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Preparing Future Engineers Through Project Based Learning

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Preparing Future Engineers Through Project Based Learning

Abstract

A significant amount of research suggests the common reasons students leave an engineering major include lack of faculty mentoring, lack of a sense of belonging, financial hardships, and course difficulties in the prerequisite STEM courses [1]. Project-based learning (PBL) potentially addresses several of these reasons and increases the chances of a student completing an engineering major.

Engineering students are more likely to persist when they feel a sense of belonging and community engagement, when they have early interactions with faculty mentors, and when they experience a series of successes [2]. The research question involves whether student research projects with small, faculty-mentored groups promotes student retention.

Students participating in Contra Costa College's Center for Science Excellence (CSE) STEM mentoring program are encouraged to apply for external internships and internal research projects. As of the last cycle before the interruption of internship opportunities associated with COVID-19, 79% of participating students intended to apply for summer internships. Students are also able to work on internal research projects mentored by CSE faculty mentors.

Over the past three years, engineering students that have participated in research projects have remained in our program and transferred at a high rate. Of thirty student research participants, fourteen have transferred into engineering majors (47%), two have transferred into other STEM majors (7%), eleven continue to take transfer preparatory courses at Contra Costa College (37%), and the educational status of three students is unknown (10%). For the college as a whole, the transfer rate is 32%, the graduation rate is 24%, and the retention rate after one year is 67%.

Current and Previous Projects

Students have participated in the past two California Solar Regattas, a solar-powered boat competition organized by the Sacramento Municipal Utility District. The student teams won a "Judge's Choice" trophy during their first year of competition. At the end of each competition, the design team has created a description of successful features and areas for improvement.

Students have participated in model rocket construction and launching each of the past two years. Four groups of students successfully constructed, launched, and retrieved their model rockets.

In summer 2019, three students participated in an onsite Arduino microcontroller project. In this project, students worked with mentors from the physics department to design, construct, and test free fall apparatuses for use in three physics courses at the college. The students successfully designed, machined, and assembled lab quantities of free fall test apparatuses that have been used by students in descriptive physics labs, physics for biological science majors labs, and

physics for physical scientists and engineers labs. At the conclusion of the project, the student team worked with their physics department mentors to determine other lab experiments that the Arduino photogate timer could be incorporated into by future student research teams.

During the largely remote-education period brought about by the COVID-19 response, several CSE engineering students have been using Arduino microcontroller kits to design and build a series of pre-determined projects to learn how to incorporate Arduino into projects. In Spring 2021, student groups designed and constructed a wind-tunnel and participated in two app design projects. The students presented their projects at our annual student research symposium.

Background and Purpose

Contra Costa College is a community college located in West Contra Costa County. The college's student body is 44% Hispanic/Latinx, 19% Asian, 17% African-American, 11% Caucasian, and 6% Two or more races. The college's student body is 60% female and 39% male. 48% of students received Pell grants. In this project, we explore the effects of providing low-income, underrepresented, and female students with hands-on research experience in STEM. In doing so, we hope to encourage them to continue their studies of science and technical fields and to give them practical context for applying what they learn in their classes. In this paper, we examine the role of project-based learning on student retention in the technical fields. The ultimate goal is to have scientists and engineers with ethnic backgrounds better reflecting the population in the country.

Method

Research has found that the first two years of college learning are the critical period for students to decide whether to stay in or leave STEM fields. This time period has been shown to be especially important to women and underrepresented minorities [3]. It is widely recognized that Project-Based Learning (PBL) or "learning by doing" is one of the major instructional elements to increase the retention rate for STEM students. PBL inspires STEM students not only with real-world problems but also with the necessary foundational skills to pursue STEM careers [4].

All student participants in the CSE program are encouraged to apply for internships and summer Research Experience for Undergraduates programs, but due to the limited number of positions available and the highly competitive nature of the application process we have attempted to create opportunities at the college as well. Mentors work with students to help shape and identify project goals and to offer guidance and support in the students' execution of the project.

While not a requirement by any means, students are encouraged to choose projects that are meaningful to them and that serve a purpose in their communities. It is probably not surprising then that projects have often involved utilizing renewable energy like the solar boat projects, building autonomous robots meant to disinfect a room, and utilizing sensors to gauge air pollution (Figure 1).

Figure 1 – (a) Student researchers at the California Solar Regatta solar-powered boat competition. (b) Student researchers preparing their model rocket carrying Arduino sensor payload for launch.

Results

Another way in which students are able to use their growing engineering knowledge to give back to the community is by helping design and build equipment to be used as demonstrations in our lectures or as devices in our labs. In summer 2019, three students participated in an on-site Arduino microcontroller project. In this project, students worked with mentors from the physics department to design, construct, and test freefall apparatuses for use in three physics courses at the college. These free fall apparatuses have been used in three different physics lab courses ever since and have already benefitted hundreds of students (Figure 2).

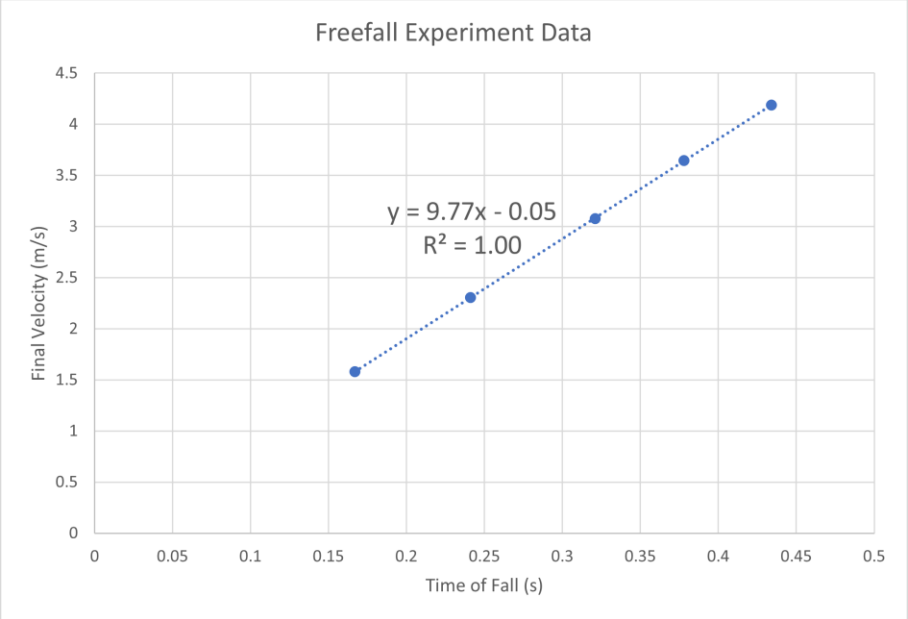

Figure 2 – Representative data from the free fall apparatus with slope representing roughly constant acceleration of 9.77 m/s^2.

Other students chose to take on projects where they could begin to build portfolios to assist them with getting an internship in a field of particular interest to them. Some projects in this vein include building a wind tunnel or examining acoustics in a tube and computational modeling of the ensuing standing waves.

Regardless of the project chosen, students are introduced to the engineering design process and given the opportunity to put to practice the skills and knowledge that they have acquired in their courses [5]. Students start with a brainstorming process to identify the problem followed by the requirements analysis (Figure 3). Projects are divided into components. Students use their skills learned from Engineering Design Graphics to create detail drawings for analysis. Team leads are chosen for each of the various components so that students have the opportunity to improve leadership skills and teamwork skills. During mentor meetings, the students report back on progress made and challenges encountered for the various components, then the team reevaluates the plan and timeline.

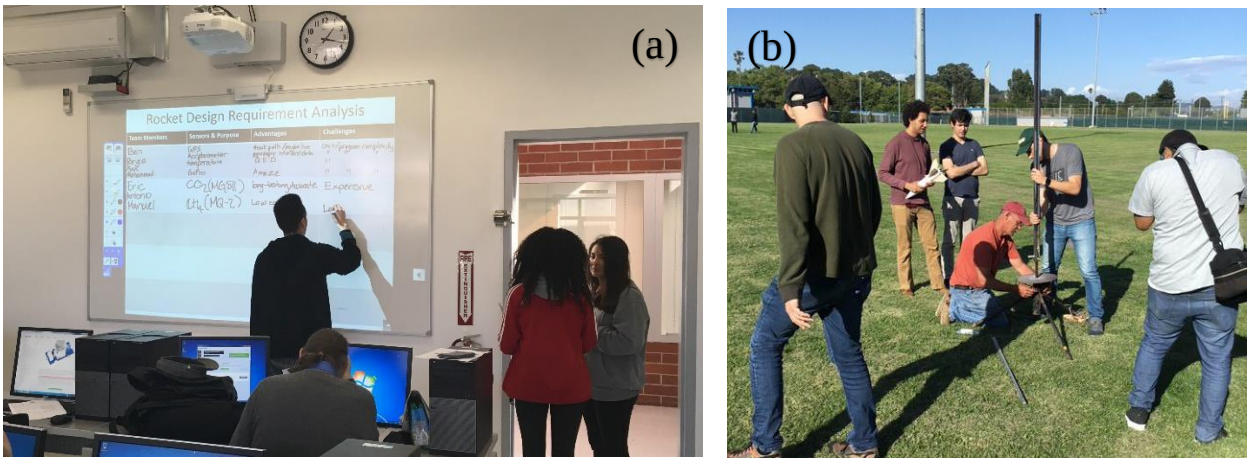

Figure 3: (a) Students discuss the design through the requirement analysis for a model rocket project. (b) Another group of students readying their rocket for launch.

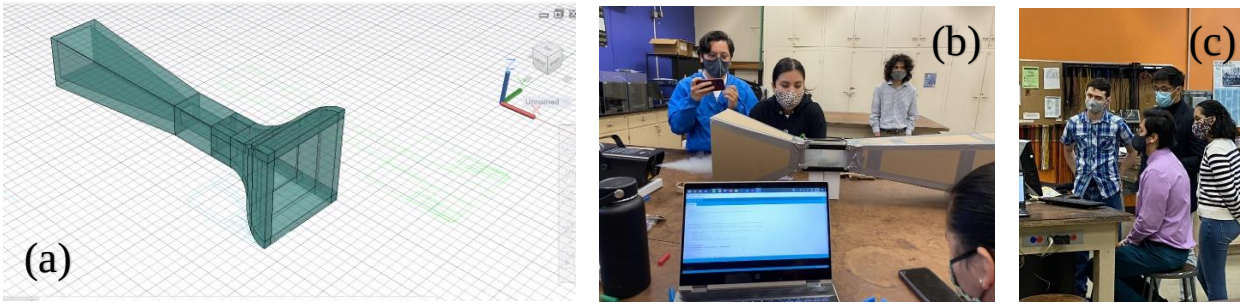

Figure 4: (a) An AutoCAD model for a wind tunnel project created by students. (b) Students in the early design process. (c) Students presenting their project during the remotely held 2021 CCC STEM Symposium.

Each project culminates in a research poster and/or a presentation at our annual STEM Research Symposium in which the broader campus community is invited to come learn from the student researchers. Through this event, students are able to practice their presentation and communication skills. They also have the opportunity to serve as an expert on a particular topic and as an ambassador for the STEM programs at this well-attended event.

Figure 5 – Student researchers presenting at the 2017 CCC STEM Symposium [6].

Survey Results

We have used the Course Experience Questionnaire (CEQ) as an instrument to measure students' perceptions of their PBL experience at Contra Costa College. The CEQ was originally developed at Lancaster University in the 1980s and is widely used to monitor the teaching quality in degree programs and courses [7]. For example, in an analysis of Australian higher education, CEQ was administered to measure the quantity and quality of student learning outcomes [8]. Shamsan and Syed used the CEQ developed by Ramden et. al to evaluate their PBL course at a college of medicine [9]. We modified the CEQ developed by Ramden to more closely examine our PBL learning environment and conducted the survey in April 2021. The questionnaire contains 25 items each with a five-point Likert scale: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree as shown in Table 1.

We sent the survey out to the current and previous students in our PBL and received 14 responses. Of the respondents 71.4% are male and 28.6% are female. Most of the responses are Hispanic/Latino (42.9%) as shown in the Figure 6.

We also calculated the weighted result for each of the items in Table 1 where 5 represents strongly agree and 1 represents strongly disagree. There are 16 items out of the 25 included items that are rated above 4 which means the respondents strongly agree with the statement. Overall, the students express satisfaction with the quality of the project, the mentor, and group dynamics. They also feel the project enhanced their problem solving (item 2), analytic (item 5), team-work (item 9) and communication (item 11) skills.

Table 1 – The CEQ Survey Results

Items	Don't Know	5	4	3	2	1
1. It was always easy to know the standard of work expected.	0	5	4	5	0	0
2. The project developed my problem-solving skills, so far.	0	10	4	0	0	0
3. The mentors of my project motivated me to do my best work	0	8	5	1	0	0
4. The workload was too heavy.	0	0	0	2	6	6
5. The project sharpened my analytic skills.	0	6	4	4	0	0
6. I usually had a clear idea of where I was going and what was expected of me in this project	0	4	6	2	2	0
7. I am satisfied with the facilities (equipment, internet, etc) in the lab	0	6	5	1	2	0
8. To do well in this project all I really need is the ability to find target information.	2	3	4	5	0	0
9. The project helped me develop my ability to work as a team member.	0	7	3	3	0	1
10. As a result of my project, I feel confident about tackling unfamiliar problems.	0	8	4	2	0	0
11. The project improved my expression skills.	0	8	4	2	0	0
12. The mentors seemed more interested in testing what I had memorized than what I had understood	1	1	0	4	4	4
13. It was hard to discovery what was expected of me in this project.	0	1	1	0	6	6
14. I was generally given enough time to understand the things I had to learn	0	6	6	2	0	0
15. The mentors made a real effort to understand difficulties I might be having with my work.	0	9	4	1	0	0
16. The mentors normally gave me helpful feedback on how I was going.	0	9	3	2	0	0
17. My mentors were extremely good at explaining things.	0	7	6	1	0	0
18. My mentors asked me many questions just about facts not concepts.	2	2	2	5	1	2
19. The mentors worked hard to make their subjects interesting.	1	5	6	1	0	1
20. There was a lot of pressure on me to do well in this project	0	1	1	1	6	5
21. My project helped me to develop the ability to plan my own work	0	8	4	2	0	0
22. The mentors made it clear right from the start what they expected from students	0	5	3	2	4	0
23. Overall, I was satisfied with the quality of the project	0	8	6	0	0	0
24. I was satisfied about: Mentors in this project	0	10	4	0	0	0
25. I was satisfied about: Group dynamics.	2	5	5	1	1	0

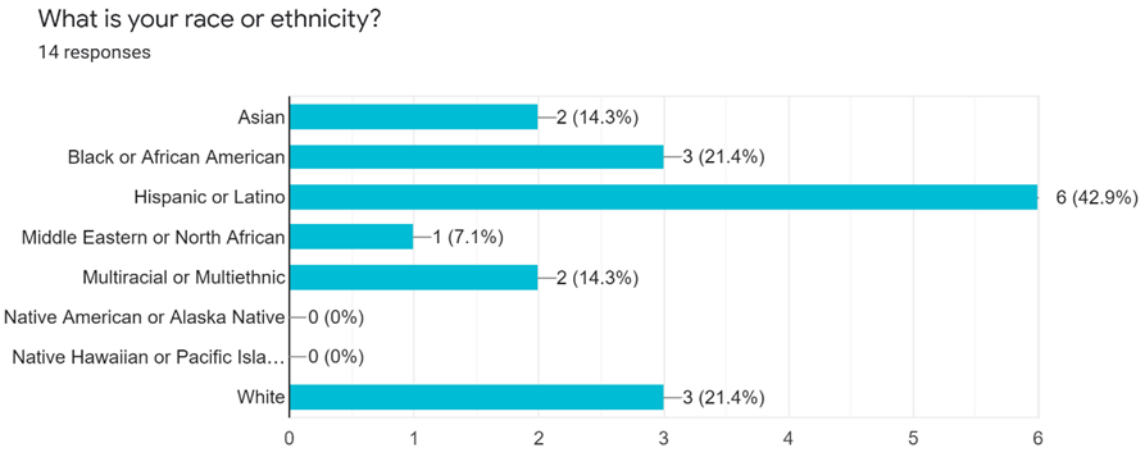

Figure 06 – Race/Ethnicity demographic information of survey respondents.

Conclusions

As one component of a larger mentoring program, we have found that project-based learning can increase student enthusiasm for their major disciplines, improve student confidence and sense of belonging, and provide motivation to persist in the STEM majors. Of the engineering students that have participated in research projects, the great majority have continued on in their STEM programs. Of twenty three engineering student research participants, ten have transferred into engineering majors at four-year universities (43%), two have transferred into other STEM majors (9%), eight continue to take transfer preparatory courses at CCC (35%), and the educational status of three students is unknown (13%). Anecdotally, several of the transferred students have indicated that they continued to seek out research opportunities after transferring.

Acknowledgements

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