

Pre-college Electrical Engineering Outreach: The Design of a Home Security System (Evaluation)

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Abstract

With the adoption of the *Next Generation Science Standards* in many U.S. states, teachers and administrators in K-12 schools have been seeking models for incorporating engineering design in science instruction. This pilot university-based program, utilizing a research-based framework of purposeful incorporation of cross-cutting concepts in secondary science education, was implemented for middle and high school physics students during six-hour-long visits with their classroom teachers. Research has suggested that secondary science educators require models of engineering activities that effectively integrate science content in engineering activities, which will promote science learning and broaden students' understanding of engineering knowledge and skills. Under the guidance of Stony Brook University faculty and engineering graduate students, the middle and high school students designed and built a home security system as a means to apply physics principles and electrical engineering practices to solve a technological challenge. Students worked in pairs to construct their designs, test their devices and subsystems in relation to given constraints, and optimize component functionality. Quantitative and qualitative survey data ($N=69$) were collected to measure student impacts. Quantitative data revealed that a high percentage of the students who attended the program showed an increase in engineering knowledge and application of technical concepts. The majority also expressed increased interest in attending college, increased interest in majoring in engineering, an appreciation of soldering as a useful skill, and recognition of how specific physics concepts were applied to electrical engineering design. Qualitative data allowed the researchers to elicit thematic elements of student impacts, including appreciation of hands-on tasks related to potential engineering careers, novelty of using circuit boards for a practical technological device, and self-efficacy in creating and building designs as part of a team effort to maximize device efficiency and performance. Future science and engineering curricular efforts may leverage these findings to replicate and design similar curricular activities for secondary classrooms.

Introduction

Numerous reports have documented the need to improve science, technology, engineering, and mathematics (STEM) preparation for pre-college students, in an effort to promote greater scientific and engineering literacy, workforce readiness, and technological and economic competitiveness [1], [2], [3]. The recent publication of the *Next Generation Science Standards* (NGSS) in 2013 brought about a new focus on the incorporation of engineering practices in K-12 science education in the U.S. [4]. To date, these standards have been adopted by nineteen states and the District of Columbia. The standards utilize three dimensions of science learning as outlined by the National Research Council's *A Framework for K-12 Science Education* in 2012: 1) scientific and engineering practices, 2) crosscutting concepts, and 3) disciplinary core ideas [5]. The science and engineering practices include foundational skills embedded in science instruction, such as asking questions and defining problems, planning and carrying out investigations, and engaging in argument from evidence. Crosscutting concepts include interrelated themes that may be applied to many scientific disciplines, for example, cause and effect, system models, and structure and function. Disciplinary core ideas have broad importance

in various sciences (e.g., physical, life, Earth) or they may be key organizing concepts in one discipline [5].

With school districts across the nation planning for the implementation of NGSS, there is a need for well-designed classroom activities that meet the goals of the standards in the context of teaching and learning science [6]. Such activities must be rigorous, coherent, and related to students' lived experiences [7]. Prior work by the research team involved afterschool engineering and science programs and summer camps that resulted in improved confidence, self-concept, and interest in STEM-related post-secondary study and careers [8]-[11], particularly for students from traditionally underrepresented groups [12], [13]. Although there has been significant work in developing high school engineering coursework and out-of-school programs (see, for example, *Project Lead the Way* [14]), more work is needed on developing engineering activities and laboratory experiences that may be directly embedded in middle and high school science classrooms. This project builds upon previous research by prioritizing the integration of engineering and scientific practices as a key tenet of the NGSS [4], and recognizing that secondary science teachers have few models for how to do so effectively [15].

Engineering and science education faculty and graduate students at Stony Brook University collaborated to design several activities as part of an NSF-funded initiative on broadening participation in engineering. This work describes the first of several activities that incorporated electrical engineering activities in high school physics and middle school physical science instruction. The College of Engineering and Applied Sciences and the Institute for STEM Education (I-STEM) hosted six-hour visits from middle and high school students in the region; they came in groups of 24 or fewer to take part in the university-based engineering activity to support their learning of physics concepts. Since the students were accompanied by their science teachers, the activity could be adapted for formal science classrooms. To maximize the potential for replication of this project, the theory and process of designing a home security system is detailed, along with preliminary evaluation results. The middle and high school versions of the home security activity instructions, objectives, assessment questions, and safety considerations are available on the I-STEM website [16].

Design Process and Disciplinary Connections

Relevance and function of the home security system. The security system is a crucial electronic device for the safety and security of human life and the protection of belongings. Such devices can be found in many places such as homes, companies, and retail stores. They can be implemented in many different ways and have varying ranges of complexity. The home security system developed for middle and high school students is a simple illustration of multiple components coming together to function as a useful tool. The personal relevance aspect of this project promotes student interest in the activity.

The design focus is on two simple main electrical components: a photo transistor and a buzzer. A transistor is usually a switch to connect a circuit together or disconnect it. The photo transistor in this design acts as a switch to enable or disable the buzzer. It is called a photo transistor because its capability to switch depends on light. When light is hitting the phototransistor, the buzzer is

disabled and thus the switch is disconnected. However, the buzzer goes off when the light through the phototransistor is interrupted.

Disciplinary core concepts. Knowledge of electrical components is foundational for creating electrical engineering designs. Therefore, it was crucial for students to understand the basic components used in electronics before designing their own devices. This design consisted of simple electrical components that are used in nearly every common electronic device, such as resistors, capacitors, timers, transistors, lasers, and a customized printed circuit board. The structure and function of most of these components in DC circuits are typically taught in middle and high school physical science, along with thematic crosscutting concepts such as electric potential and energy transfer.

Engineering practices. The home security device prototype was designed as an example of technological advancement based upon scientific principles related to DC. However, the design team was challenged by incorporating opportunities for students to employ engineering practices with a pre-fabricated circuit board. NGSS requires students to have the opportunity to revise designs to meet constraints, optimize performance, and/or adjust functionality [4]. Since the home security activity was designed as a day-long experience at a university and time was limited, the team developed several potential ways for students to change device performance, such as the addition of a memory element as described below. Optimization opportunities are important for enhancing student interest and self-efficacy [10].

Standards alignment and instruction. The home security activity was aligned with existing New York State science education standards for both middle and high school, Advanced Placement Physics, and NGSS to establish its applicability and usefulness in teaching physical science concepts at multiple levels of complexity (for more details, see [16]). Teachers were encouraged to develop additional assessment tasks to meet the needs of their particular curricula. Select examples of alignment with specific standards are provided in Table 1.

Table 1

Sample Standards Alignment of the Home Security Alarm System Activity

SAMPLE STANDARDS ALIGNMENT
Next Generation Science Standards (NGSS) [4] HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. MS-PS2-3: Cause and effect relationships may be used to predict phenomena in natural or designed systems.
New York State Regents Physics Standards, High School [17] Standard 1, Key Idea 1: Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints) which is used to develop technological solutions to problems within given constraints.
New York State Intermediate Level Science Core Curriculum, Grades 5-8 [18] Performance Indicator 4.4e: Electrical circuits provide a means of transferring electrical energy.
Advanced Placement Physics 1 [19] Learning Objective 5.c.3.3: The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit.

Anecdotes and full illustrations of each component were explained to students through the activity document [16], as well as the instructional presentation, to make the project more appropriate, enjoyable, and understandable. Students were introduced to schematic diagrams of electronic devices, which are somewhat different from typical diagrams in physics textbooks (Figure 1). Care was taken to explain that physics and electrical engineering sometimes employ different visual representations but the underlying science concepts are consistent.

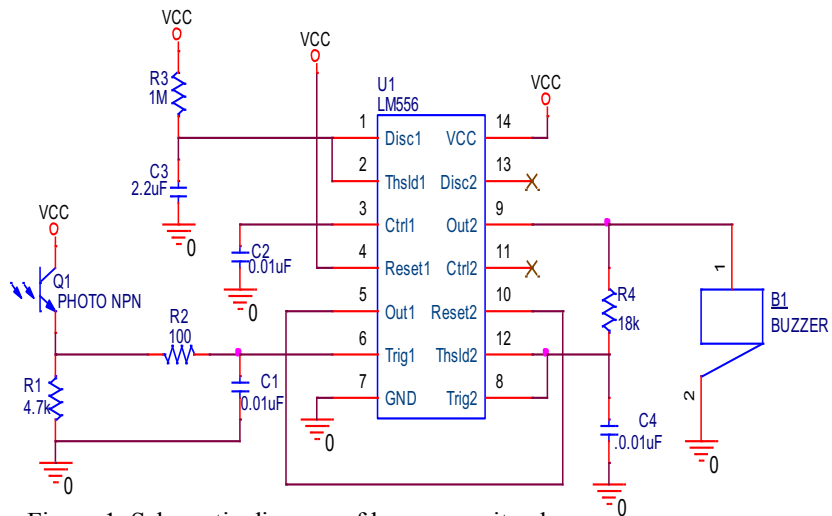


Figure 1. Schematic diagram of home security alarm

Logistics and challenges of project design. Many constraints such as cost, age appropriateness, and functionality were involved in designing the engineering project for middle and high school students. The electrical engineering design at hand met several constraints and is appropriate for students between the ages of 11-18. These components are very inexpensive and thus the project, on average, costs \$2/student. Thus, this project is cost efficient yet effective in integrating engineering practices in physics instruction. The functionality of the devices was tested and students took their devices home for personal use.

One of the problems faced during the design of the device was the buzzer. As mentioned previously, the buzzer sounds if the light that goes through the phototransistor is interrupted. However, one does not want the buzzer to sound indefinitely; instead it is preferable that it sounds for a specified amount of time. Obviously, in real security systems, this feature can be controlled through smart phones or tablets. However, for the sake of simplicity, we added a timer integrated circuit to the design to help control this feature. The timer enhanced the design in two ways. First, it controlled the duration of the buzzer sound when the light was interrupted, and secondly, the buzzer frequency was controlled. This design optimization feature is important for students to recognize a key consideration in everyday engineering design.

The functionality of the design can be further improved by adding a counter or a memory element to it. For instance, if a student wishes to implement such a device in her own room but she happens to be out, then the buzzer would be inaudible. Since this device is implemented in a simple way, it does not integrate with smart phones to allow remote detection of security issues. Thus, a memory element made of transistors can be used to register that the light was interrupted at any time. Also, a counter can be used to determine how many times the light was interrupted.

This project meets two main constraints that are of concern in every school: cost and effectiveness. The cost is relatively low and the effectiveness is very high. Having secondary

school students design something they can use in their own homes will increase their motivation to engage in engineering activities. Also, the design was chosen based on popularity. Most students have dealt or seen such systems whether it was in real life or in an action movie; such authentic connections increase accessibility and have the potential to close achievement gaps [6]. By designing their own security systems, students largely felt accomplished and were more likely to understand related physics concepts, the device designs, and the electrical engineering practices in creating them.

Evaluation

Quantitative and qualitative survey data from four classes of high school physics students ($N=69$) were collected to measure impacts. Survey questions included 11 Likert-scale items, along with open-ended questions regarding what students liked about the activity and what they thought could be improved. Quantitative data revealed that a high percentage of the students who attended the program showed an increase in engineering knowledge and application of technical concepts. The majority also expressed increased interest in attending college, increased interest in majoring in engineering, an appreciation of soldering as a useful skill, and recognition of how specific physics concepts were applied to electrical engineering design. As indicated in Table 2, students were particularly enthusiastic about their enjoyment of the activity, their improved understanding of engineering design, and their ability to relate engineering design practices to what they had learned in their physics classes. The activity shows promise for improving pre-college students' interest and self-efficacy in engineering, while also increasing knowledge and awareness of engineering careers, consistent with the recommendations of the National Academy of Engineering [20].

Table 2

Student Survey Responses Regarding Home Security System Activity

ITEM [RESPONSES]
1. I enjoyed this engineering lab activity. [84% strongly agree, 16% agree]
2. I enjoyed visiting a college campus. [82% strongly agree, 10% agree]
3. This lab activity increased my interest in engineering. [54% strongly agree, 31% agree]
4. This lab activity increased my understanding of engineering. [54% strongly agree, 36% agree]
5. This visit increased my interest in pursuing an engineering-related field as an area of study in college. [38% strongly agree, 26% agree]
6. This visit increased my interest in attending college. [58% strongly agree, 19% agree]
7. This visit increased my interest in attending Stony Brook University. [44% strongly agree, 23% agree]
8. This laboratory increased my understanding of the process of electrical engineering design. [48% strongly agree, 48% agree]
9. This laboratory improved my soldering skills. [72% strongly agree, 28% agree]
10. I understand how the home security device relates to concepts I learned in physics class. [52% strongly agree, 36% agree]
11. I can excel in an engineering major. [77% strongly agree, 21% agree]

Qualitative data allowed the researchers to elicit thematic elements of student impacts, including appreciation of hands-on tasks related to potential engineering careers, novelty of using circuit

boards for a practical technological device, and self-efficacy in creating and building designs as part of a team effort to maximize device efficiency and performance. Students were asked to comment on what they liked about the engineering laboratory activities. Notable student responses included: *“I was able to experience hands on tasks suited for my career field,” “I liked the hands-on work because we really get to experience making a circuit ourselves. I have never used a real circuit board to make a basic device before,” “It was very interactive and understandable,” “I enjoyed how we were able to build a device that could be applicable in the real world. I also appreciate how helpful the instructors were.”* Science teachers were also invited to comment on the activity, with one noting *“Students were saying how they never knew what engineering was and how this experience opened up this career possibility for them, which is great to hear.”* Other science teachers provided feedback on how the activity could align more seamlessly with school-based physics instruction, for example, by explaining component functionality earlier in the instructional portion of the activity. These comments illustrate the potential of university-based engineering experiences in improving technological literacy and inspiring students to pursue post-secondary engineering study.

Conclusions and Broader Impacts

The university team of engineering and science education faculty and graduate students created a promising activity for incorporating electrical engineering practices in physics instruction. The initial evaluation data indicated students and teachers were enthusiastic about learning more about engineering and how the science concepts learned in school informed design solutions to technological challenges. By offering the activities for middle and high school students accompanied by their teachers, it is hoped that science teachers will incorporate their acquired engineering practices and skills in traditional disciplinary instruction. This will maximize the impact of the project and inspire a new generation of engineering talent earlier in the STEM pipeline.

Future initiatives will build upon the promising success of this activity. Additional innovative electrical engineering-based laboratory activities related to light strobes and 3-D printing are in the development and evaluation phase. The team plans to have five such activities completed by the end of the calendar year. We also plan on expanding to other engineering domains, starting with biomedical engineering and materials science. This will broaden engineering opportunities for secondary students in biology and chemistry classrooms. Future research will involve focus groups and interviews with participants to identify long-term and more nuanced understandings of projects impacts. These efforts will build capacity for rigorous secondary science education with embedded engineering practices, which will improve readiness for post-secondary STEM study and technological literacy.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 1647405, National Grid, and PSEG. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding partners.

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