Science and Mechatronics Aided Research for Teachers (SMART): A Research Experience for Teachers Site in Mechatronics

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Abstract

This paper reports on a pre-college outreach program titled Science and Mechatronics Aided Research for Teachers (SMART). The SMART program provides an opportunity for pre-college educators to enhance their technical competency through professional development in the areas of science, technology, engineering, and mathematics (STEM). Ten selected teachers attended the first offering of the program in summer 2003. Ten new teachers will be selected during each of the two remaining program years, 2004 and 2005. The teachers receive training/research experience through four-week long summer workshops. The SMART program is focused on introducing the multidisciplinary field of mechatronics to teachers using a structured and integrated learning environment consisting of training, mentoring, and research. The program provides teachers with experience, skills, and resources in mechatronics-oriented prototype product development via hands-on learning so that by the end of the program they can use and integrate mechanism, sensor, actuator, and microcontroller technologies to develop prototype mechatronics-enabled science experiments for pre-college laboratories. Finally, the program equips the teachers to integrate project-based learning in their STEM curriculum.

1. Introduction

High school science and math courses are increasingly considered as "gatekeeper courses," i.e., students who excel in these subjects succeed in high school and continue at college. However, the inherent rigor of science and math presents great challenges for the educational system. A lack of fully prepared teachers and general teacher shortages are limiting educational attainment of students in the U.S.A. While the explosion of information technology, prevalence of computers, and even video games are transforming students' expectations, high school science curricula and laboratories have yet to tap the full potential of modern technologies. High schools continue to present science and math proficiency in a traditional fashion. Outdated and uninspired laboratory instruction has created a general lack of interest in STEM disciplines among students. This has resulted in low academic achievement in science and math and apathy about STEM careers among high school students.

Even as the above problems remain to be addressed, rising expectations for a 21st century workforce continue to ratchet up academic performance standards in the STEM areas. For example, from 2001, entering high school freshmen in New York have been required to take 3 credits of science and math each, instead of the 2 credits needed previously. Furthermore, students must now meet technology literacy standards through either a technology course or a math/science course that integrates technology. Finally, while earlier students received local diplomas by scoring 55—64 out of 100 on the Regents exam, now standards are being raised by abandoning the local diploma. See [1] for details.

Without intervention, these dynamics do not bode well for the quality of pre-college STEM education. As technology continues to profoundly impact our daily lives, it is imperative that all students receive comprehensive, quality STEM education from adequately trained teachers. See [2] which mandates technological literacy for all Americans.

In the spirit of [3, 4], the SMART program [5] offers a remedy to the above malaise by providing a paid research opportunity to high school teachers. Funded by the Division of Engineering Education and Centers of the National Science Foundation (NSF), under its Research Experience for Teachers (RET) program, SMART aims to enrich education in the pre-college environment by providing teachers from the New York metropolitan region with enhanced STEM educational content through training/research workshops. The SMART program explores mechatronics as a vehicle to engage teachers with hands-on activities to hone their research skills and enable them to participate in prototype product development. These experiences give teachers the ability to enhance their schools' science curriculum and laboratories at the program's conclusion. In 2003, the first year of the program, 10 teachers were selected from a pool of 35 applicants to participate in a four-week summer workshop.

This paper is organized as follows. In Section 2, we provide an overview of program's intellectual focus and rationale for selecting this focus. In Section 3, we describe program activities. In Section 4, we present two illustrative examples of prototype mechatronics-enabled pre-college relevant science experiments developed under the program. In Section 5, we draw some concluding remarks.

2. Intellectual Focus of the SMART Program

The exciting field of mechatronics—synergistic integration of mechanical engineering, control theory, computer science, and electronics to manage complexity, uncertainty, and communication in engineered systems—is serving as a vehicle to engage and stimulate the interest of teachers in hands-on, STEM learning activities. The typical knowledgebase for the design of mechatronic systems comprises of system modeling and analysis, decision and control theory, sensors and signal conditioning, actuators and power electronics, hardware interfacing, rapid control prototyping, and embedded computing. The relevant technology applications of mechatronics include medical, defense, manufacturing, robotics, automotive, and distributed systems and smart consumer products. The SMART program is leveraging Polytechnic's mechatronics laboratory, developed through a prior NSF grant, to create an exciting, motivational, and hands-on training/research program in mechatronics.

Rationale for selecting the mechatronics theme: The SMART program is using mechatronics to introduce pre-college teachers to *i)* measurement systems, *ii)* control systems, and *iii)* computer hardware and software for measurement and control. The mechatronics theme for this RET project is selected for several reasons. First, mechatronics is an exciting, "high-tech," and inherently multidisciplinary technology, which facilitates a basic introduction to various engineering disciplines. Hands-on mechatronics training/research can fuel teachers' imagination and provide an opportunity to reinforce and enhance their STEM skills. Second, measurement and control technologies represent "growth industries," with high demands for qualified graduates. By integrating RET experience in their teaching, the SMART alumni will promote STEM careers, in general, and mechatronics oriented careers, in particular, to their college-bound students. Third, measurement and control systems consisting of sensors, actuators, and physical plant provide an avenue for physics-based system modeling, which can be used to illustrate technological applications of pre-college STEM curriculum to engage student interest. Fourth, computer-based measurement technology eliminates the drudgery of manually collecting and recording precise data in science laboratories. In addition, real-time graphical representation of data being collected enables immediate correlation with the underlying physical phenomenon. Fifth, mechatronics prototype project development activities provide teachers invaluable systems integration experience wherein they learn *i*) to identify objectives from given problem specification; *ii)* to determine variables to be sensed and manipulated; *iii)* selection of and interface requirements for sensors, actuators, analog/digital electronics, and microcontroller hardware; and *iv)* the mechatronics product development cycle consisting of design, model, simulate, analyze, refine, prototype, and validate stages. Sixth, each of the skills learned in this program (e.g., instrumentation, sensing, actuation, analysis, feedback control, data acquisition, and computer programming) is valuable in itself, independent of the others, and provides a foundation for applying a systems approach to problem solving.

3. Program Activities

The SMART program is designed as a two-week guided training followed by a two-week independent research experience. The first day of the program consists of an orientation to the university and its surroundings, mechanical engineering department, library research, and the mechatronics laboratory. The mechatronics laboratory orientation provides an introduction to laboratory practice and safety rules. In addition, experimental demonstrations of a variety of educational and research projects are given to build-up teachers' interest in the program.

The guided training component of the program provides the teachers an introduction to foundational elements of mechatronics, e.g., sensors, actuators, electronic/electro-mechanical components, and microcontroller technologies. Each morning and afternoon session of guided training includes an hour lecture, two hour structured project activity, and an hour for discussion. Topics listed in Table 1 are covered in lectures. The structured project activity for each session augments the corresponding lecture and consists of hands-on experiments with clearly stated objectives, sequence of steps to follow, expected results, etc. The structured experiments illustrate and reinforce the material covered in lectures and allow for further exploration. The discussion hour of each session provides the teachers an opportunity to reflect on the session's work and brainstorm ways of integrating corresponding activity to illustrate pre-college science and math concepts.

Table 1: SMART lecture topics

Lecture #	Topic	Lecture #	Topic	Lecture #	Topic
1.	Resistors	7.	ADC	13.	Transistors
2.	Mechatronics	8.	Servomotors	14.	Relays
3.	LEDs	9.	555 Timer	15.	H-Bridge
4.	Buttons	10.	Thermal Sensors	16.	DC Motor
5.	Capacitors	11.	Robotics	17.	RC Filter
6.	Optoelectronics	12.	Infrared Sensors	18.	Op-Amp

A number of activities for structured experiments have been adapted from Parallax Inc.'s comprehensive and innovative laboratory curriculum titled "Stamps in Class" educator's program [6]. In particular, we have adapted activities from Parallax's freely downloadable texts titled: What's a Micro-controller, Basic Analog and Digital, Earth Measurements, Industrial Control, and Robotics. Parallax also markets specially developed component kits corresponding to each of the aforementioned texts. These kits are being used to expose the teachers, via hands-on activities, to microcontrollers, analog and digital conversion, measurement systems, industrial control, and robotics. All structured experiment activities use Parallax's Basic Stamp 2 (BS2) microcontroller and require programming in PBasic. See [7] for further details on BS2 and PBasic.

In preparation for the inaugural 2003 SMART program, the project team designed and developed five mechatronics-enabled physics experiments relevant for pre-college laboratories: light reflection experiment [8, 9], light refraction experiment [10], heat conduction experiment, pendulum experiment, and static friction experiment. Often, the discussion hour was used to present these experiments to the RET participants as an enrichment activity and to illustrate that *i)* mechatronics can aid in the design, development, and operation of exciting experimental tools to demonstrate pre-college level STEM concepts and *ii)* educational experience of pre-college students can be enhanced through the use of mechatronics-aided laboratory experiments.

In the research experience component of the program, teams of 2 teachers design and develop prototype mechatronics-aided science projects. In order to ensure that teachers remain engaged, excited, and motivated to excel in the project activity, they are advised to carefully select projects that illustrate grade 9—12 level STEM concepts. Beyond this advice, each team of teachers independently develops its project concept in the first two weeks of the program and gets it reviewed and approved from the SMART personnel by the end of the second week of the program. This provides the teachers two weeks to complete their projects. The PI and his undergraduate and graduate research assistants are available to teachers as resources during this second phase of the program. Through the independent project activity, teachers experience the typical design, model, analyze, refine, prototype, and validate cycle arising in real-world mechatronics system development. They perform integration of various elements of mechatronics, *viz.*, sensors, actuators, electro-mechanical components, mechanisms, microcontrollers, etc. Each team of teachers also completes project portfolios consisting of: working prototype, video demonstration, presentation slides, report, and website. In the afternoon session of the last day of the program, teachers present and demonstrate their projects. The 2003 SMART program participants developed mechatronics-aided science projects to demonstrate concepts of projectile motion, speed, time, static balance, robotics, etc. See [5] for details.

As evidenced from the preceding, throughout the SMART program teachers perform active learning tasks to reinforce their existing science and mathematics skills and enrich their STEM experience through exposure to real-world engineering applications. Through this strategy, the teachers themselves begin to appreciate the relevance of STEM skills to solve real-world technological problems and are enticed to embrace technology to reform pre-college STEM curriculum.

In order to recognize the teachers and showcase their projects, on September 13, 2003, we held a "SMART Day @ Poly." At this event, the 2003 SMART alumni presented their prototype mechatronics-enabled science experiments to colleagues and administrators from their schools and school districts. Over 30 attendees present at the event included pre-college teachers, school and school district administrators, Poly students and faculty, the 2003 SMART alumni, and project personnel. All attendees commented positively about the teachers' accomplishments. The event enabled us to disseminate the activities of the 2003 RET project to the pre-college community.

Finally, the SMART program was featured on WABC-TV and NY1 News in summer 2003.

4. Illustrative Mechatronics-Enabled Science Experiments

In this paper, we briefly describe two sample prototype mechatronics-enabled science experiments developed under the SMART program. To learn about other prototype science experiments developed under the program, see [5, 8—10].

4.1. Static friction experiment test-bed: This test-bed is designed to experimentally determine the coefficient of static friction between various surfaces. It consists of a horizontal base and a plate whose inclination can be varied using a H-bridge controlled DC motor (Figure 1). A mass with four different surfaces serves as a test object. In particular, experiments are conducted to determine the coefficient of static friction between the plate, which undergoes inclination change, and any one of the faces of the test object. An infrared (IR) transmitter and receiver are mounted on the opposing sidewalls of the plate to face each other. This IR transmitter-receiver pair is used to detect movement of the test object. A stopper has been placed at the free end of the plate so that by placing the test object snug against it the IR beam will be tripped at the instant the test object begins to slide. Once the IR receiver has been tripped, the BS2 shuts down the motor. The angle at which the mass begins to slide is measured by a rotary potentiometer interfaced to an 8-bit Analog to Digital Converter (ADC). This angle measurement is used to determine the coefficient of static friction. A stopper has been installed at the foot of the plate to prevent the test object from falling down. See [5] for additional details.

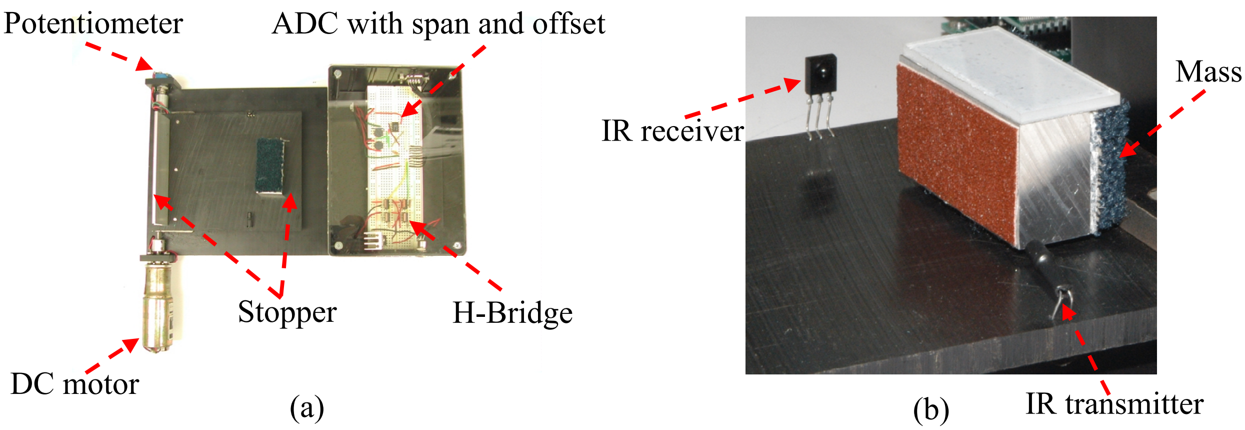

Figure 1: (a) Overhead view of the static friction coefficient test-bed (b) Detailed view of IR pair to detect movement of the test object

4.2. Projectile motion experiment test-bed: This test-bed is designed to demonstrate the physical law of projectile motion. It consists of a ball, a catcher, and a launcher (Figure 2). The launcher is installed on a platform whose inclination can be varied using a H-bridge controlled DC motor. A rotary potentiometer interfaced to an ADC is used to sense the angular position of the launcher. The launcher driven by a solenoid, which is controlled by a solid-state relay, is used to launch the ball. A cart that moves along two supporting metal rods is used as a catcher. A servomotor drives the catcher. Another rotary potentiometer interfaced to an ADC is used to sense the position of the catcher along the track. As an illustrative example of the projectile motion demo, one begins by specifying an inclination angle for the launcher. Next, the catcher is automatically driven to the corresponding target position such that when the ball is launched it lands on the catcher. See [5] for additional details.

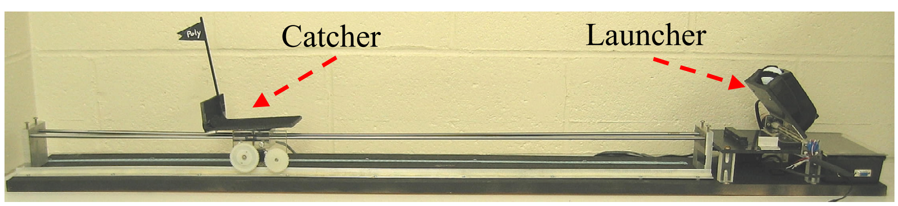

Figure 2: Projectile motion test-bed

5. Conclusion

The SMART program is advancing discovery and learning by exposing pre-college teachers to the multidisciplinary field of mechatronics via training, research, and prototype experiment development. The 2003 SMART participants enhanced their knowledge of mechatronics as revealed by the pre- and post-project assessments (technical quiz and survey). The program was well received by the 2003 SMART alumni as documented in the report of an evaluator, who conducted personal interviews with them.

The program is empowering the teachers to reinforce STEM training and educational experience of a diverse student body from the New York metropolitan region. Within 7 months of attending the program, the 2003 SMART alumni are now leading efforts at their schools to adopt mechatronics technology to stimulate their students' interest in STEM fields. Several teachers are leading new robotics programs at their schools. Many 2003 SMART alumni have reported their success stories to the SMART project team, a sampling of which is given below.

Mr. Richard Balsamel of Science High School, Newark, NJ, raised over $4,000 from his school district for mechatronics kits and supplies and began a mechatronics research club. In addition, he is introducing mechatronics in his physics classes by integrating three sample activities that are done by students. Mr. David Deutsch of Manhattan Center for Science and Math High School, New York, NY, raised over $3,000 from his school and through a Children's Aid Society for mechatronics and robotics kits. He is training students in an after school program on Mondays by holding a mechatronics club. Mr. Paul Friedman of Seward Park High School, New York, NY, raised over $1,500 from his school's alumni association for robotics kits. He has partnered with a colleague to train students in an after school program on Fridays. Mr. Robert Gandolfo of Plainedge High School, North Massapequa, NY, reported on his SMART experience in his school district newspaper [11]. Finally, Ms. Marlene McGarrity of The Christa McAuliffe School, Brooklyn, NY, raised over $1,500 for a project titled "Young Engineers are Made in Brooklyn through Robotics and Mechatronics," through an on-line grant agency. From this grant, she obtained wheeled robots and mars rover kits and is using these in her seventh grade classroom. She also wrote an article [12] on her SMART experience.

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