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Engineering Outreach: Yesterday, Today, and Tomorrow

This article discusses the current landscape of outreach efforts in the United States to engage K–12 students in engineering. It then provides an overview of two programs run by the College of Engineering and Applied Sciences, and the Institute for Science, Technology, Engineering, and Mathematics Education at Stony Brook University (SBU) to promote student participation and interest in engineering. These efforts are aligned with the recently released Next Generation Science Standards (NGSS), which emphasize incorporating engineering design principles in K–12 science education. We describe two models, one in the form of an on-campus summer camp and the other as a series of after-school activities with both on- and off-campus offerings. These experiences are rarely available in K–12 schools and have the added benefit of exposing students to engineering faculty and researchers. The programs are focused on electrical and computer engineering with emphasis on signal and information processing and analysis and have hosted more than 200 students for the past six years.

We argue that offering continuing education opportunities to teachers and counselors at schools will have a considerably higher impact, and we describe two innovative programs targeting those populations as well as a new format of student experiences based on one-day campus visits.

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Overview

A major challenge in our increasingly technological society is the need to build awareness and excitement for engineering careers to help attract the engineers of the future. Unfortunately, students often view engineering as an unattractive and inaccessible subject and career option [1]. Contributing to this view is the traditional lack of engineering instruction in elementary, middle, and high schools (known collectively as the K–12 schools), compounded by a limited awareness of engineering knowledge and careers among teachers and school counselors [2], [3]. However, the recent adoption of the NGSS [4] by 16 states has shown tremendous promise for widespread proliferation of engineering in K–12 education.

The NGSS explicitly integrates science content knowledge, engineering practices, and cross-cutting concepts so students may identify, explain, and solve everyday problems through engineering design. The NGSS complement the American Society for Engineering Education (ASEE) K–12 Science, Technology, Engineering, and Mathematics (STEM) Guidelines for All Americans [5], which emphasize the scope of engineering practice, understanding engineering design, and applying STEM concepts to technological challenges. These standards and guidelines present an opportunity for universities to impact precollege engineering education by sharing resources and expertise. This article explores the current status of engineering education and careers in the United States, successful engineering outreach programs and curricula, and the efforts at SBU in advocating for a broader participation in engineering through university–community partnerships.

Recent reports have documented the chronic shortage of engineering talent in the United States [6]–[8]. The U.S. Bureau of Labor Statistics projected an increase of 365,000 engineering job openings, due to replacing current engineers between 2010 and 2020, and an additional need for 160,300 engineers due to new job growth [9]. It is questionable whether colleges and universities will be able to maintain the pace with engineering employment demands. There were 106,658 bachelor's degrees awarded in all engineering disciplines in 2014–2015 in the United States [5], yet there are indications that retention and diversity in undergraduate engineering programs are persistent concerns [10]. Undergraduate engineering enrollment in the United States was 541,705 in 2014, including 104,033 women, 27,163 African Americans, and 60,017 Hispanic students [11]. The graduation rate of engineering majors in the United States was 60% over six years [12], with both academic preparation and nonacademic factors contributing to attrition [12], [13]. The traditional disparities in undergraduate engineering education are reflected in the demographics of the current workforce. In 2014, there were 1,680,854 engineers in the United States, of whom 12.9% were women, 3.6% were African American, and 8.3% were Hispanic [11]. Disparities in engineering interest develop before college, with 14.5% high school men and just 2.5% of high school women intending to major in engineering [14]. Students entering higher education to study engineering need to be prepared differently, and it is essential that more diverse populations are attracted to and retained in the field [15].

Issues in K–12 STEM education

Intrinsic to the shortage of engineering talent is a lack of tradition of engineering education in K–12 schools [16], [17]. This has been manifested in current policies and existing science and mathematics curricula, inadequate teacher preparation, and limited resources for providing appropriate student guidance. There has been much discussion about the inclusion of engineering in K–12 classrooms and disjointed state efforts to do so [18], [19], yet research into STEM integration has not kept pace with changes in policy [20]. New York State, for example, has no distinct K–12 teacher certification in engineering and does not allow engineering coursework to meet licensing requirements. New York State is not prepared to meet the incorporation of engineering content and practices necessitated when the NGSS are fully adopted [21]. These standards originated in the U.S. National Research Council's Framework for K–12 Science Education [22], which recommended curricula that incorporate cross-cutting concepts, scientific practices, and disciplinary core ideas. With most states moving forward on the adoption of the NGSS, school districts will be required to provide engineering experiences embedded within traditional science, mathematics, and technology curricula.

K–12 STEM teachers and the need for professional development

Current science and mathematics teachers will require significant professional development to incorporate engineering knowledge and design principles in their classroom teaching. Most science teachers are unfamiliar with engineering practices, lack confidence in teaching design principles, and have an inaccurate understanding of the skills and training required for engineering careers [23], [24]. Limited resources are currently available to help them overcome these restrictions [20]. Research-based principles provide a compelling model for effective professional development supporting effective NGSS implementation, which complements the goals of ASEE [25], [26]. In-service teacher professional development is necessary to facilitate meaningful integration of science content and engineering design.

Purzer et al. proposed that teacher professional development should emphasize evidence-based decision making through collaborations with science and engineering education researchers. New curricula should be developed that integrate science content and engineering practices; teachers should encourage critical thinking and the development of literacy skills with the aid of formative assessments [25]. Stereotypical contexts should be avoided (e.g., building fast cars) to reduce inequitable practices in engineering education and encourage diverse participation in engineering careers [27]. A related STEM knowledge integration model suggests that students should learn diverse ideas about science and engineering, develop evaluative criteria, and test their ideas by collecting evidence [28].

In Bell and Gilbert's model of effective professional development [29], successful teachers express a desire to improve their practice, reflect critically on their pedagogy, integrate new ideas, and become empowered to implement new strategies and inspire others through collaboration. Frequent opportunities for interactions with colleagues and mentors contribute to curricular reform efforts [30]. Theoretical support is further evidenced by research suggesting professional development should be sustained over time [31], [32]. Effective training programs typically require 50–80 hours of instruction in authentic settings before significant treatment effects are evident [33], [34].

School counselors and the need for STEM training

The need for school guidance personnel trained in appropriate precollege academic preparation for engineering study is acute. Many high school students depend on the advice of counselors in choosing elective coursework and deciding where to send college applications. Counselors often have final decision-making authority on which courses a student will take. Engineering is a discipline where gateway precollege STEM coursework determines access to and success in the college major [35], [36]. Counselors and science teachers have been highly influential in encouraging students to pursue STEM-related careers, particularly those whose parents cannot advise on necessary choices [37], [38]. Access to high-quality STEM counseling is typically limited for underresourced schools [39], where students may be dissuaded from pursuing advanced science and mathematics in ill-conceived efforts to prioritize graduation rates [40]. Also, engineering is often viewed by counselors and teachers as a course of study for the academic elite, which further diminishes encouragement [24].

Underresourced student guidance has had a dramatic impact on the preparation of high needs students to pursue engineering. Just 4% of underrepresented students have taken the mathematics and science courses required for admission to the majority of engineering schools [41]. Each successive level of mathematics and science course-taking has been associated with an 8.2% increase in the likelihood of declaring a STEM major [42]. Coursework in physics and calculus is particularly significant [43]. Research has suggested that providing support and training school counselors regarding the value of STEM coursework will have a positive impact on students' STEM performance, course choices, and awareness of STEM careers [44], [45]. Counselors are well positioned to manage the alignment between students' career expectations and curricular decisions [46]. More work needs to be done with school professionals in the position to educate high school students on the challenges and rewards of engineering study.

Theoretical support for precollege engineering education

Student-related engineering program designs are supported by a sociopsychological theoretical framework that synthesizes elements of the expectancy-value model and the theory of planned behavior. Career choice has often been associated with outcome expectations or the anticipation of probable results from chosen actions [47]. This construct is partially explained by the expectancy-value model, which suggests that behaviors are based upon two considerations: the anticipation of actual outcomes and the importance or value attached to that choice [48]. Students generally do not choose careers in which they do not feel competent, and they do not see their relevance and social value early in the academic pipeline; this is particularly true for traditionally underrepresented students in math-intensive fields such as engineering [49]. The choice of engineering majors and persistence in the field has been linked to whether students possess an engineering identity that is consistent with their sense of self [50].

The theory of planned behavior [51] built upon the expectancy-value model by suggesting that one's controllability of career choice is predicated by self-efficacy. The theory states that human behavior is guided by likely consequences, the normative expectations of others, and beliefs about inhibiting factors. Engineering may be viewed as an achievable career choice if students have the confidence that they can overcome potential obstacles along the way. For example, undergraduate engineering majors have often experienced declines in self-efficacy early in their academic majors, and social supports are necessary for overcoming their self-doubts [52]–[54]. Our educator-related project designs also incorporate expectancy value and the theory of planned behavior in professional development; we believe teachers must be aware of these constructs in appropriately advising students about engineering careers.

Current outreach efforts in the United States

Research has shown that early exposure to engineering activities can significantly increase student awareness of engineering as a rewarding career path. Effective engineering programs in K–12 education have tended to incorporate inductive teaching approaches, which are referred to as problem-based or discovery learning. Collaborative knowledge construction is another strategy for modeling engineering practices [55], [56]. When working with diverse groups of students, engineering pedagogy that is interactive and student centered helps students recognize their cultural capital and improves their overall engagement [57]. Engineering education based upon NGSS and ASEE guidelines can improve engineering knowledge and skills as well as the scientific literacy necessary to understand and solve real-world problems [58]. These pedagogical principles have guided many engineering education projects. We provide some examples of these existing programs to situate our own work in building upon successful models.

The core objective of many outreach efforts is to align activities and workshops consistent with ASEE's goal that all Americans will be able to apply concepts of science, technology, and mathematics to engineering processes and problems [5]. Previous work in the field has generated engineering curricula for students and research on their impacts has been mostly positive [58], [59], [60]. Some curricula are for full-year courses specifically in engineering. For example, Project Lead the Way (PLTW) [61] developed curricula for one-year high school courses in introductory engineering, aerospace engineering, civil engineering, digital electronics, and other engineering-related focus areas. They provide professional development, resources, and ongoing training for teachers to implement PLTW curricula effectively. A review of PLTW research revealed that participating students performed as well or slightly better than non-PLTW peers, while teachers reported increasing their STEM integration over time [62]. Engineer Your World, a high school curriculum developed by UTeach at University of Texas Austin [63], is a one-year engineering design course based on socially relevant issues. Students learn about engineering design and habits of mind while also exploring the breadth of engineering professions.

Other engineering education innovations were designed for teachers to incorporate engineering in their existing science, technology, or mathematics curricula. The Infinity Project [64] provides two-day professional development for teachers to create and implement individual design projects in their middle and high school classrooms. Engineering Is Elementary was created for elementary and middle school teachers to include engineering activities related to real-world problems [65]. Out-of-school time (OST) programs, such as In the Middle of Engineering (IME) [66], provide informal exposure to engineering activities that parallel their school-based science and physics curricula. IME is targeted toward girls in middle and high school and involves women engineers as teachers and role models. These programs and others have resulted in increased STEM interest among participating students [17], [67], an internal construct that often leads to further STEM persistence.

Current outreach efforts at SBU

Our current outreach efforts focus on OST programs targeting high school students. Participation in OST programs has been shown to improve students' interest in STEM study and careers [68], so we have developed these programs to increase the number of students who intend to major in engineering. We describe two of our outreach initiatives here to illustrate how research and best practices informed our project designs. The first one is an engineering summer camp for high school sophomores and juniors. The second program comprises school and SBU-based OST engineering programs for freshman, sophomore, and junior students. For both programs, special emphasis has been placed on recruitment of underrepresented and high needs students and financial support has been obtained to promote their inclusion.

The goal of these programs is to expose students to the challenge, passion, and opportunity of engineering through an ample menu of hands-on activities in engineering with particular focus on the field of electrical and computer engineering. Whenever possible, tasks related to signal and information processing and data analysis are included as part of the activities. The general learning objectives include: 1) understanding and gaining appreciation for what engineers do, and, in particular, what electrical and computer engineers do; 2) learning basic theoretical and practical concepts related to the electrical and computer engineering fields; and 3) learning how to analyze an engineering challenge both qualitatively and quantitatively, how to design a solution for a problem by breaking it into smaller pieces, and how to evaluate and test the proposed solution.

The activities have been created and initiated by SBU faculty in engineering, physics, and science education with the assistance of staff and graduate students and with the support of both internal and external funding. Industry experts guide and advise on topics of interest for the activities and STEM teachers affiliated with SBU provide pedagogical and curriculum insights. The activities have a class size of 20–24 students.

There are different ranges of difficulty for the activities depending on students grade levels and backgrounds. In all activities, students are assessed on their knowledge, practical application of engineering skills, justification of designs based on data, and their ability to engage effectively in the peer-review process. Activities involve different engineering disciplines in general, but as mentioned previously, the greatest focus to date has been on electrical and computer engineering as well as computer science, leveraging the expertise of the College of Engineering and Applied Sciences faculty. As we shall see, many projects incorporate sensing or signal/data analysis, whereby students are introduced to elementary forms of signal processing techniques and basic concepts. The pedagogical design of each activity is currently aligned with the NGSS with the following guiding principles:

- Each performance expectation must combine a relevant practice of science or engineering with a core disciplinary idea and cross-cutting concept [4]. The activities combine science concepts with engineering design; for example, students learn about basic electromagnetism principles when building metal detectors.
- Students engage collaboratively in argumentation from evidence [22]. They advocate for their chosen designs by explaining their reasoning and associated evidence for their claims. For example, when building a pilotable helium balloon, they present their prototype in a peer-review process and debate various design components. They respond to diverse perspectives and assess the merits of counter arguments [4].
- When developing models, students have the opportunity to revise the designs based on evidence to optimize performance [4]. Students consider the relationships among the components of their system when making modifications.

In addition to academic activities, the programs include presentations by engineers from local industry and the Office of Admissions and Career Center at SBU to discuss career opportunities and requirements for engineering programs. This is consistent with research that suggested students career expectations are important when choosing pathways to specific postsecondary careers [47], [69].

Engineering Summer Camp

The Engineering Summer Camp was developed for high school students in their sophomore and juniors years [70]. This residential two-week university-based program was offered from 2009 to 2015 and is currently being redesigned for broader implementation. A total of 93 students have attended the camp (23 female), 16 of whom were totally or partially awarded scholarships to attend the camp based on their socioeconomic status.

The menu of activities has changed over the years and has been modernized and adjusted according to students' and instructors' feedback as well input from a board of advisors comprising teachers and social science experts. Figure 1 shows some students participating in the 2012 camp. Here we briefly describe four activities that have been offered over the years, although more than 20 different ones have been developed and instructed. Most of them have a duration of one camp day (about six hours of instruction) although there are some exceptions that require up to two days.

Understanding sonar, radar, and GPS

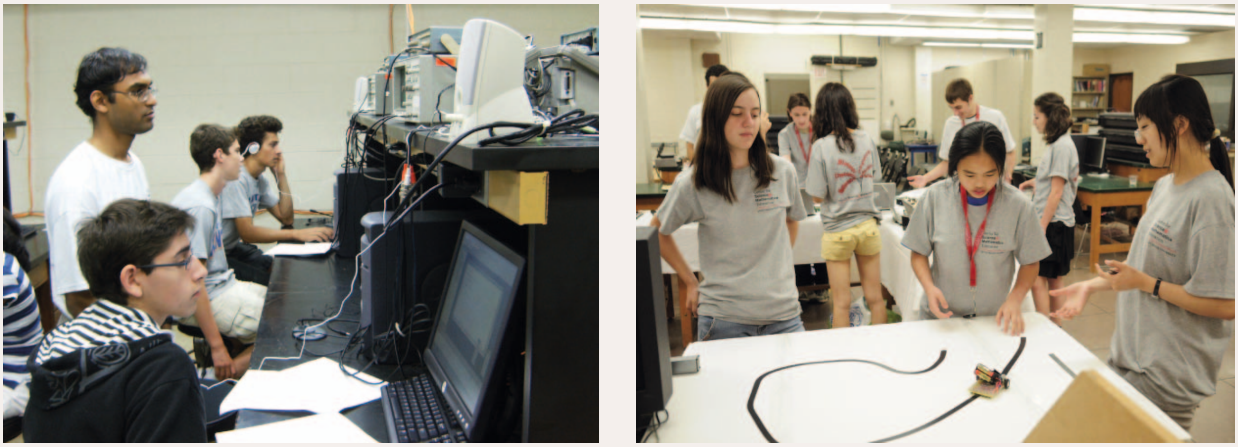
This activity consists of a series of experiments to highlight the simplicity of measurement of the speed of sound (which is the key to sonar operation) and object localization [which is the fundamental principle used in sophisticated applications like radar and global positioning system (GPS)]. We briefly describe two experiments related to the activity.

Experiment 1—Measuring the speed of sound

The speed of sound is measured using an experimental setup consisting of a speaker and two microphones. The speaker generates a pulse waveform, which is recorded on each of the microphones. The time delay between the subsequent arrivals of the waveform at the microphones is measured using a PC-based software oscilloscope and the sound card. Based on the known distance between the microphones and the measured delay, the students can calculate the speed of sound.

Experiment 2—Object localization

Students learn the concepts of trilateration and multilateration. These methods allow determination of an object location in a sonar or radar system using time of flight or time difference of arrival, respectively. Multilateration is also used to determine location in GPS receivers. The effect of measurement errors is also discussed, along with some techniques to optimize the solution in that case. The students calculate the algebraic solution for the location of an object using trilateration in a noise-free case. The data for this case can either come from oscilloscope measurements performed by the students (in which case there is some small error), or the students can be given synthesized data.



(a) (b)

FIGURE 1. Different activities from the 2012 Engineering Summer Camp for high school students: (a) understanding frequency with speech and music and (b) line-following robot.

The students also develop a method for solving the multilateration problem with noisy measurements using the computer. This can be accomplished either in Excel or in a programming language such as MATLAB, depending on the students' background.

Understanding frequency with speech and music

This is a series of experiments in which students are led to an understanding of the importance of the concept of frequency in everyday signals, mainly in speech and music. The experiments are performed in real time on dedicated digital signal processing (DSP) chips, using a visual programming environment. Audio clips and the students' own voices are taken as inputs via microphones, and loudspeakers are used as the main outputs. In addition, preset oscilloscopes are used to obtain a real-time visual concept of the outputs. The experiments enable the students to create sound effects on their own, in addition to performing assigned tasks. Figure 1(a) shows students in the DSP laboratory working on various experiments.

Experiment 1—Effects of suppressing and removing frequencies from a signal

Students first synthesize and play sinusoids of various frequencies and change frequencies while listening to the outputs. They then synthesize and play sums of sinusoids, both harmonically related and nonharmonic, and change relative amplitudes while listening to the outputs. By inputting an audio signal (music or the student's voice) to the DSP board and listening to the effects of preprogrammed filters (high pass, bandpass, and low pass) on the signal, they observe how these effects change as the cut-off frequencies are altered. The same exercise is repeated by inputting a recorded audio signal corrupted by noise and using a low-pass filter to lower the noise audibility. Finally, some initial concepts related to Fourier manipulation of signals is introduced, and students synthesize or input a square-wave and listen to the output. Then they pass the square-wave through a narrow-band, bandpass filter, and vary the center frequency to identify the sinusoidal components. The outputs are observed both audibly and on the oscilloscope.

Experiment 2—Effects of shifting and scrambling frequencies

A preprogrammed frequency shifter is used to shift the frequencies of voice inputs in both directions (up and down) by up to an octave to demonstrate the effects of pitch changes. The frequency shifter demonstrates the limitations of sampling by continually raising the output frequency until aliasing converts it into a low frequency. Also, the frequency shifter is set to half of the sampling frequency, which results in spectral inversion (high frequencies are converted to low and vice versa). The result is a simple voice scrambler, which is tested on the students' voices. Finally, a more complex voice scrambler, based on multiband spectral shifting and inversion, is demonstrated and again tested with the students' voices.

Line-following robot

Students learn concepts related to a line-following robot, a mobile machine that automatically follows a specified path without the need for human steering [Figure 1(b)]. Such a machine has various applications in areas such as industrial automation, warehousing, and automatic guided vehicles on roads of the future. A line-following robot has three main components: a sensing system, a drive system, and a microcontroller. The sensing system is responsible for determining the position of the robot with respect to the line it has to follow; the drive system generates the motion of the robot; and the microcontroller runs the control algorithm that controls the speed and direction of the robot along the specified line. Students build, program, and test a line-following robot. The sensing system consists of six reflective optical sensors. These sensors have a light-emitting

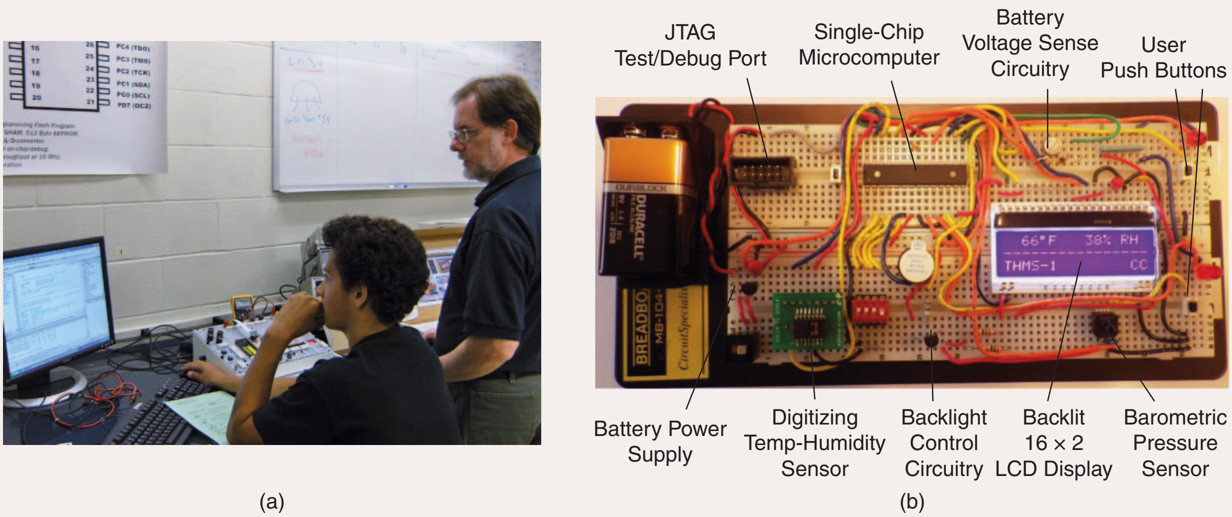


FIGURE 2. The creating prototypes activity at the 2012 Engineering Summer Camp: (a) the lab session and (b) the final device, a portable battery-powered temperature, humidity, and barometric pressure-monitoring system. JTAG: Joint Test Action Group.

diode (LED) and a phototransistor. The LED emits a light toward a surface, and the phototransistor enables measurement of this light reflected from the surface. The line is specified with a black color on a white/light colored surface. When an optical sensor is above the white surface, a large amount of light is reflected back to the phototransistor. If, on the other hand, the optical sensor is directly above the black line, very little light is reflected back to the phototransistor. Thus, by using a sensor array on the bottom of the robot, students determine the position of the robot with respect to the line by measuring the outputs of all the sensors. The drive system for our robot consists of two small dc motors. The shafts of the motors are coupled to rubber wheels attached to axles connected to the main body of the robot. The torque generated by the motors is transferred to the wheels to give motion to the robot.

- Students use an Atmel ATmega8 microcontroller. A control algorithm is implemented that controls the speed and direction of the robot. The microcontroller has six analog-to-digital converter channels that are connected to the outputs of the six sensors. This allows the microcontroller to determine the position of the robot with respect to the line and control the speed and the direction of the robot accordingly. Pulsewidth modulation (PWM) varies the speed of the dc motors and allows for varying speed of the motor by changing the width of successive pulses sent to the motor. These pulses are fed to the motor through a simple drive circuit consisting of a logic-level metal–oxide–semiconductor field-effect transistor and a diode. The higher the width of the pulses, the faster the motor rotation and robot speed and vice versa. The direction of the robot is controlled by a differential mechanism whereby the speed of one of the motors is increased or decreased with respect to the other to turn the robot in a particular direction.
- The complexity of the path and the speed with which the robot can follow it depends upon the control algorithm implemented in the microcontroller. Students explore three types of algorithms; in other words, bang-bang control, proportional control, and proportional-derivative-integral control. Based on the observed results of the line following, they tune the control parameters of these algorithms to achieve better performance.

Creating prototypes

This topic is essentially "Microcomputers 101." Students learn and utilize fundamental microcomputer system design techniques, resulting in the construction of a fully working design prototype. The design is a simple ambient temperature monitoring system. This two-day activity has a lecture/laboratory format. A full design overview is provided, and by the end of the second day, each student has constructed, fully tested, and optimized the system prototype.

- Each day students spend approximately two hours in lecture, and the remaining time in the Embedded Systems Design Laboratory. The lectures present important theoretical descriptions of the hardware and software utilized for the implementation of the system. The lab periods are spent constructing, testing, troubleshooting, and verifying proper system operation of their prototype [Figure 2(a) shows a lab session of the activity].
- Theoretical concepts during the initial day include discussions about system block diagram (high level), the system schematic, and fundamental operations, as well as basic breadboarding concepts. The lab session is used to give an overview of the

breadboarding system and wiring techniques, explanations on the solderless breadboard and system parts layout, a description of interconnect and wiring techniques, and system wiring. For the second day, the lecture revolves around concepts of data processing and collection, application program high-level flow chart, introduction to application modules and coding, and system troubleshooting and operation. The practice consists of continuation of system wiring, applying power (the strobe test), troubleshooting and verifying basic system operation, and adding one or more system extensions as time permits. Figure 2(b) shows the final device with the different components.

In addition to the strictly academic activities, students are also exposed to campus life and a variety of extracurricular events, for example, meeting with engineering admissions staff and having lunch with engineers working in university laboratories and industry. On the last day of the camp, there is a showcase of built devices and experimental results from the different activities (see Figure 3), and a panel of judges decide on different awards that are given during a closing ceremony.

Data were collected from 38 students over a two-year period (2012–2013); this was done after the researchers improved the previous instruments to collect more nuanced data on the students' engineering knowledge and attitudes. Students significantly improved their knowledge of electrical and computer engineering principles and processes as measured by pre/postassessments; this outcome was observed for both female and male participants. Students' confidence in performing engineering tasks also significantly improved as a result of their participation, although motivation for engineering careers did not change (likely due to self-selection for the camp) [70]. Qualitative data revealed students felt empowered by making connections between engineering principles and their personal experiences and interests, as well as optimizing and improving functionality of their designs. Survey responses indicated students particularly enjoyed meeting with university researchers and industrial engineers. These interactions helped students strengthen their engineering self-identity and envision themselves in engineering occupations in the future [71]. The camp activities were modified over several years and serve as the test bed for our other initiatives with expanded outreach to students and science teachers.

After-school engineering offerings

The after-school engineering program was developed with local school districts to inspire high school students in grades 9–11 with the opportunities and rewards of participating in engineering. It was piloted in the fall of 2015 and is mostly an off-campus program hosted by local schools with at least a one-time campus visit per student group. It consists of several out-of-school offerings (of about two and a half hours each) spread throughout the academic year for at least 24 hours of exposure to engineering disciplines as well as computer science, with an emphasis on the processing of signals and data related to different technological problems. The activities combine exploration of theoretical concepts with hands-on practice. Approximately 72 students have benefited from these preliminary offerings with nearly half of the attendees identified as female students. Moreover, in these first offerings, all students attended schools in high needs districts. Qualitative and quantitative data were collected to measure student impacts. Our preliminary research showed that students were enthusiastic about learning about engineering and programming to design solutions, and they were more motivated to pursue engineering after participating in the program. However, they did note that they were generally dissatisfied with school counseling on engineering study and careers—a finding that confirms our recent efforts [72], [73]. In the future, we will train K–12 science teachers to incorporate the activities in their curricula.

The activities are continuously reviewed and adapted according to state-standardized curricula and feedback from teachers and students. Figure 4 displays students engaged during the 2015 offerings. We briefly describe three activities as examples of our efforts: persistence of vision clock, discovering the radio, and a night-light. We note that, due to the time constraints at each school visit, one activity is usually spread out across more than one day.

Persistence of vision clock

In this activity, students learn how our vision is somewhat deceptive, and many types of visual displays take advantage

FIGURE 3. The 2013 Engineering Summer Camp for high school students at SBU. Students participate in the engineering exhibition and competition at the closing ceremony.

of these optical illusions. The offering is motivated with real-world examples, and students learn that our perception of a rapidly flickering light source being constantly illuminated is called the *persistence of vision*. We take advantage of this property to display the time and other text using a single row of LEDs.

- The foundation of the project is a small microcontroller that we custom program in assembly language. This microcontroller is capable of executing millions of instructions each second and is responsible for flashing the LEDs at the required speed. The LEDs are moved across our field of vision leaving a trail of flashes that appear as text floating in space.
- The project is based on a custom printed circuit board and requires soldering skills in its assembly. Most of the computer code is prewritten, and the student makes changes to customize the unit to display the desired text.

Experiment 1—Understanding persistence of vision

Students use function generators and LEDs to demonstrate the phenomenon of persistence. We detect the lowest flashing rate that appears constant to each student, we move the LED and observe the "trail" that the flickering LED leaves, and we observe the effect of duty cycle on apparent brightness.

Experiment 2—Building the project and coding

Students solder to assemble the project and test the board. They learn enough assembly language programming to make simple changes to the microcontroller program. This enables the unit to display an arbitrary string of text that the student chooses [see Figure 4(a)]. In addition, the unit is capable of displaying the time of day.

Experiment 3—Strobe effects

The project has a mode that flashes the LEDs at an adjustable rate. Students use this feature to observe rotating objects and measure their corresponding rotational speeds. They also demonstrate effects related to sampling at speeds greater than the Nyquist frequency.

Discovering the radio

In this laboratory exercise, students learn the basic theory of amplitude modulation and detection as used in the transmission and reception of AM radio signals. They build a tuned-radio-frequency (TRF) one-chip AM radio from a dedicated kit.

- In the process of building the radio kit, students become familiar with circuit components such as variable capacitors, air-wound inductors, electrolytic capacitors, resistors, and, of course, the single integrated circuit chip used for detection. They also learn about transistor audio amplifier stages and become acquainted with the notion that the job of engineers is to design and build properly functioning circuits. Students learn the processes of AM tuning, detection, and audio amplification as they complete the various stages of the kit.
- Familiarity with small hand tools is useful but not required, as the skill can be rapidly acquired in this experiment. Soldering is required; however, students quickly learn the necessary techniques even with limited prior experience [see Figure 4(b)].

A night-light

This is a simple project that allows novice engineers to apply basic electrical engineering concepts to daily life. The students are given materials to create an optical switch-activated LED module or, in layman's terms, a night-light. Concepts related to voltage dividers, photo-resistors, transistor functioning, and the handling of a prototype breadboard are introduced. With the completion of this project, the students have the introductory skills necessary to design their own electrical engineering projects.

- This project uses a straightforward dc-analog design. A single 9-V battery powers the circuit. The voltage

(a) (b)

FIGURE 4. Activities from the 2015 After-School Engineering Program for students in grades 9–11: (a) persistence of vision clock and (b) discovering the radio.

divider uses a photoresistor, which can vary from 27,000 Ω to 200,000 Ω, a sufficient range to function as a switch. Following the voltage divider, a simple positive-negative-positive bipolar junction transistor is implemented in common collector mode to increase current flow. Finally, the output consists of an array of LEDs connected in a series to serve as a light source.
- For those students who wish to work on more advanced designs, additional modules are available.

Experiment 1—On/Off toggle switch

An additional toggle switch can be added to break the connection from the battery source to the rest of the circuit. This can help tremendously in saving battery life.

Experiment 2—Fine-tuning with a potentiometer

A potentiometer is used to replace the 100,000 resistor in the circuit. Varying the impedance on this potentiometer adjusts the sensitivity of the light switch. Students get a schematic, the materials for the project, and a short lesson on how the electronic circuit works. Figure 5(a) displays the students working in the lab to build the night-light and (b) shows the schematic of the project.

On-going endeavors

Our ongoing work builds upon what we have learned from past outreach efforts as well as the research base in engineering education. These projects are to be implemented in the coming year with a pilot design phase and accompanying research components to measure impacts empirically. This allows us to make formative changes and maximize programmatic effectiveness for scaling the following year. Our projects are designed to attract, retain, and support precollege students in engineering. We plan to educate school counselors and science teachers on the diversity of engineering career pathways as well as engineering disciplinary knowledge and process skills. By targeting these two groups, we will build capacity and competence for studying engineering, a profession that contributes to global technological advancement. The overarching goals are twofold. Engineering should not be viewed as a separate discipline but rather an essential component of students scientific literacy, complementing traditional science content with structured opportunities to design solutions to scientific problems. Furthermore, the field of engineering will be diversified with students from an untapped talent pool to contribute to the global competitiveness of the United States.

Counselors and teachers

Our work with science teachers and school counselors began in 2017, with our previous work developing engineering activities for students as the starting point for professional development. We will train science teachers to incorporate engineering design in their instruction, and we will work with school counselors on their efforts to advise students on pre-engineering coursework and the diversity of engineering careers. The professional development workshops will be modeled upon previous similar offerings at SBU. With external support, summer STEM education workshops have been offered for elementary teachers, middle school mathematics and science teachers, and high school chemistry and physics teachers [74]. Our theoretical model reinforces our emphasis on professional development in authentic settings for both science teachers and school counselors. In addition, the teacher workshops will incorporate ASEE's Standards for Preparation and Development for Teachers of Engineering [75], which include literacies in engineering design, engineering careers, and engineering and society.

The science teacher workshops will educate teachers to incorporate engineering aspects of the NGSS in their New York State-standardized science curricula. Twenty-four participants will attend each four-part workshop, with each teacher impacting approximately 150 students per academic year. We expect to recruit four cohorts during the first year with expansion in subsequent years. Participants will build their engineering skills by applying design principles while teaching science content and process. Each cohort will be immersed in a program of mutually reinforcing

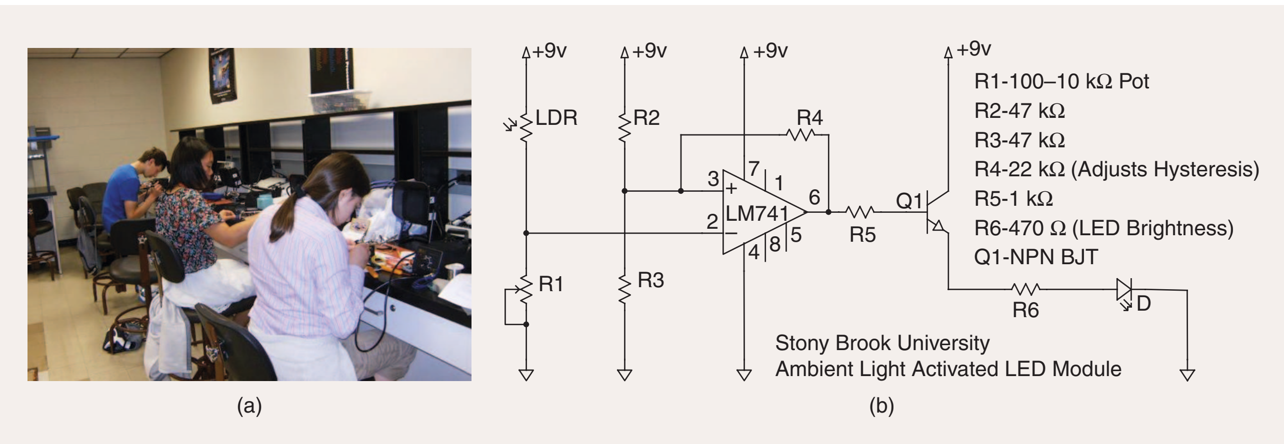


FIGURE 5. The night-light activity at the 2015 After-School Engineering Program: (a) students soldering the circuit and (b) the schematic of the project.

components: 1) introductory work in engineering related to their curricula in living environment, physics, chemistry, and earth science; 2) classroom-based action research that builds teachers' ability to use data as a formative assessment to inform instruction; and 3) collaborations with engineers and STEM researchers to learn about engineering pathways and careers. Teachers will learn activities that we have previously piloted and have the flexibility to modify them for their students. Each activity will include a detailed explanation of science content and how it relates to state standards and the NGSS, followed by instruction in engineering pedagogical content knowledge. The teachers will learn a variety of assessment strategies for informing their instruction, for example, rapid, response systems, performance tasks, and questioning techniques. They will be encouraged to participate in professional learning communities to share their knowledge with other teachers in their districts and strengthen their commitment to engineering integration.

School counselors will participate in workshops to build their knowledge base in advising students about appropriate precollege engineering coursework and engineering career pathways. Once again, our prior work with students provided data to inform the content and structure of this professional development. The counselors will be immersed in a one-day training including diversity training; introductory work in engineering related to supporting competencies in science and mathematics curricula; and informative talks with engineers, STEM researchers, and university staff to learn about the diversity of engineering employment opportunities. The professional development workshops will be held at different off-campus sites and led by engineering and science education faculty and university staff. Discussions about science content and how it relates to New York State Standards and the NGSS will also be part of the training. The workshops will involve industrial engineers and staff from the Admissions Office and Career Center at SBU, so counselors will learn about qualifications for schools of engineering and specific disciplinary skill sets. The counselors will be recruited from the 125 school districts in the region, and the broader impact will be considerable since they interact with 175–300 students per academic year.

Engineering teaching laboratories

This outreach component has been modeled upon existing teaching labs in biotechnology and chemistry that have been offered at SBU since 1992, where students in grades 6–12 participate in inquiry-based experiences not readily available in their schools. More than 5,000 students have participated each year, and data have shown immediate increased student motivation to pursue STEM [76]. However, the initial offerings were a one-day-only experience for students and long-term impacts were not measured. This initiative expands and builds upon the models success, with the ultimate goal that teachers will adapt these OST engineering teaching laboratories into their classroom science instruction. In doing so, the project may be scaled to impact more students. The evaluation of prior pilot activities supports the age-appropriateness of this and other proposed activities for students in grades 9–11.

Students will come to campus during the school day and spend six hours working on a proposed hands-on activity that is aligned with the NGSS. Here we describe two activities that are in the pilot stage with full implementation scheduled for the coming year.

Linking fiber optics

The goal of this activity is to teach basic engineering concepts related to communications with an emphasis on fiber optics. The activity involves engineering theory related to transmitters and receivers; physics content knowledge related to Snell's law, refractive indices, Ohm's law, and electrical components of a circuit board (aligned with New York State's Physical Setting Standards [77]); and engineering skills such as soldering, testing functionality, debugging systems by detecting and isolating malfunctions, and minimizing signal distortion. Required materials include basic electronic components that will be purchased so students can build their own prototypes. Students discuss and debate the advantages and limitations of fiber-optic communication, optimal designs based on their own evidence, societal impacts of this technology, and potential future developments in communication.

Competitions are also part of the activity. For example, students receive an arbitrary length of fiber link, and they test the maximum distance for which reliable communication is maintained. They then increase this distance by using their knowledge and creativity. Solutions involve increasing the input power of the LED or the amplifier gain by using a different resistor.

Learning images through apps

Students learn about images through app programming. The activity involves the introduction to computer science-related concepts such as pixels, digital images, and movies; science content knowledge related to optics and communication (aligned with New York State's Physical Setting Standards [77]); and programming skills such coding, debugging, and code optimization. Required materials include a laptop with the appropriate software (we will use the open-source web application App Inventor for Android) and an Android tablet to download and test the product (we had most of the devices in place as part of previous outreach offerings, and we will renew existing materials as the project progresses). Most regional school districts indicated that these materials are available in their schools. Students will first learn image-related topics (pixel, RGB color model, or intensity) and programming concepts (for example, control flow instructions) using the open-source computing environment Octave. They then will learn how to develop mobile apps using App Inventor. Differences between Octave and App Inventor will be discussed, especially on issues related to their capabilities when dealing with images. Students will be instructed to create an app step by step, to troubleshoot and download the apps to Android devices and, finally, test them. Later, engineering teams will have an app competition.

Some prototype apps will be provided, and each group will decide to either add innovative elements to the existing prototypes or create a completely new one. At the end of the activity, each group will give a brief presentation.

Concluding remarks

Engineering education is at a crossroads with recent efforts to create inspiring engineering experiences for K–12 students. There is a persistent need to attract and retain students in engineering postsecondary study and careers, and educators and policy makers have responded with widespread adoption of the NGSS to incorporate engineering knowledge and skills in science instruction. We aim to advance engineering education by creating and refining programs that improve STEM teaching and learning by building passion, preparation, and confidence for engineering study among secondary students.

Our programs involve several stakeholders—students, teachers, and counselors—in a multifaceted effort to address weaknesses in precollege engineering accessibility. More students will be exposed to engineering as a means to solve problems by applying scientific knowledge, and their teachers and counselors will have the skills to communicate these processes and advise students on academic trajectories that lead to engineering careers. We will continue leveraging the expertise of engineering and science education faculty to designing innovative experiences that ultimately diversify the engineering talent pool. Although our previous and current student offerings focus on electrical and computer engineering with signal and information processing, we plan to expand to other engineering disciplines to offer students a broader vision of engineering careers. In doing so, we hope to contribute to the knowledge base in engineering education so effective outreach strategies might be incorporated in classroom teaching and advisement.

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to choose the wavelet family, the transformation level, and the corresponding support size of the filters were brought to light.

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