AN OUTREACH AFTER-SCHOOL PROGRAM TO INTRODUCE HIGH-SCHOOL STUDENTS TO ELECTRICAL ENGINEERING

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ABSTRACT

We report on a university-based pilot initiative to introduce students in grades 9-12 to electrical engineering practices. The after-school program consisted of two modules of four two-hour sessions and targeted students from two different local schools. They were exposed to hands-on electronic activities as well as programming practices related to image processing. The data collected from weekly surveys revealed that students found the program more challenging and engaging as the course progressed and they were motivated to pursue future engineering study. Additional schools in the region have requested the opportunity for their students to participate in the program at the university.

***Index Terms*—** K-12 education, electrical engineering, outreach programs.

1. INTRODUCTION

Recent reports have documented the shortage of engineering talent [1, 2, 3], largely due to a limited tradition of engineering education in K-12 education [4]. While the importance of increased science, technology, engineering and mathematics (STEM) education is widely acknowledged, there is little agreement about how this might be achieved. Also, major educational and administrative obstacles impede such progress. New York State, for example, has no K-12 teacher certification in engineering and does not allow engineering coursework to be used to meet science teacher content requirements. Clearly, New York and other states are not prepared to meet the incorporation of engineering content that will be necessitated when the Next Generation Science Standards (NGSS) are fully implemented [5].

The inclusion of engineering design programs in K-12 education has been shown to promote interest and attract a wide range of students to engineering post-secondary study and careers [6]. Effective engineering programs in pre-college education have incorporated inductive teaching approaches, which are often referred to as problem-based, discovery, or inquiry-based learning. Felder & Silverman's seminal paper [7] emphasized active student participation, relevant and contextual engineering problems, shifting modes (visual and verbal) of presentation, and concrete and abstract engineering principles. Collaborative knowledge construction has also facilitated students understanding of what it is like to be an engineer and engage in engineering practices [8, 9]. In addition, research has shown that students have developed stronger interest in STEM when interacting with professional scientists and actively performing hands-on experiments [10], and STEM interest is a significant predictor of participation in the field [10]. The collaboration described in this study was intended to strengthen the ties between the university and the K-12 community, as well as to expand and diversify the STEM pipeline.

At Stony Brook University (Long Island, New York), the Center for Science and Mathematics Education (CESAME) and the Department of Electrical and Computer Engineering (ECE) have been closely collaborating for several years in efforts to inspire students to follow engineering career paths. The variety of engineering programs for K-12 students developed by the team include summer camps, research projects, and professional development workshops [11, 12, 13, 14, 15]. The activities have particularly focused on promoting diversity by recruiting students from high-needs school districts. Although the programs have been implemented outside of school, they were developed to complement the existing school-based science curricula.

In this paper we describe in some detail the latest initiative for high-school students, which was designed to motivate them to pursue engineering careers, particularly electrical engineering. The program was based upon a knowledge integration model, which suggests that students should learn diverse ideas about science and engineering, develop evaluative criteria, and test their ideas by collecting evidence [16]. This program was unique and innovative because it addressed documented weaknesses in pre-college engineering education. For example, engineering taught through device-specific tasks has often dissociated science

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MODULE 1: Image processing through apps	MODULE 2: Electrical engineering concepts and gadgets
Session 1 – Introduction to MATLAB and images • Getting started with MATLAB • Programming basics • Introducing images: pixel, colormap and more • Creating black/white and colored images	**Session 1 – Building a microphone** • Introduction to soldering and safety in the lab • Building of a transducer for sound, a simple unidirectional microphone • Testing the microphones using the sound recorder utility available on the computer
Session 2 – Images and movies • Reading and manipulating images • Understanding the properties of images • Introducing dynamic images: frames • Creating a movie using images	**Sessions 2-3 – Finding treasure** • Introduction to electromagnetic waves, self-induction, phase response, oscillator and transistor. • Building of a metal detector with a printed circuit board and the necessary components. • Testing of the assembled device by detection of metal objects that are not in vision with satisfying sensitivity.
Session 3 – Introduction to Apps • Introduction to app inventor • Creating basic apps and apps based on the principles of making a movie from images	
Session 4 – Apps and images • Learning to use the Canvas and Image Sprite component in app inventor • Creating an app based on color images • Taking pictures using the app and edit it • Creating their own innovative apps	**Session 4 – A night-light** • Introduction to photo-resistors, transistors, potentiometers, voltage dividers and hysteresis. • Building of an optical switch activated LED module.

Fig. 1. Schedule of the program. Left: *Image processing through apps*. Right: *Electrical engineering concepts and gadgets*.

content from engineering design decisions [17]. This collaboration between engineering and science education was intended to strengthen the knowledge base in effective, replicable models for pre-college engineering education.

Through a partnership with two local schools, CESAME and ECE provided students the opportunity to explore various aspects of electrical engineering with two modules taught in four two-hour sessions (16 hours total). The program was conducted after regular school hours in campus facilities and each module hosted 24 students at a time (with a total of 48 students attending the program). Students were able to sign up for one or two modules, depending on the guidelines set by their school. One of the modules of the program taught basic image processing concepts through programming apps. The other module combined basic theoretical and practical lessons on fundamentals of soldering and electronics. Preliminary data were collected to analyze student engagement, implement programmatic modifications, and propose future research on student impacts.

The remainder of the paper is as follows. The next section gives an overview of the camp and contains two subsections, one for each of the modules of the program. Section 3 discusses the feedback received from the students and schools, and finally, Section 4 includes some concluding remarks and details of future research plans.

2. THE PROGRAM

The program hosted 48 students from two local schools (24 from each one), who were randomly divided the first day in two groups (each group had half of the students from each school). Each group participated in the same activities but followed a different time schedule. In particular, the program consisted of two after-school modules of four two-hour sessions each. In one module, entitled *Image Processing through Apps*, students were introduced to basic image processing concepts. It combined programming using the software packages MATLAB and App Inventor for Android to understand electrical engineering topics. The ultimate objective was for students to create their own apps. In the other module, entitled *Electrical Engineering Concepts and Gadgets*, students learned basic electrical engineering concepts, were exposed to soldering and safety in engineering labs, and created three basic gadgets: a microphone, a metal detector and a night-light.

All activities were run at the university campus and were instructed by faculty, staff and graduate students from ECE. In addition, undergraduate students from the same department and students from the Master of Arts in Teaching in the Science Education Program served as teaching assistants in the classroom.

Figure 1 displays the general schedule of the program and its modules with a summary of their core objectives. The specifics of the modules will be detailed in the next subsections.

2.1. Image Processing through Apps

In this module, students were introduced to concepts related to images and image processing. To make the workshop more appealing and relevant, the theoretical explanations were combined with programming practices. In the first two sessions, students learned the topics by programming with the computing environment MATLAB [18]. For the remainder of the module, students learned how to develop mobile apps using App Inventor for Android, an open-source web application [19]. In Fig. 1 (left), a comprehensive layout of the module is provided.

- *Sessions 1 and 2*: In session 1, concepts like pixels, RGB color models or intensity were introduced. Students learned programming basics such as control flow instructions of the form if-else and for loops for text-based programming. They practiced their new programming skills by using MATLAB for processing of images and experimenting with basic filters. Later in session 2, dynamic images were introduced and students learned how to program movies from sequences of pictures.
- *Sessions 3 and 4*: In this part of the workshop, App Inventor was the learning tool. It is an interface for Android development, which differs from the text-based programming language in that it is logic-based visual software without syntax (e.g. the text-based `if-else` are visual blocks). The differences between MATLAB and App Inventor were discussed, especially on issues related to their capabilities when dealing with images. Students were instructed to create their first app step by step, so they could learn the basics of how to use App Inventor. They also learned how to troubleshoot and download the apps to Android devices and test them. In the last session of the workshop, students were split into groups and had an app competition. Some prototype apps with different difficulty levels were provided and each group decided to either add innovative elements to the existing prototypes or create a completely new one. At the end of the workshop, each group had a brief presentation and awards were given for the most innovative ideas.

Figure 2 (top) shows some students working with App Inventor and creating apps.

2.2. Electrical Engineering Concepts and Gadgets

The second module introduced students to basic electronics and a variety of engineering concepts as well as to elementary soldering and safety rules in electronic labs.

- *Session 1 – Properties and application of sound.* Students were introduced to a wide variety of concepts, tools and techniques for the understanding and investigation of the properties of sound. There was an introductory lecture, interspersed with many demonstrations. When showing that (ordinary) sound is a longitudinal wave in a medium, we spoke at length about vacuums, the properties of materials in vacuum and the transducers used to measure them.

Fig. 2. Top: Students programming apps. Bottom: Students soldering the metal detector circuit.

  This led to building a transducer for sound: a simple unidirectional microphone. Students soldered, used electrical insulation and used mechanical strain-relief to make sturdy and reliable microphones. To test the microphones, students used the sound recorder utility available on almost any computer. If there were time, three free software tools for looking at sound were analyzed: a SoundCard Oscilloscope, the sound editing program Audacity and the audio spectrum analyzer SpectrumLab.
- *Sessions 2 and 3 – Electromagnetism and metal detectors.* This was a two-session activity. Students learned how to apply physics and engineering principles intrinsic to the problem of building a metal detector. Concepts related to electromagnetism were discussed, including electromagnetic waves, self-induction, conductivity, phase response, and oscillator and transistor function. In addition to learning the theory, students built a metal detector with a printed circuit board and the necessary components. The assembled device was tested to detect metal objects with optimal sensitivity. Students learned how to trouble shoot their devices and optimize their designs. Figure 2 (bottom) displays a snapshot during the activity.
- *Session 4 – A night-light.* This activity allowed students to apply basic electrical engineering concepts to everyday life. Students were provided the materials to create an optical switch activated LED module, or in layman's terms, a night-light. They learned the concept of voltage divider, the usage of a photo-resistor, the function of a transistor, and the handling of a prototype breadboard. With the completion of the project, students had the foundational skills necessary to design their own electrical engineering projects.

3. FEEDBACK AND DATA ANALYSIS

Data were collected in the form of exit surveys administered at the high schools immediately after the university activities. Although the sample size was limited, data provided insights into students attitudes towards the engineering activities. The proof of concept approach was utilized to collect preliminary data on student outcomes and potential programmatic modifications.

The surveys were voluntary and included both open-ended and Likert-type responses. Students were asked to rate their enjoyment of the lab session on a 1-5 ordinal scale, and they were asked to comment on what they most liked about the session and what could have been improved. Data were compiled and disaggregated for the *Electrical Engineering Concepts and Gadgets* and *Image processing through apps* modules. Fig. 3 represents all student responses collected throughout the program. Students overwhelmingly reported their enjoyment of the camp; 162 of 199 unique responses were positive. Additionally, a weighted average was calculated for responses in each category: extremely enjoyable (5), very enjoyable (4), neutral (3), fairly enjoyable (2), and not at all enjoyable (1). The range of the averages was 3.50-4.67 (standard deviation = 0.41) with 6-30 student responses collected each week. We chose to analyze responses for the 5 weeks of the program when at least 10 students completed surveys.

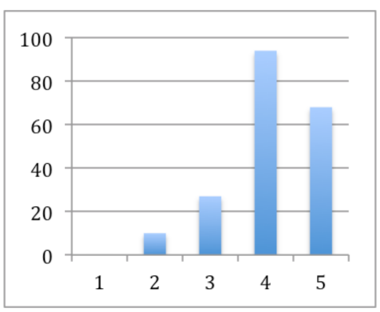

Fig. 3. Total student responses regarding interest and enjoyment of camp (N= 199 unique responses; 5 = extremely enjoyable, 1 = not at all enjoyable).

Quantitative data revealed that students most enjoyed the *Electrical Engineering Concepts and Gadgets* module, which involved building devices designed to solve simple technological problems. The weighted averages were between 4.13-4.67 with the metal detector activity ranked highest. Students' open-ended comments indicated they liked working independently and efficiently to create a useful product. Some representative comments included: "The extensive interactivity was enjoyable," "I loved learning about the interesting parts of the circuit," and "Proud to have a working metal detector!" One student said, "We were able to see our hard work come to fruition," indicating satisfaction and self-efficacy with her engineering task. Students also commented repeatedly on the expertise of their instructors and how much they appreciated their kindness, effort, and patience. The individual interactions between the instructors and students were frequent and productive, so students felt empowered and inspired.

Data indicted that students enjoyed the *Image Processing through Apps* activities, with weighted survey averages between 3.18-4.30. Their enjoyment increased with each week of the module as they acquired the skills to make their own apps. One student commented, "For people like me without programming experience, this was an extremely useful tool in a process that would otherwise require a great deal of learning." They repeatedly indicated how much they enjoyed the autonomy to create their own apps, for example, "We had the freedom to be creative," "I got to learn so many new things about creating an image and how to read an image," and "We got to actually make a movie - more interesting, more complex, more hands on work." Their comments revealed that some students had background knowledge in basic programming or found the initial work with MATLAB tedious. However, once all students had fundamental programming knowledge and they could work independently, their interest and enthusiasm improved dramatically.

4. CONCLUSION

A new after-school initiative for high-school students offered by Stony Brook University (Long Island, NY, USA) through the Department of Electrical and Computer Engineering and the Center for Science and Mathematics Education, is described. The program focused on introducing students in grades 9-12 to electrical engineering topics by offering two modules of four two- hour sessions on *Image Processing through Apps* and *Electrical Engineering Concepts and Gadgets*. The program modules were an overwhelming success. Students created three products and numerous apps by applying their newly learned engineering knowledge and skills. We concluded that some minor changes would improve the program, specifically, determining the programming backgrounds of students beforehand and placing them in different groups accordingly. Otherwise, evidence indicated that the students were engaged consistently and gained an appreciation for the role of engineering and programming in creating design solutions. In the future we plan to develop additional modules and expand our current program to involve more schools in the region, as well as offer professional development to K-12 teachers to replicate these engineering activities in formal classroom settings. We will also research the intentions of these students to pursue engineering majors in college. Long-term impacts will provide additional support for program replication and expansion.

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