introduction

The explosive growth of information technology, ubiquity and low cost of computing hardware, and an accelerating pace towards miniaturization are driving design innovation, enhanced functionality, and shorter life cycle in an ever increasing number of engineered products. Amidst these trends, retaining and strengthening the U.S. leadership in scientific discovery and technical innovation requires the development of an "innovation economy." To ensure the U.S. competitiveness in the 21st century innovation economy, there is an urgent need to develop a scientifically and technologically trained workforce,[1—3] which necessitates the design and implementation of novel curricula, methodologies, and paradigms for STEM education. Thus, the recently released Next Generation Science Standards[4, 5] (NGSS) offer a unified framework, which explicitly (1) integrates engineering design in K-12 science standards and (2) draws connections to the Common Core State Standards for Math[6] (CCSSM).

Although today's students effortlessly interact with modern technological artifacts, they often lack an understanding of the underlying engineering, technology, and business processes. As technology continues to impact our daily lives, it is essential that all students receive comprehensive, quality STEM education. Offering meaningful and motivating engineering contexts that exploit modern technologies, such as sensors, microcontrollers, mechatronics, robotics, etc., within science and math courses constitutes a compelling strategy to address the NGSS and CCSSM while enhancing science and math learning for all students. Unfortunately, many teachers lack preparation and training to use modern technologies in science and math teaching and often have less experience with technology than the students they teach. Thus, there is a critical need for teacher professional development (PD) to promote the integration of modern technologies in science and math learning.

In this paper, we provide a progress report on a teacher PD project involving a six-week summer workshop and several academic year follow-up activities. Section 2 provides an overview of the project, including objectives, rationale for the intellectual focus, teacher recruitment process, and structure of project activities. Section 3 provides illustrative examples of teachers' research activities and lesson plans developed by them. Section 4 provides highlights of project assessment. Finally, Section 5 offers some concluding remarks.

2. Overview

In 2013, under an NSF-funded Research Experience for Teachers (RET) Site project, 12 middle and high school teachers participated in a six-week summer workshop focused on sensors, microcontrollers, mechatronics, robotics, and entrepreneurship. The project mentoring team included five engineering faculty and one technology management faculty, who led six graduate researchers to partner with teachers as research collaborators. The Director of university-based Center for K-12 STEM Education facilitated teachers' participation in STEM-related social media events. An external evaluator conducted project assessment. The project team created a motivational and engaging program for teachers that included training in modern technologies; immersion in inquiry-based, hands-on, collaborative research; and opportunities to foster entrepreneurial skills. The overarching objectives of the project are as follows.

1. Introduce teachers to modern technologies, such as sensors, microcontrollers, mechatronics, and robotics through training, mentoring, and real-world collaborative engineering research, to renew their science, math, and research skills.

2. Provide teachers with experience, skills, and resources in hands-on, engineering research and entrepreneurship, including prototype product development, so that they can integrate real-world technology used by scientists and engineers in their classrooms and labs.

3. Enable project personnel to integrate their research, teaching, curriculum and lab development, and outreach activities.

Mechatronics is selected as the intellectual focus of this project for several reasons. First, as a multidisciplinary subject, mechatronics can provide an introduction to multiple engineering disciplines. Second, hands-on mechatronics training and research can fuel teachers' imagination and provide an opportunity to reinforce and enhance their STEM skills. Third, exposure to building-blocks of mechatronics, i.e., sensing, actuation, and computing technologies, can introduce teachers to real-world tools used by practicing engineers. Fourth, diverse technological applications of mechatronics provide numerous opportunities to practice and hone teachers' skills in creativity, inventiveness, and entrepreneurship.

2.1. Teacher Recruitment

In-service teachers with regular appointment in any middle and high school of New York City (NYC) and three years of teaching experience in physical sciences, mathematics, and pre-engineering provided a pool of candidates for the project. We attracted teachers through the prestige of NSF support and emphasized the value of skills gained through mechatronics training, engineering research, and entrepreneurship experience for future professional growth. The program was advertised through a website containing program announcement, activity description, and electronic application material. Moreover, a program brochure, with a tear-away application form, was widely distributed (e.g., mail to Principals and Assistant Principals of math/science of over 300 high schools; email and in-person to teachers who mentor participants in science fairs and robotics competitions; etc.). In spring 2013, an “RET Open House” was held to serve as an information session for teachers. To facilitate good matching of teachers and mentors, during the open house, teachers were encouraged to interact with the mentors and visit their labs. After the open house, the mentors and teachers interacted, as needed, to narrow their teaming arrangement. During the application process, teachers were required to prioritize their choice of research projects. The selection committee consisting of the project personnel and the director of K-12 Center recommended 12 candidates for the program from amongst more than 30 applicants. The selection was based upon the evaluation of application material submitted by the candidates (e.g., cover letter, formal application approved by the school principal, scholastic record, vita, statement of interest, strength of letters of recommendation, commitment to develop and integrate project activities in the curriculum, etc.). Among the 12 participants in 2013 were five women and three teachers from underrepresented minority groups.

2.2. Project Structure and Activities

The workshop was divided into two parts: a two-week guided training followed by a four-week collaborative research experience. The first day of the program provided an orientation to the university, engineering departments, library, and participating labs, including an introduction to lab practice and safety. In addition, experimental demonstrations of a variety of educational and research projects were given to stimulate teachers’ interest in the project.

In the first eight days of guided training, each morning and afternoon session included a 60 minute theory, component, or concept introduction; a 150 minute structured, hands-on project; and a 30 minute discussion. The guided training sessions introduced to teachers sensors, actuators, electronics, electro-mechanical components, microcontrollers, robotics, etc. The structured project for each session augmented the corresponding introductory lecture and consisted of hands-on experiments and design activities, allowing teachers to experience integration of sensors, actuators, electronics, electro-mechanical components, microcontrollers, and robotics to prototype a variety of mechatronics projects. These activities illustrated real-world applications of fundamentals covered in introductory lectures to reinforce and impart a greater sense of understanding. Such a curriculum and instruction strategy exposed teachers to fundamental mechatronics design principles as they learned the core concepts through activities wherein they built practical devices that integrated and illustrated their learning. The discussion portion of each session provided participants with an opportunity to reflect on the session’s work and to brainstorm ways of integrating these activities in K-12 STEM learning.

On the last two days of guided training, an entrepreneurship module—consisting of instruction, experiential learning, group discussion, reflection, and site visit—was conducted. The session introduced teachers to the concept of entrepreneurship and business planning. For experiential learning, in small teams, teachers developed business plans for a product that they envisioned. Specifically, they developed a description of how the product works, performed a market analysis to identify potential customers and competitors, and developed sales and cost projections to determine profitability. In addition, for a half-day session, the teachers visited a university-based technology business incubator where they learned about available resources to support start-up companies. The teachers visited with representatives from several start-up companies to learn about their businesses and start-up culture. Next, the teachers learned about a myriad of ways in which entrepreneurs can raise funds to produce and market a product or service, including from family, friends, financial institutions, government agencies, crowd-funding sources, angel investors, venture capitalists, etc. For experiential learning, in small teams teachers discussed how to acquire capital to bring their ideas to market and pros and cons of their choices to ensure the success of their business. This cumulative experience exposed teachers to the range of activities involved in being an entrepreneur.

On the second day of the four-week research experience, the teachers had a unique opportunity to attend a day-long workshop conducted by a team from the United States Patent and Trademark Office (USPTO). Through this workshop, teachers learned about many facets of intellectual property (IP), including patents, copyrights, and trademarks. They were introduced to an array of educator resources including links to useful websites, lesson plans, and sample worksheets. For experiential learning, teachers worked in small teams to design an innovation to an existing product (USB, backpack, pen, or ruler) for which they completed patent and trademark searches to ensure that their products were in fact unique and potentially patentable. The products developed included a backpack with an integrated mobile device charger, a ruler with a built-in camera to take images and measure images on a micro-scale, a USB data storage device integrated into women's accessories (ring, belt, or necklace), and a retractable, color-coded multi-USB with a stylus for touch pad use. After each group's presentation, USPTO representatives provided a critique *a-la* the "Shark Tank" reality television show.

In the four-week long research experience phase, teams of two teachers conducted research in a collaborative environment consisting of graduate researchers, undergraduate summer research assistants, and five engineering faculty. They developed lesson plans to highlight salient aspects of their research that illustrate grades 6—12 level STEM concepts. The technology management faculty periodically met with teachers to discuss potential for developing business ideas based on their research. Each team also completed project portfolios consisting of: a research project report, presentation slides, and a website. On the last day, in the afternoon session, teachers presented and demonstrated their research projects to the university community. Illustrative examples of teacher research projects and lesson plans are given in Section 3.

Throughout the summer workshop, teachers' were engaged in a variety of activities to become part of a wider community of educators and learners and share their experiences with them. For example, teachers began the project on the very first day by attending a university-wide event titled "Summer of STEM," which served as a unified umbrella for the launch of an array of university-based K-12 STEM education projects. The event was attended by well over 200 K-12 STEM participants. Dr. Theresa Maldonado, Director of NSF's Division of Engineering Education and Centers (EEC), served as the Plenary Speaker at the event. Other prominent speakers at the event included: (1) NYC-based venture capitalist Fred Wilson whose tech investments have included Twitter, Tumblr, Foursquare, Zynga, and Kickstarter, (2) Congressman Hakeem Jeffries, our local representative to the U.S. House of Representatives, and (3) other speakers from the New York University (NYU). Moreover, for the first two week, teachers posted updates of their daily learning and hands-on experiences on the project website. During the collaborative research experience phase, each research team posted their weekly progress reports on the project web page. Finally, several teachers and their graduate student collaborators participated in a roundtable discussion on a Google Plus social media event.

To develop an on-going partnership with teachers, several follow-up activities have been conducted. First, in early fall, on a weekday afternoon, an "RET Day" was held at the university to showcase teachers' research and lesson plans to other teachers. The event was attended by over 35 teachers. In late fall, on a weekday afternoon, teachers visited the university to participate in a research seminar attended by mentors and research students of all teams. The research students presented reports on the progress of their research projects after the summer workshop. Each teacher is to be visited at his/her school by the respective mentor or research student. While some visits have already taken place in fall, others are scheduled for spring. Finally, many participating teachers are mentoring their students to participate in a university-based student idea competition. Through exchange of ideas and advice, the project team continues to support efforts of teachers to integrate project activities in their schools

3. Research Activities and Lesson Plans

Measuring Electric Current in a Motor for the Purpose of Determining Energy Consumption: Mentored by a mechanical engineering faculty Prof. Joo Kim, teachers Timothy Dennis and Peter Tsun collaborated with a Ph.D. student Dustyn Roberts to address the technical challenges of measuring the electrical energy consumed by a DC motor. In particular, the challenge is to accurately measure the electrical current through a DC motor. This challenge arises from the need to determine the current consumed by a DC motor that is part of a servo-motor and the current is bi-directional. Two different pre-made sensors and two different op-amp circuits were evaluated to measure the current through the DC motor. The full report by the team provides details of measurement methodology, results of current measurement, and future research directions. For classroom implementation, the teachers developed a lesson titled *Analyzing Motion with an Updated Version of Galileo's Ramp Experiment.* Specifically, the teachers considered an experiment of Galileo in which a ball is caused to roll down a ramp to understand its motion. Galileo used a pendulum as a timing device and bells to mark the ball position at each second. The updated experiment will use a ramp with sensors attached to a microcontroller and hand-held stopwatches to enable students to collect information about the motion of a ball rolling down a ramp. Students will compare the data recorded using stopwatches *vis-à-vis* the data collected using the microcontroller. Due to experimental errors, the two sets of data will differ slightly. Comparing the two sets of data collected by different methods will be a basis for a discussion about accuracy and precision. Students will look at how the number of decimal places changes the precision of the measurement. Moreover, they will understand that the reaction time of students affects the accuracy of the measurements.

Facial Recognition and Learning with Embedded Computing: Human fascination with robotics continues to grow as technologies and algorithms improve. One way in which humanoid robots can behave more like humans is to design robots to distinguish between objects and people, as well as learn to recognize new objects and people. Mentored by the author, teachers Kelly Brandon and Jigar Jadav collaborated with a Ph.D. student Jared Alan Frank to develop a facial recognition algorithm and its implementation on a single-board computer. Specifically, an algorithm was developed using Local Binary Pattern Histograms for facial recognition and a combination of K Nearest Neighbors and confidence threshold values for facial learning. The system is designed for a humanoid robot currently in development. The robot's eyes consist of two webcams that may be used for face recognition and learning. However, the system was implemented and initially tested on a laptop with a built-in webcam. The robot continues to grow as parts are continuously designed, made, and tested on the robot's body. Currently the robot's processing and control comes from an attached laptop acting as its brain. The use of a single-board, embedded computer, e.g., a Raspberry Pi, was investigated to replace the laptop. Initial testing revealed that video capturing on the Raspberry Pi is slower than that of a laptop. However, the facial recognition and learning system was still able to recognize and label known faces and learn new faces using the embedded device. Such a system with facial recognition and learning on an embedded device may be used in robots, security systems, or even as smart doorbells. For classroom implementation, the teachers developed a lesson titled *Angular Velocity: Sweet Wheels*. In this lesson, groups of students will predict, measure, and analyze the relationship between linear velocity, wheel radius, and angular velocity using a LEGO robotic vehicle. Students will use pairs of wheels with various radii to compare the times the vehicle takes to travel a set distance. Group data will be collected and analyzed to find the angular velocity of the vehicles, which are all set to the same motor speed. Students will experiment with the variables, such as radii and motor speed (angular velocity), and other factors, such as weight, that they may discover, to optimize the speed of the vehicle. A group discussion will ensue relating the conclusions from the investigation to cars, trucks, bicycles, and other such vehicles.

Development of an Air Quality Measurement Module for an Aquatic Mobile Robot: Mentored by a mechanical engineering faculty Prof. Maurizio Porfiri, teachers Channa Comer and Dwight Young collaborated with a Ph.D. student Jeffrey Laut on a citizen science project which is developing a cyber-human infrastructure for real-time monitoring and hazard detection of the natural environment. In the project, marine sensor units are mounted on an aquatic mobile robot (the robot). The robot is deployed into a local canal, once each week, to collect water quality data (dissolved oxygen, pH, water temperature, and conductivity) and take photographs both above and below water. In this effort, the teachers enhanced the environmental monitoring capabilities of the robot with the development of a module consisting of a sensor array to collect air quality data (Carbon monoxide/Volatile Organic Compounds (VOCs), Nitrogen Dioxide, Ozone) and associated weather data (humidity, temperature, barometric pressure). For classroom implementation, the teachers developed a lesson titled *Sensing Weather*. In this two-part lesson, students will learn how sensors are used in weather instruments and how scientists use weather instruments to track weather. In the first part of the activity, students will assemble a simple temperature and humidity sensor with electronics circuitry and microcontrollers and use the design process to create a housing for their sensory system. In the second part of the activity, students will use their weather sensors to collect weather data over the course of seven days, display the data, and analyze the data to determine trends and relationships between weather factors.

The research projects and lesson plans, respectively, developed by the remaining teachers in summer 2013 are listed below.

Research*: Testing a Transparent Hydrophilic Copolymer as a Suitable Soil for the Observation and Study of Plant Root Growth* and Lesson: *Transparent Soil? That Hot*!—Linda Dombi and Jason Econome

Research*: Design and Function of A Humanoid Robot* and Lesson: *Robotic Clock to Explore Equivalent Fractions*—Alexa Goldstrom and Zulficar Habib

Research*: Effect of Heat Treatment on the Hardness of Magnesium Alloy AZ91D; The Effect of Microballoon Density and Strain Rate on the Properties of Syntactic Foam Composites* and Lesson: *Test and Compare Material Properties*—Jason Rann and Charisse Nelson

4. Evaluation Results

To obtain quantitative feedback, teachers were administered pre- and post-project (1) technical quizzes containing the same 30 multiple-choice questions, ordered differently, and (2) surveys of self-perception of familiarity with mechatronics and entrepreneurship concepts. The project team developed, administered, and graded the technical quizzes in which teachers' average performance was 48.06% (pre) and 62.2% (post); yielding a 29.5% improvement as a result of the workshop. An external evaluator used a 35-item survey to assess teachers' familiarity with mechatronics skills, concepts, and devices introduced during the workshop. While at the start of the project, teachers reported low levels of familiarity with project topics (average: 1.58/4), by project's conclusion, teachers reported higher levels of familiarity with project topics (average: 2.38/4), indicating general familiarity with the topics. The average reported increase for the mechatronics items was 0.80. The pre-/post-survey also included 7 items on familiarity with areas of business, intellectual property, and innovations. While at the start of the project, teachers reported low levels of familiarity with project topics (average: 1.62/4), by project's conclusion, teachers reported higher levels of familiarity with project topics (average: 2.88/4). In this case, the average reported increase was 1.26.

To obtain qualitative feedback on project effectiveness, the external evaluator performed the following activities: interviews of selected research supervisors, site visit to interview teachers and conduct observations in their research labs, and follow-up interviews with selected teachers. Following are samples drawn from the 2013 evaluation report.

The teachers reported that they were generally satisfied with the structure of the first two weeks. Some had previous experience with robotics and consequently found it easier. Those for whom the material was new reported varied experiences. Following are some example comments. (1) "I liked it a lot, it turned into a design class, …, and it would be easy to use in my class." (2) "It was all completely new to me, I learned so much, …, for me the hardware side was new, and we did lecture/practice and that was good." (3) "It's a great integration of math, science, technology, and engineering. It brought together a lot of things I had done in college. I was looking for a course like this for 15 years."

The teachers expressed a high degree of enthusiasm for both the incubator visits and the intellectual property workshops. A few thought they would try to produce materials that could be marketed to other teachers, and all believed that the increase in business knowledge and an understanding of how start-up companies work would be useful to them in working with their own students. The teachers commented that students often ask about the real-world applications of skills and knowledge learned at school, even as related to technology. Moreover, in response to a survey item asking about the most important entrepreneurial activities, eight respondents listed exposure to the incubator, and four mentioned the inclusion of a business plan or new product in connection with their research. Following are two example comments. (1) "Going to the incubator was amazing. I want to bring my students and have them be exposed to the entrepreneurial environment." (2) "Working in teams designing products and researching patents before getting the product in the market place."

The teachers identified a number of areas contributing to their learning, satisfaction and progress with research. They identified: teamwork, learning in new areas, achieving success, and completing the project. The following are sample comments from an open-ended survey item asking what was most satisfying in the research. (1) "Working with other researchers." (2) "The relationships and mentoring from graduate student in the lab." (3) "The fact that I was able to complete an entire relevant experiment." In responding to an item asking about challenges in the research projects, the teachers listed: waiting for supplies, lack of background in skills in some areas such as programming, writing the report, and some uncertainty about details. The following are sample responses to the open-ended item asking about the greatest challenges in the research. (1) "Not having a firm grasp of the fundamentals of electronics and higher-level mathematical operations." (2) "Programming the microcontroller and calibrating our air quality sensors." (3) "Getting together the supplies and performing the experiment for the first time was very challenging." (4) "Setting and meeting a useful research goal with the limited time available." In interviews and visits to the labs, the participating teachers expressed a high level of satisfaction and confidence in: what they had learned and accomplished in the research; the new skills acquired; and the expectation of bringing related research projects to their students.

In the comments section of surveys and in interviews, the teacher commented frequently on *new learning*, since many aspects of research were new to them. These included: designing an experiment, identifying variables, making connections across disciplines, identifying materials needed, learning in new areas, trouble-shooting when things went wrong, relating theory to practice, and writing up the results. For example, many teams described setting goals, troubleshooting, and problem solving as critical skills in responding to challenges arising in their research. In a visit to the lab, the teachers showed and described their project. They were optimistic about what they had learned, how they had responded to challenges, and the potential that the project had for working with their students. Another teacher discussed efforts to fix hardware problems that were, in fact, due to faulty equipment. He indicated that, after a lot of troubleshooting, once the hardware was working, it was easy to set up.

The teachers mentioned *lessons and methods to bring back to school*. For example, a number of them indicated that the habits of research they were acquiring during the summer would be transferable to their students when they returned to school. They commented on the importance of time and that time-constraints are ever present. After the two weeks of mechatronics classes, there was a period of four weeks for the research. Some teams said they lost time waiting for supplies. Time was also needed to work on the written reports, lessons, and posters. Finally, time was needed to make adjustments when the research did not proceed as planned. The teachers identified a number of ways in which they would bring back what they had experienced and learned during the summer to benefits their students. These included: the lessons they were preparing for use in the classroom, increased familiarity with robotics, research skills, and connections with the university. When asked in the post-program survey how they expected to use what they had learned, the teachers offered a wide range of comments. (1) "Allowing students to become more familiar with circuitry and relating engineering to their daily experiences." (2) "Plan to continue to do project-based learning and plan to incorporate more mechatronics and possibly make a course robotics based." (3) "Incorporate some of the entrepreneurship components into how students present their work and include some of the summer materials in classroom curriculum." (4) "Use the information and skills learned here to motivate and enlighten students on a daily basis about the world of engineering that has most likely been kept from them."

5. Conclusions

In summer 2013, this RET Site project provided 12 teachers a six-week PD experience in an authentic research environment. Following a two-week structured learning experience involving mechatronics, robotics, and entrepreneurship, in two-person teams, teachers collaborated with graduate students in on-going engineering research projects. Through their participation in the project, teachers have gained familiarity with an array modern technology, engineering concepts, and entrepreneurship strategies. Moreover, they have proposed various ways to integrate their summer research experiences in their classroom teaching of science and math. The teachers are now prepared to provide their students with a solid foundation for college-level study in STEM disciplines and integrate real-world, hands-on, learning activities in their STEM curriculum.

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