2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32410

A University-High School Partnership for Introduction to Engineering: Building Community with Underrepresented Students (Evaluation)

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A University-High School Partnership for Introduction to Engineering: Building Community with Underrepresented Students

Abstract

Engineering outreach to K-12 students is the leading way to increase enrollment in engineering programs, especially for underrepresented students. This paper will describe a partnership in which a university professor teaches an introductory engineering course to local high school students on the university's campus. The high school involved is a private college preparatory school for underserved students in the area that is unable to offer an in-house engineering course. The students that take this course, of which 44% have been female, and 82% have been non-white, receive both high school and college credit. The introductory engineering course includes a set of modules, each focusing on a different engineering topic and skill. Each student is given an engineering kit that, along with the modules, will assist them in finally building a table-top wind turbine system complete with electrical, software, mechanical, and structural subsystems. This course has been taught three times so far, and data has been collected through student surveys, interviews, and anecdotal findings. This long-term relationship-building program is innovative because it is more than outreach. Instead, it is about bringing the students into the campus community. The authors will assess the outcomes of this program in terms of student comfortability with engineering skills, students chosen major after high school, and the gender and race/ethnicity breakdown of both. In addition, this paper will discuss the qualitative impact of this program on the university and the high school involved.

Introduction

Outreach to high school students can take many forms. There are countless examples of successful university programs that are designed to increase engineering awareness among pre-college students that are not traditionally represented in the engineering pipeline. The goals for this program were to develop community with those students, to go beyond one-time outreach, and to include the students in the fabric of the university.

The high school students participated in a university course taught by a university professor in the university's maker space. The course, spanning an entire 16 week semester, enabled the students to experience engineering, university offerings, and some aspects of college life.

This report will begin by describing the program and partnership. Next, it will present data from surveys used to assess the program's impact on student interest and skills in engineering. Finally, it will discuss the program's impact on the students and the institutions.

Background

This program can be seen from many lenses. It can be first seen as a STEM outreach program. As described by Nadelson & Callahan, outreach programs can take many forms [1]. Programs can be 1-2-hour demonstrations highlighting an engineering phenomenon, or it can last several weeks with the students possibly living on campus during the program. Most outreach programs will attempt to increase awareness of engineering and increase familiarity with college and typically focus on extracurricular or co-curricular activities. The program described in this paper is neither extracurricular nor co-curricular; instead, it is academic in which the students are participating as part of their requirements for the high school diploma.

Some programs do incorporate engineering design into the high school coursework. Apedoe *et al.* describe a program to bring an engineering design problem into a high school chemistry course to facilitate instruction of difficult chemistry concepts via a real-world application [2]. Some engineering programs are entirely academic, such as Project Lead the Way [3]. Project Lead the Way is a well-established program providing an engineering-specific curriculum and training to high school educators.

This program can also be seen as a school-university partnership; however, most partnerships focus on teacher professional development. Brady describes that some of these partnerships include supervision and mentoring, collaborative teaching initiatives, action research, joint professional development, shared planning, and school enrichment and support [4]. This program is a partnership focused on students.

Ultimately, this program is innovative, as it is a university offering a high school class. The course is unique to the university's community. The course material is essentially the same as a university course, but the teaching methods are changed to blend the college and high school experiences. It is a university introduction to engineering course being taught to and for high school students, and only high school students.

Before beginning this program, constituents wondered why there were so few students from the local high schools enrolled at our university. There are two high schools (one public and one private) within two miles of the university campus, but very few students were applying to the School of Engineering from either school. At the same time, there were questions about the prevalence of high-school engineering courses and the distribution of that curriculum across schools providing education to typically underserved populations.

The program that was developed aimed to address the following challenges:

1. Increase exposure of the university (academics specifically) to high school students in the neighboring community
2. Increase availability and access to an engineering curriculum for high school students in the neighboring community
3. Develop connections between the university and STEM faculty at high schools in the neighboring community for professional development
4. Assess the students comfortability and interest in engineering before and after the course

Program Description

For three years, students from a nearby high school have been taking an introduction to engineering course taught by a university professor in the university's maker space. On a small scale, the goal was to expose the students to engineering and the university, but on a large scale, the goal was to expose these students (many of whom are first-generation) to the opportunities available in college.

Partnership

De La Salle North Catholic High School (HS) is a private college preparatory high school providing education to underserved students from the Portland, Oregon metropolitan area. The school offers standard math and science courses but does not have the resources or faculty expertise to offer any engineering curriculum. The school focuses on college and career readiness. In fact, the students all participate in a corporate work-study program. Participation in the program means that the students attend classes at HS four days per week and spend the fifth day working at a local company or organization.

The 12-14 HS students enrolled in this course each year have been juniors. They have all taken an algebra-based physics course and are typically in the school's pre-calculus course. Significantly, they have not been exposed to calculus or calculus-based physics, which are typically co-requisites for college-level first-year engineering courses.

The University of Portland (UP) is an undergraduate-focused four-year liberal arts university with a College of Arts and Sciences and four professional schools (education, nursing, business, and engineering). The School of Engineering offers four undergraduate degrees in computer science and mechanical, civil, and electrical engineering. The first course taken by students in the School of Engineering is a project-based introduction to engineering course that exposes the students to basic concepts in each of the four disciplines via experiential and hands-on learning.

Course Logistics

The partnership began with a memorandum of understanding between the two institutions. It outlined the credit articulation agreement and the general procedures for the course. In the Fall of every year, the HS liaison coordinates and selects students for the course. During Spring 2017, 12 students took the course (11 completed it as one student moved away from the area). During Spring 2018, 13 students took and completed the course. During Spring 2019, 14 students took and completed the course. These students will receive high school elective credits as well as two college credits for the university's introduction to engineering course. The students take the course on UP’s campus twice per week (Tuesdays and Wednesdays) for 1.5 hours each (three hours total per week). The course extends beyond their school day, so they are allowed to have a study hall period during their last period on Mondays and Thursdays. As mentioned above, the students are working at their internships on Fridays.

The students are each provided a kit of supplies that they will need for the modules and project for the remainder of the course. The students perform the course modules and project in groups of two to three.

The course is directly and indirectly funded. Initial development of the course was provided by a private donor who has close ties to both institutions. That money provided funds for initial supplies and a stipend for an undergraduate student teaching assistant each time the course is taught. Indirectly, the HS has been funding transportation for the students and a substitute teacher that monitors a study hall course on days when the students are not at the university. During the first year, the instructor taught an overloaded schedule to make this possible, but since then, it has become part of the instructor's standard course load. The university has agreed to waive tuition and fees for the students.

Curriculum

The first day of the course focuses on an introduction to the course and a presentation about the safety procedures of being in a university lab classroom.

Technical Topics

The remainder of the course focuses on designing a table-top wind turbine system. The system is divided into an electrical subsystem, software subsystem, machines subsystem, and a structural subsystem. Each subsystem will be covered separately in a 2-3 week module, and at the completion of the module, the students will have completed that portion of the wind turbine.

The first module covers basic electrical circuits, and the end result is the electrical subsystem. The students spend approximately three weeks learning about multimeters, batteries, breadboards, resistors, diodes, LEDs, motors/generators, and how to design circuits to accomplish tasks. At the completion of this module, the students will have designed the circuit that is needed to harness and convert the rotational energy from the wind turbine (to be designed in a later module) into usable and safe electrical energy that illuminates LEDs and can be monitored by the software subsystem.

The second module covers basic computer programming, and the end result is the software subsystem. The students spend approximately three weeks learning the Arduino platform and basic programming concepts of syntax, algorithms, functions, input/output, and logic. At the completion of this module, the students will have designed the software program that is needed to measure the electricity being produced by the electrical subsystem and to display the magnitude of that electricity via an LED array.

The third module covers blade design and gears, and the end result is the mechanical subsystem. The students are tasked with selecting blade angles that provide the most rotation of the blade system. They are also taught basic gear theory, so they can design a gear train to use mechanical advantage to generate more electricity at a given wind speed. At the completion of this module, the students will be able to tie their blades and gears to the electrical generator, which is then connected to the Arduino computer via a conditioning circuit.

The fourth and last module covers trusses, and the end result is the structural subsystem. The students design and manufacture a truss structure out of balsa wood that will elevate and support their mechanical system off the ground so that it can effectively harness the wind energy. At the completion of this module, the students will combine all four subsystems to produce a working table-top wind turbine.

Informally, through each module, there is a scaffolded expectation of 'test and iterate.' It is especially apparent during the third and fourth modules that require the students to use fans to test their blade/gear system for performance. Inevitably they find ways to improve their designs, iterate, and continue to develop the turbines until the end of the semester.

On the last day of class, the students perform a 'demo day.' The HS teachers, HS administrators, university administrators, supporters, and some students' families attend. The student teams demonstrate and present their turbines to the audience.

Non-Technical Topics

Throughout the semester, representatives from a variety of UP offices come to speak to the students about college transition and opportunities. The Office of Admissions and Office of Financial Aid come and talk to the students about applying to and paying for college. The Office of Studies Abroad has come to talk to the students about the potential of international education experiences, which are uniquely offered in college settings.

During the first year of the course, college readiness topics (discernment, applications, essays, financial aid, and opportunities) were all discussed at length. During the second and third years, these topics were not covered, which will be discussed below in 'Outcomes and Impacts.'

Assessment

Student Grades

Each class session, the students are given short, in-class worksheets that will lead them through the activities. The small class size enables direct supervision of each student, so the students are able to complete these assignments accurately. In general, the hands-on activities require that the students complete the worksheets correctly. The students' grades come from these worksheets, participation, behavior, and attendance. Since the class is almost entirely hands-on, requiring the tools and equipment available in the lab, there has not been homework assigned. The grades are compiled at the end of the term and submitted for the official university transcript. The final grades are also provided to the HS liaison, which converts them to the high school system and submits them for the high school transcript.

Program Evaluation

The program is evaluated by measuring the impact of participation in the course on the students. The students are surveyed on the first and last day of the course. The survey, which was approved via the university's institutional review board (IRB), is based on the work of Faber *et al.* [5]. The survey uses the Likert-scale to assess student attitudes towards engineering mindset, engineering disciplines, engineering skills, college likelihood, and interests, as well as some basic demographic information.

Additionally, the UP instructor works with the HS liaison to track the students through their senior year as they make decisions about college and majors.

Outcomes and Impacts

The students were surveyed at the beginning and end of the semester for demographic information as well as their own perceptions about engineering skills.

Demographics

The students were asked to voluntarily self-identify their race/ethnicity and gender. The authors standardized their responses. By the end of the 2019 cohort, 39 students had taken the course. There were 17 female students (44%) and 22 male students (56%). The student racial/ethnic identities were grouped into seven categories (Hispanic, non-Hispanic White, Black, Asian, Pacific Islander, Middle Eastern, and Multiple/Mixed). The racial/ethnic breakdown is shown in Figure 1. For comparison, in the US in 2018, only 21.9% of students earning engineering bachelor's degrees were female, and 38.5% of students earning an engineering bachelor's degree were of an ethnicity other than white [6].

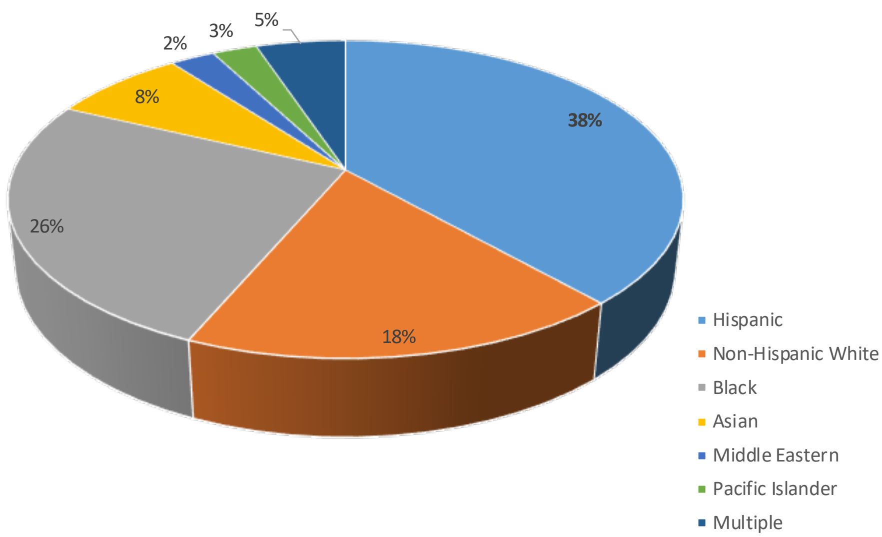

Figure 1: Racial/Ethnic Distribution of 39 students in three cohorts.

Skill Improvement

The aforementioned course curriculum should improve the students' engineering skillset. The skills that should be directly improved are – computer-aided drafting, 3D printing/rapid prototyping, fabrication (i.e., woodshop or metal shop), electrical circuitry (i.e., soldering, wiring, etc.), computer programming, and Arduinos.

It is possible that some students had some engineering experience or skill before participating in the course. Each student was asked twice (once at the beginning of the semester and once at the end of the semester) to rate their comfortability with the six engineering skills on a Likert Scale from 1 (low comfortability) to 5 (high comfortability). The difference in their 'comfortability rating' is calculated from the beginning of the course to the end and used it as an indicator of improvement in the skill. Figure 2 presents the total change in all students' comfortability ratings for each skill.

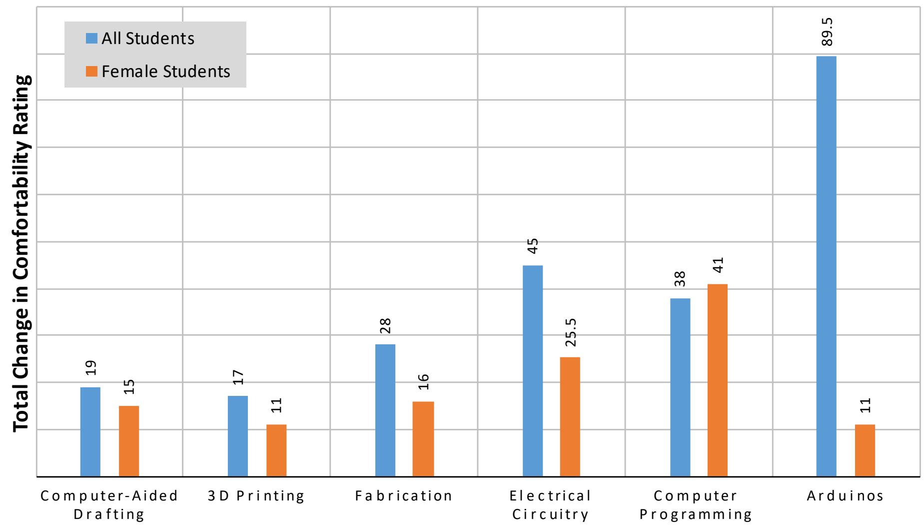

Figure 2: Total Change in Comfortability Rating for Six Engineering Skills.

As expected, the course caused an increase in the overall comfortability with engineering skills. There is a noticeable improvement in their comfortability with Arduinos, which can be explained by comparing the first and last day scores. Figure 3 presents the average comfortability ratings on the first day and last day of the course. In general, the students did have some familiarity with the first five skills but had minimal familiarity with Arduino.

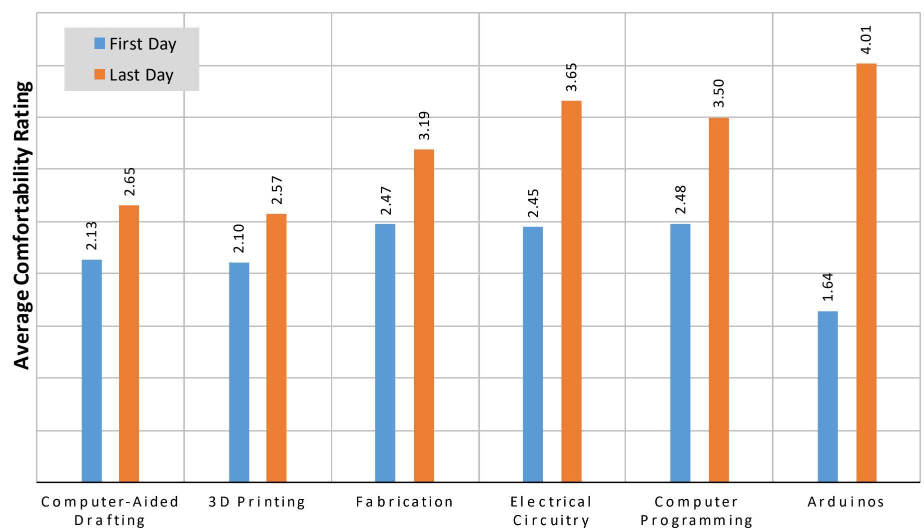

Figure 3: Average Comfortability Rating for Six Engineering Skills on First and Last Day of the Course.

Colleges and Majors

The students were all juniors at the time of the course, so they had not yet selected colleges or college majors. Their college and major choices were tracked, generally immediately following their high school graduation, to determine their paths. Over the three cohorts, 95% (37 of 39) students indicated they were planning to attend college right away.

Over the three cohorts of the program, 38% chose to pursue engineering or computer science in college. Only 18% of female students from the program chose to pursue engineering or computer science in college. For comparison, SWE reports that 20% [7] of bachelor's degrees are awarded to women in engineering in computer science, and ASEE reports that the number is 21.9% [6]. Over the three cohorts, 27% of Hispanic students chose to pursue engineering or computer science in college. For comparison, APS reports that 23% [8] of bachelor's degrees are awarded to Hispanic Americans. Excitingly, 50% of Black students from the program chose to pursue engineering or computer science in college. For comparison, APS reports that only 13% [9] of bachelor's degrees are awarded to Black/African Americans. The complete major choice data is presented in Figure 4. Five students (13%) enrolled in STEM fields at the university that hosted the program.

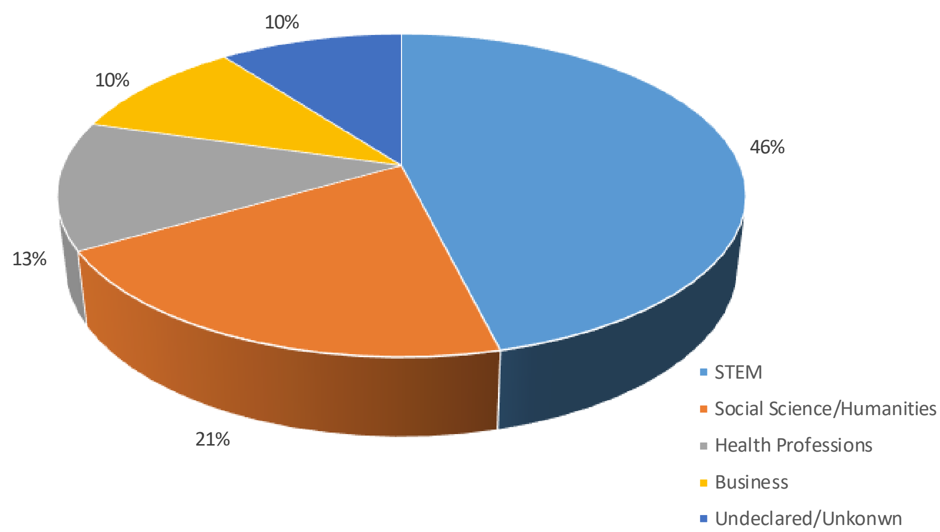

Figure 4: Major Choice Distribution of 39 students in three cohorts.

As Figure 4 shows, many students did choose to enter the STEM field. However, there was also significant interest in majoring in social sciences/humanities, health professions, and business.

This course was one of HS's first offerings in professional preparation and exposure, which lead to some interesting anecdotal and informal outcomes.

Anecdotal and Informal Observations

Since this course began, HS has developed a series of courses, clubs, and facilities that deepen the students' experience in STEM and college.

<u>Changes at the High School</u>

First, there are now two new co-curricular STEM/Engineering clubs for the students to participate in: a robotics club and a programming club. Second, the school has developed a new course for all juniors dealing with college preparedness. Previously, the high school's college counselor would meet with each student individually to help them with the college process. This worked well, but it was inefficient. After the first year of the UP course, HS implemented a course for all juniors to cover similar topics about college. Third, HS is working to develop a mini-MakerSpace based on the lab classroom that the students used at UP. This room is designed to allow the students to use materials and tools to innovate and prototype ideas. Last, there has been a push at HS to offer more higher-level professional electives to students in topics including programming, anatomy, robotics, and an intro to health professions. They have also worked to develop partnerships with other colleges at UP and other universities.

Individual Experience

The most exciting and rewarding aspects of the course came informally as part of the student experience. For the first few weeks, the students would arrive on campus and would come straight to class, and would leave immediately following the class. They were offered tours – to see the library, sports fields, stadiums, eating areas, study spaces, and lounges. Eventually, the students became more and more comfortable on campus.

Slowly, they would stop at the dining hall before class to get some French fries, they would stop at the bookstore and browse, or they would come to campus with a coffee from the nearest kiosk. Eventually, they would leave class and go to the study room to work on homework or sit in the lounge and 'hang out.' Some of the students got to know the baristas by name. It was not every student, but many of them become more and more comfortable on campus. It felt as though they stopped feeling like they were visiting and started feeling like it was their campus.

The professor felt the impact too. The HS invited him to participate in their end of year awards banquets, which made him feel like he was part of their community.

Conclusion

There are so many ways and reasons to reach out to high school students, and all are important and useful in improving the engineering pipeline. We speculate that the duration of an outreach program changes for different age ranges. Short programs (a few hours) increase large-scale exposure and engagement, perhaps ideal for K-5 students. Medium-length programs (weekends or a few afternoons) start to develop skills, interest, and confidence, perhaps ideal for middle-school and early high school students. Long, deep programs (semester long or overnight summer institutes) serve the purpose of full-time immersion. Students in these programs spend time doing real college-level engineering at a college, so one barrier to an engineering future – not knowing it is possible – is removed. These students are likely in the college-selection process, so engaging them in this way has a profound impact.

The work presented here is a labor of love for the UP instructor. It began as a small idea to somehow work more closely with the neighboring high school. It has become a full-fledged part of his everyday activities.

The program has deepened relationships between STEM faculty at HS and UP, and it has exposed 39 students to a school down the street that few of them had ever considered.

After three years of the program, the students feel more at home on a college campus, and perhaps more excitingly (for the instructor), I feel incredibly at home in a classroom of high school students.

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