A SYNERGISTIC APPROACH TO OUTREACH AND TEACHING: COMBINING SERVICE LEARNING AT THE COLLEGE LEVEL WITH A SUMMER HANDS-ON OUTREACH PROGRAM IN CHEMICAL AND BIOMOLECULAR ENGINEERING FOR HIGH SCHOOL GIRLS

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Abstract:

A synergetic approach to combine service learning at the university level with a high school outreach program is described. A holistic view is presented by discussing the importance of outreach and service learning, survey results, and outcomes. Overall, it was found that the unique program increased the self-efficacy (belief about one's abilities) of students ranging from high school to graduate level, and positively impacted the social responsibility attitudes of university student participants.

Keywords

Active Learning, Diversity, Self-efficacy, Outreach

INTRODUCTION

According to the 2023 National Center for Science and Engineering Statistics (NCSES) Report on Diversity and STEM, women earned about half of all bachelor's degrees, 46.2% of all master's degrees, and 41.0% of all doctoral degrees in the US in 2020.[1] However, they only earned 26% of the mathematics and computer science bachelor's degrees and 24% of the bachelor's degrees in engineering. Compared to the demographics of the general population, the number of women in science and engineering is disproportionate. Women's low entry to science and engineering is because of several social and environmental factors such as lack of encouragement, self-ability beliefs, career ambitions, guidance, discrimination, and bias toward their abilities.[2-4] Most people implicitly associate science and technology careers with boys and humanities and arts with girls.[5] Such stereotypes further discourage women and limit their progress in engineering and science fields.[5, 6] Additionally, the public may not understand what engineers do and place an oversized emphasis on math and science rather than engineering being a discipline that involves critical thinking and problem solving. This further contributes to the lower enrollment of women in engineering programs.[7] Thus, it is crucial to have programs that provide relevant information and hands-on activities on emerging engineering technologies and scientific methods at high schools and universities to encourage women to pursue careers in science and engineering. Such activities and information attempt to counter implicit thoughts that persist in society and provide women not only encouragement but confidence to pursue science, technology, engineering, and mathematics (STEM) careers.

One way to achieve such a goal is through hands-on summer programs where high school students get an opportunity to gain some research experience and interact with college student mentors.[8-11] The benefits of these type of research experiences in high school are that they provide the students with an opportunity to learn applications of science and engineering, foster creativity, and promote critical thinking. These programs also encourage students to pursue careers in science and engineering fields. Studies have shown that summer programs help students gain positive attitudes towards STEM,[12-14] increase their confidence in their understanding of STEM content and laboratory techniques[14, 15] and increase their intent to continue taking classes in STEM fields or to pursue a STEM career.[16, 17] In Latin America the W-STEM project is a great initiative to improve strategies and mechanisms to guide, encourage, and improve women's access to STEM programs.[18] Another example includes the Broadening Access to Science Education (BASE) summer camp on the Fairfield University campus in Fairfield CT, USA.[19] The program Future Girls of STEM at Purdue University is designed and implemented by women faculty members to increase girls' interest in STEM field and has inspired the programing featured in this paper.[20]

At Case Western Reserve University in the Department of Chemical and Biomolecular Engineering, the Widening Opportunities for Women in Science (WOWS) Program was created because of the expected positive impact on the local community. This is a 4-week program that provides a hands-on research experience for girls in Cleveland, OH, USA. The goal of the program is to enhance awareness about research as well as engineering careers and help participants make informed choices about their future. The program kicks off with a welcome presentation where information on chemical engineering is shared. Afterward, students are engaged in hands-on laboratory experiments under the guidance of graduate and undergraduate student mentors. The high school students perform engineering calculations, analyze data, and interpret results through interactive discussions with their mentors. Finally, at the end of the program, they share their results with their peers, mentors, and family in the form of poster presentations. The proposed learning activities perfectly fit into the framework of K-12 education developed by the National Research Council (NRC).[21] According to NRC, several practices are essential in learning science and engineering such as asking questions and defining problems; developing, and using models; planning, and carrying out investigations; analyzing and interpreting data; using mathematics;

constructing explanations and designing engineering solutions; engaging in arguments based on evidence; obtaining, evaluating, and communicating information.[21]

An integral part of the high school outreach program is to create projects that could be utilized during the summer. We strategically revised a portion of a protein engineering class to generate new projects for the WOWS program. The portion of the class that was modified was a hands-on module designed to teach students project management skills through the design and testing of peptides for several applications in science and engineering. In this portion of the class, graduate and undergraduate students work in teams to create an engineering project plan (EPP), which is an essential management tool in industry and business that enables employees of different backgrounds to work together to achieve a common goal.[22-24] A detailed description of the EPP module, its implementation in the class, and the outcomes are described in our previous work.[22] From the statistical analysis of the pre- and post-surveys, it was found that the students in the class gained confidence and their anxiety levels dropped when performing engineering design tasks. Herein, we aimed to continue teaching the beneficial project management skills to graduate and undergraduate students but modified the module to engage students taking the class in designing and testing peptides specifically for outreach purposes.

This modified activity where college students create peptides for outreach represents a form of service learning. In recent years significant attention has been given to the service-learning component of education, and initiatives have been taken to integrate it into the curriculum in the form of class projects, extra-curricular activities, or research projects.[25] Studies have also suggested several benefits of service learning, including a better understanding of the course material, improved problem-solving skills, enhanced civic engagement, development of leadership and mentoring skills, enhanced reciprocal relationship between educational institution and community, enhanced social responsibility, awareness regarding social justice, and improved community life.[26-28] It has been argued that the social responsibility attitudes of scientists and engineers can be increased by providing them knowledge about the direct impact of their work on society.[29, 30] It is critical for engineers to understand the social impact of engineering.[31] Data from a study conducted at Stanford University indicate a disconnect between ethical realities of engineering practice and what students learn in engineering school. The study also revealed that engineers regularly face ethical issues at their workplace.[32] Between 2012 and 2014, the Engineering Professional Responsibility Assessment was administered with the goal to measure the change in the attitudes of engineering students toward personal and professional social responsibility.[33] The responses collected for both undergraduate and graduate students from five institutions were assessed. The results showed that the social responsibility attitudes of around 57% of students did not change over time. The attitudes of around 23% became more negative, and 20% of students gained a positive attitude towards social responsibility.[34] The study also revealed that decline in social responsibility attitudes of the students with time was correlated with less participation in volunteer activities. Another study suggested that the sense of social agency drastically decreased for engineering students with time.[35]

Here, we describe the execution of our unique combination of biomolecular engineering service learning at the undergraduate- and graduate-levels via a protein engineering class module with high school outreach, as well as report survey results, outcomes, and benefits of the program to provide a holistic view of these combined efforts (Figure 1). In this integrated approach the service the undergraduate and graduate students are performing is designing outreach activities for the WOWS program as part of their protein engineering class requirements. In doing so, the undergraduate and graduate students in the protein engineering class learn transferable project management skills and utilize class content to design and test a functional peptide. The designed outreach activities help achieve the goals of the WOWS program, which are to introduce high school girls to the engineering profession and give them a hands-on experience with biomolecular engineering in the laboratory. We report the results of social responsibility surveys given to undergraduates and graduate students who took the protein engineering class and assess whether the modifications of the module for service learning had an impact on the engineering design self-efficacy of the students in the class.[22] We also report survey results assessing the science self-efficacy[36] of the high school girls who participated in the WOWS outreach program and who participated in student-designed activities.

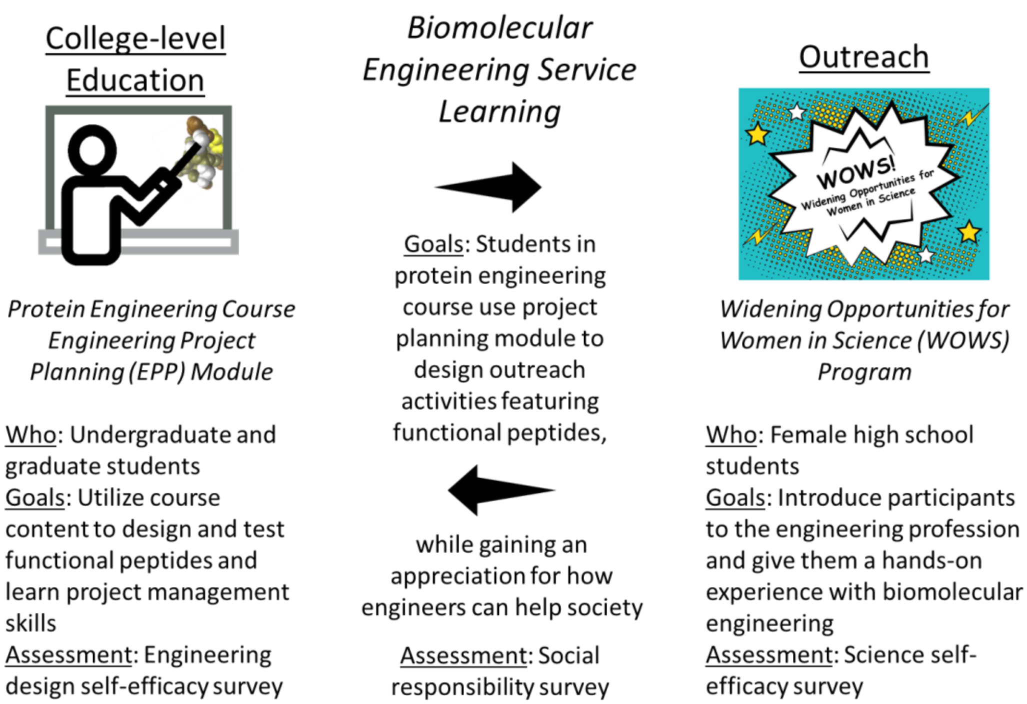


Figure 1: An overview of our synergistic approach to outreach and teaching where we modify a university protein engineering course module for service learning to develop outreach activities for high school students.

PROGRAM DESCRIPTIONS AND METHODS

WOWS (Widening Opportunities for Women in Science) Program

The WOWS Program is a hands-on outreach program dedicated to providing high school girls information about engineering and meaningful laboratory experiences. Local high school students in Cleveland are invited to participate in planned research activities for two hours on Tuesdays and Thursdays for a duration of 4-weeks during the summer. The activities in different phases of the program are shown in Figure 2.

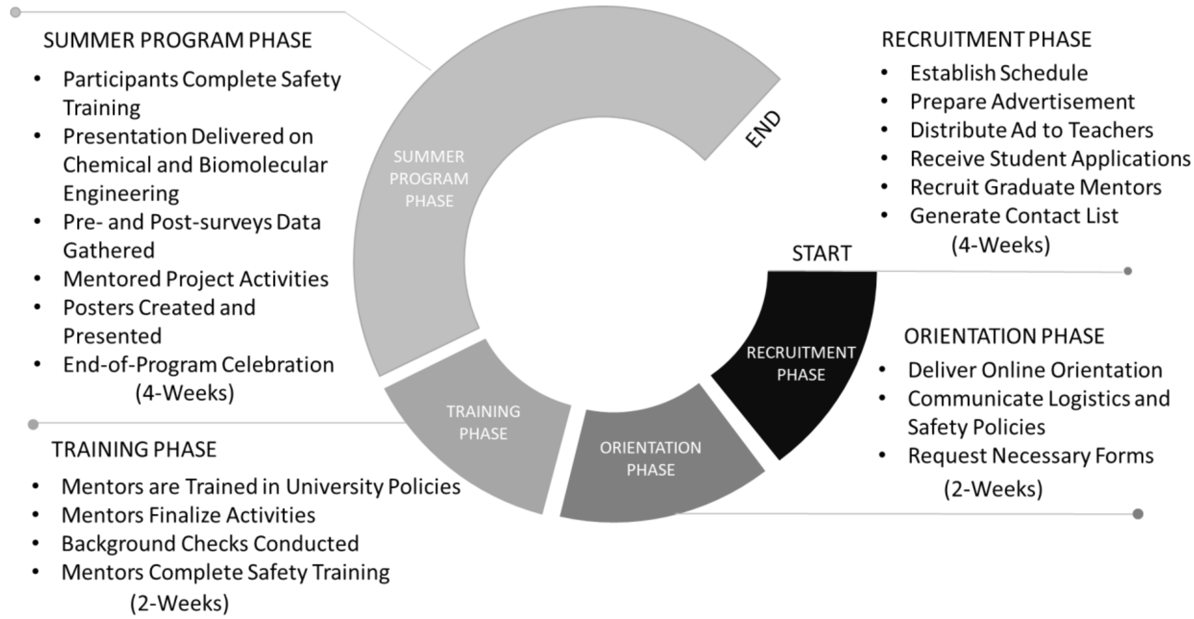


Figure 2. The activities planned during different phases of WOWS Program. The timeline of each phase is also provided.

In the Recruitment Phase the WOWS coordinator sets up the schedule of events as shown in Figure 2 with the goal to select students interested in the program. In the Orientation Phase an online overview of the WOWS Program is organized to cover details about the program schedule, logistics, safety training information, and necessary forms to fill out per university policy. In the Training Phase mentors undergo background checks, complete all necessary safety training, and are given an overview of the university policies regarding working with minors. Mentors consist mainly of graduate students and some undergraduate students and are not necessarily the same students who took the class. The Summer Program begins with the high school students' arrival on campus. This phase consists of reviewing the program information, logistics, safety training, pre- and post-surveys[36] and two-hour meetings (Tuesday and Thursday) every week for four weeks, often in the laboratory to do activities. Information about chemical and biomolecular engineering is shared based on a summer outreach activity at Purdue University.[11] The students work in the research lab under the direct guidance of mentors, of which are roughly seventy percent are women engineers. It has been shown that having the same gender mentor can be more effective in generating confidence for the students.[37] The role of the mentor is to not only guide them with their projects but also ensure that they perform the experiments safely. Under their direct supervision, the students learn advanced research techniques and operate equipment in the lab to complete a project. Mentors may also act as role models and speak with participants about questions they might have regarding various career options. In the last week of Summer Program, students showcase their work in the form of posters and share their experiences.

Modified Module in a Protein Engineering Course for Service Learning

The goal of the engineering project plan (EPP) module is to design peptides for specific applications. Students in the protein engineering class work in groups to combine protein engineering knowledge with project management skills to craft an EPP and execute it.[22] The module activities were easily adapted for service learning (Figure 3) where the new goal was to design and test peptides for the WOWS program. Similar to our previous study of the EPP module, at the start of the course, an engineering design self-efficacy survey was given to the students.[38] The same survey was given again at the end of the course to determine if students had improved their self-efficacy in engineering design tasks because of the activities in the EPP module. The module started with a lecture on the elements of an EPP and how to craft one. In addition, a lecture about underrepresentation in STEM and the benefits of the WOWS program was delivered at this time. The class was divided into groups with 3-5 protein engineering students per group. In the first three weeks the students in the class met and planned their projects and turned in the minutes of their meetings. In week 4 the students in the course gave a kick-off presentation, and the first draft of the EPP package was due for submission. After the kick-off meeting, the protein engineering students ordered their peptides and required chemicals. In weeks 5-11 the students in the course continued to conduct the meetings, ran tests, and performed analysis on the functionality of their designed peptides. Bi-weekly meeting minutes were due for submission. The final EPP report was due in week 12, and the final presentations were delivered. Prior to the final presentations, a brief reminder of the benefits of the WOWS program was given during the lecture.

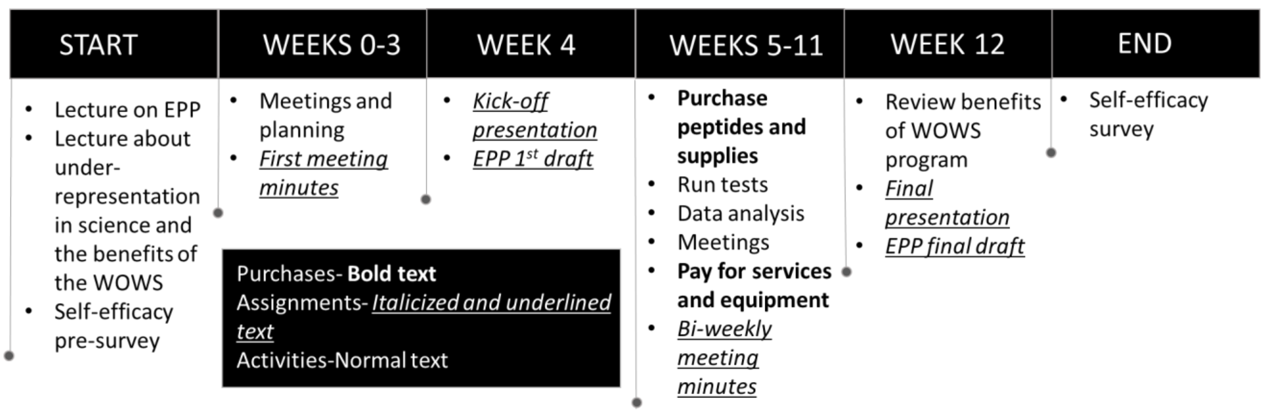


Figure 3. Timeline of activities, assignments, and purchases for an engineering project planning (EPP) module modified for service learning in a protein engineering course.

As an example, the objective of one classroom project completed by a combined undergraduate and graduate student group was to design short (under 50 amino acids) elastin-like peptides (ELPs) that exhibit transition behavior close to body temperature, as it has significant implications in targeted drug delivery and would be a relatable topic for outreach. The undergraduate and graduate students then designed short peptides based on literature, ordered them from a peptide synthesis company, and studied their transition temperature with the help of UV-Vis to prove they worked as expected. As part of the project, they also developed a week-by-week plan for the outreach activity with these peptides (Table 1). An added benefit to the program is that leftover peptides from the class can be used in the outreach activity for the summer.

TABLE 1

An example activity for the WOWS program generated by the service-learning module in the protein engineering class with some editing by the program coordinator.

	Day 1	Day 2	Learning Goal

Week 1	Lab safety, basic lab techniques (pipetting), and introduction to ELP	Training on how to make solutions of peptide and salt with specific concentrations and more basic laboratory techniques (pH)	Gain safety awareness and proper equipment use
Week 2	Training on plate reader, gather data for UV-Vis data at variable temperatures for different ELPs	Gather UV-Vis data at variable salt concentrations	Learn how temperature, salt and ELP hydrophobicity impact transition temperature
Week 3	Training on encapsulation, gather data for encapsulation of fluorescent molecule using a positive control ELP	Gather data for encapsulation of fluorescent molecule using a negative control ELP	Show utility of ELP in drug delivery and reinforce concept of positive and negative controls
Week 4	Perform data analysis, make charts and graphs, and go over poster outline	Finish poster and practice poster presentation	Conduct data analysis to determine the transition temperatures and trends and present findings

During their EPP project, the undergraduate and graduate students designed and purchased two different ELPs from GenScript with different hydrophobicity. They conducted experiments using varying salt concentrations, based on related literature, to find the transition temperature of these ELPs. To find the transition temperature, the students used UV-Vis spectroscopy at room temperature and then ramped up the temperature from 25 to 45 °C in 5 °C increments within the temperature limitation range of the instrument. The peptides were cooled in a similar manner to confirm reversibility. Then they analyzed the UV-Vis data for sharp changes in absorbance measured at 400 nm as the temperature was varied. The group found neither peptide showed any changes in absorbance versus temperature without salt or with low salt concentration. At higher salt concentrations, around 2 M NaCl, one ELP peptide with higher hydrophobicity showed a transition at 35°C, which is around body temperature (Figure 4).

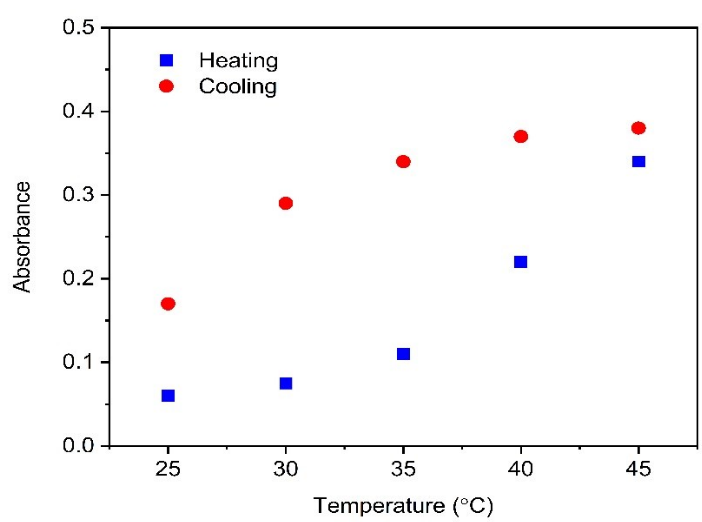


Figure 4. The change in absorbance with temperature during heating and cooling of an ELP peptide designed for outreach purposes.

Methods

Four surveys were conducted to assess our educational programs. As part of the modified EPP module in the protein engineering course, a survey on the self-efficacy of the students in engineering design was administered, as was done previously,[22, 38] to ensure that the changes made to the module for service learning did not have a negative impact on the benefits to graduate and undergraduate students' engineering design self-efficacy that we observed previously. Another survey was conducted in the protein engineering class to assess the social responsibility attitudes of the undergraduate and graduate students before and after they participated in the modified EPP module for service learning.[39] The questions related to personal social awareness, professional development, and professional connectedness and were asked using a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). During the summer WOWS program, relatively simple surveys were used to assess if the program helped participating high school students learn about chemical engineering and assess the impact of the program on their science self-efficacy.[11, 36]

SURVEY RESULTS AND DISCUSSION

WOWS Summer Program Survey Results

One goal of the WOWS Program is to give high school girls information that can help them make decisions about their career path and promote gender equality and diversity in engineering profession. A 20-min presentation is given to the high school students about chemical engineering. The objective was to assist the high school students in learning more about the engineering discipline and career opportunities in engineering profession. A survey is distributed before and after the presentation to assess the impact of the presentation. Although the WOWS program was run in the summer in years prior, the data presented in Figure 5 is from one year where the module was modified for service learning. A two-tailed t-test showed a significant increase in the students' responses to the statement "I understand what chemical engineers do." Thus, the activity was successful in providing high school girls with information that could help shape their career paths. Around twenty percent of the students did not expect to take engineering-related courses in the future, likely because some of the high school students participating in the program were from an AP Biology class and were anecdotally pursuing medical careers but interested in research and biomolecular engineering according to their essays. Both the presentation and survey are based on a previous outreach activity developed at Purdue University, and the survey results are comparable with those activities.[11]

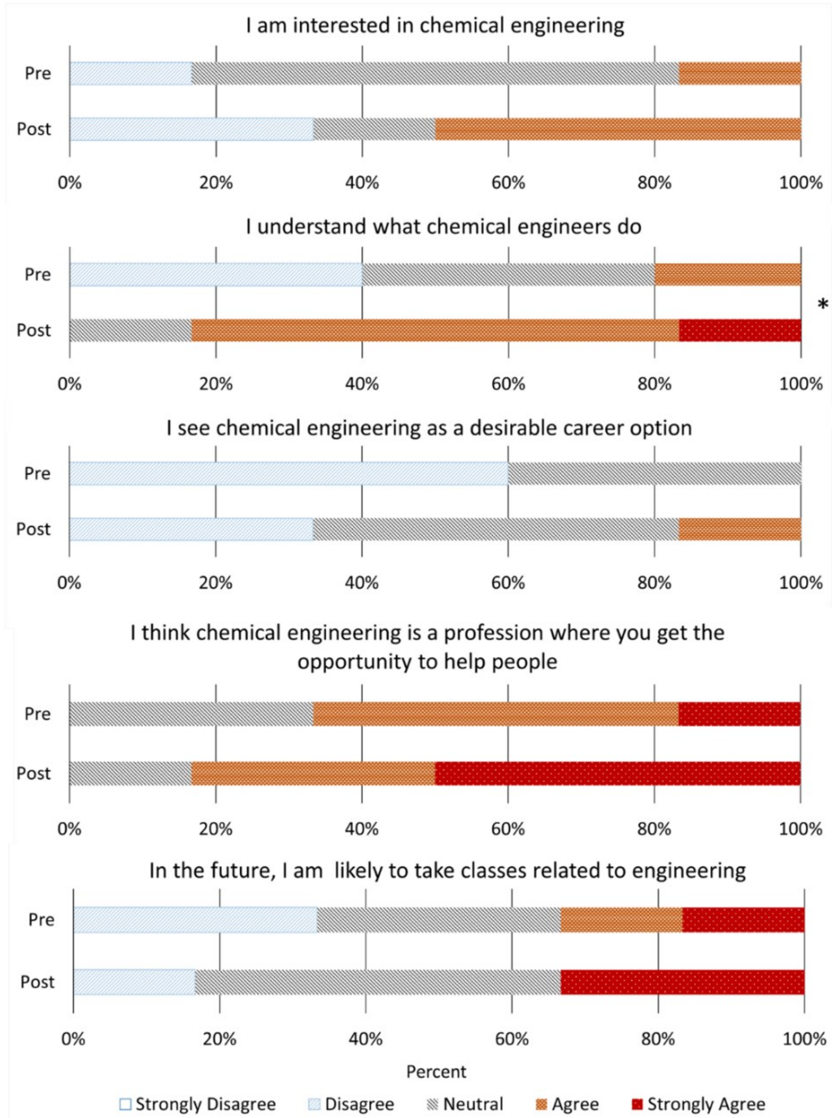


Figure 5. Participating WOWS high school students' perceptions of chemical engineering. A two-tailed t-test assuming equal variance was performed on survey data taken before and after a presentation on chemical engineering (* means p-value ≤ 0.05). Data were tabulated on a 5-point Likert scale (e.g., strongly disagree = 1 and strongly agree = 5). These surveys were generated with a group of n = 6.

Another survey was chosen to give an indication of high school students' science self-efficacy[36] at the beginning and the end of the 4-week WOWS program. The survey was split into two parts with statements specific to *learning* science and statements specific to *doing* science. We note that this validated survey instrument was developed in informal science learning environments with adult participants. The analysis of the survey is reported in Figure 6. For statistical analysis, per the survey directions, results for reverse coded statements ("It takes me a long time to understand new science topics," and "It takes me a long time to understand how to do how to do scientific activities") were translated to the corresponding positive score (e.g., a 2 was converted to a 4). Note that Figure 6 shows the true responses to these reverse coded statements. Then, results were compared in aggregate over all students in a two-tailed t-test assuming equal variance and there was a significant increase in the students' self-efficacy for learning and doing science (p-value < 0.05).

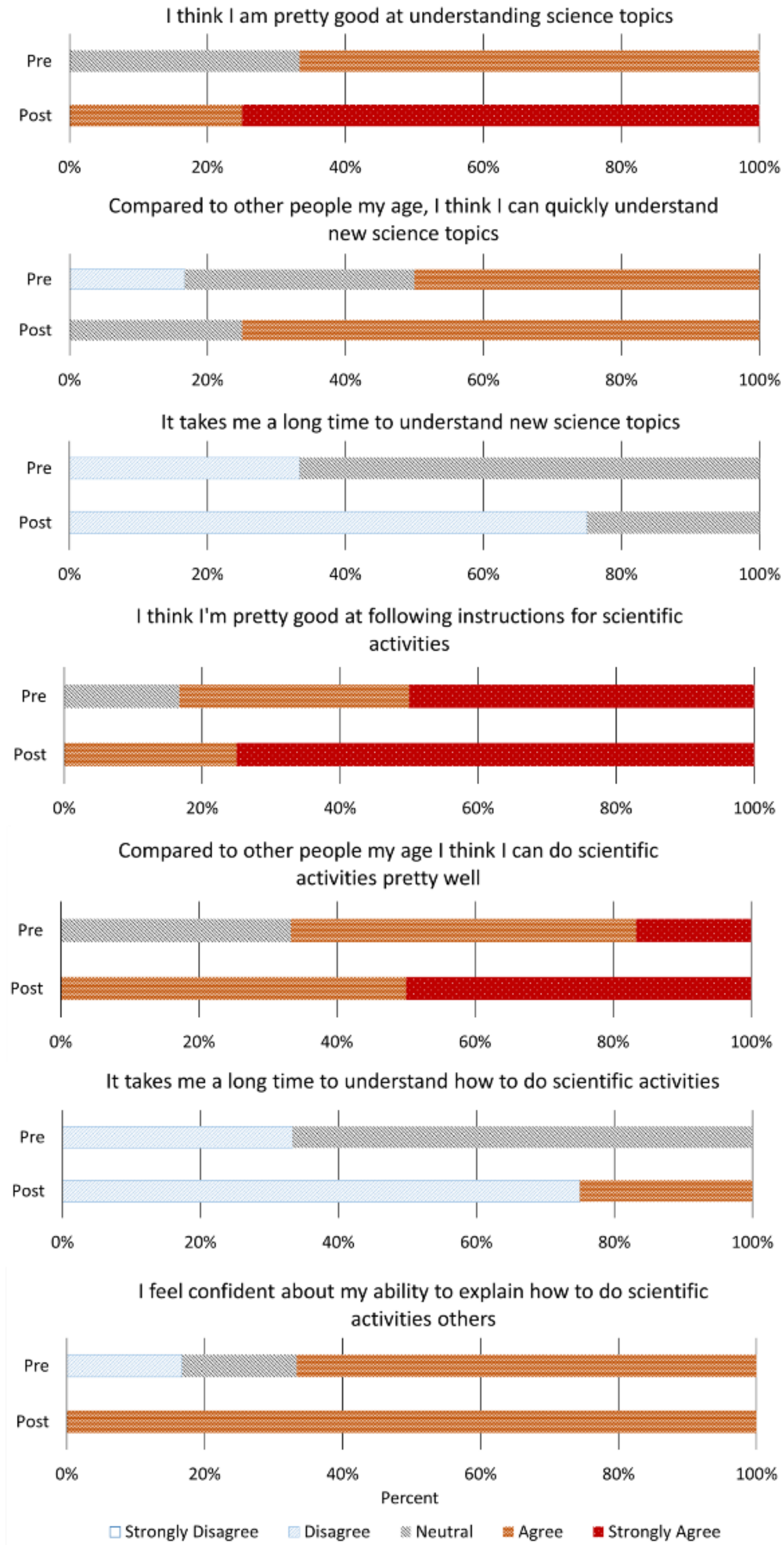


Figure 6. High school student science self-efficacy comparison before and after the WOWS Program. The overall scores were compared between the pre- and post-surveys per the survey instructions, and it was determined via a two-tailed t-test assuming equal variance that the WOWS Program had an overall positive impact on the students' self-efficacy for learning and doing science (p-value < 0.05). We note that one survey was not returned in the post-survey, and one student responded with all the same number so that survey was also removed for this analysis, per the survey instructions. Making sample size for pre-survey and post-survey $n = 6$ and $n = 4$, respectively. Data were tabulated on a 5-point Likert scale (e.g., strongly disagree = 1 and strongly agree = 5).

Protein Engineering Course Surveys

Figure 7 reports the self-efficacy of the undergraduate and graduate students in engineering design tasks before and after executing the modified EPP module in the protein engineering class. The levels of confidence, motivation, expectancy of success, and anxiety are shown. Consistent with our previous study,[22] the protein engineering students experienced an improvement in their confidence and motivation in performing general engineering design tasks. The expectancy of success had increased, and the students felt less anxious after the EPP module. Relatedly, a recent study has been conducted to learn how makerspaces are providing opportunities for the engineering students to improve their efficacy.[40] The data were collected from three universities and analyzed to assess the correlation between makerspace participation and engineering design self-efficacy. At two universities, higher levels of confidence, motivation, and expectation of success in conducting engineering design were observed for those who used makerspace in comparison to those who were never involved in the makerspace activities. Overall, the results show a positive impact of hands-on activities on engineering students' learning and their self-efficacy. Another study was done to find the difference in the self-efficacy between traditional and practice-based learning, and the results show that practicum improves the design self-efficacy of students.[41] These studies and ours support project-based learning to improve self-efficacy among the engineering students.

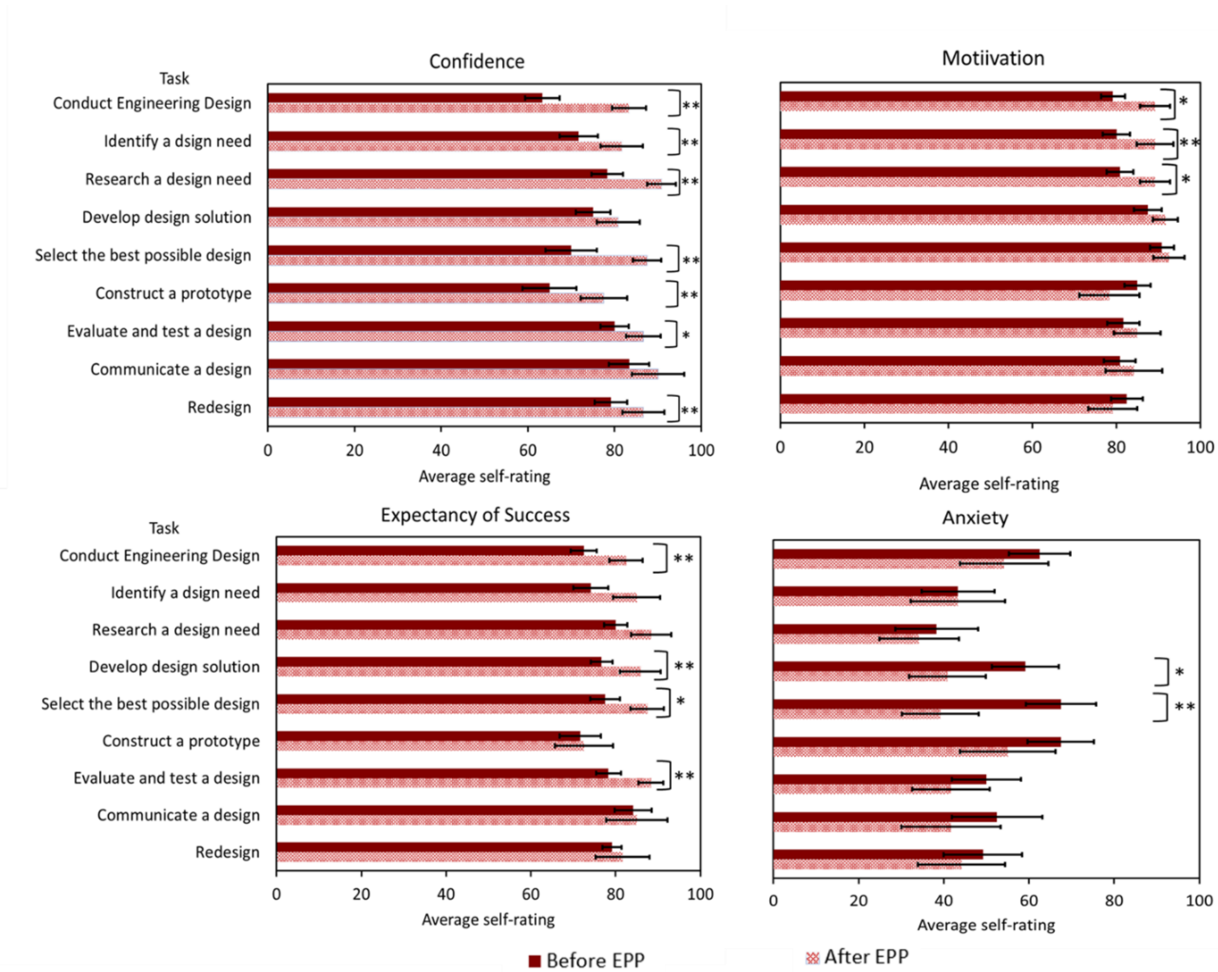
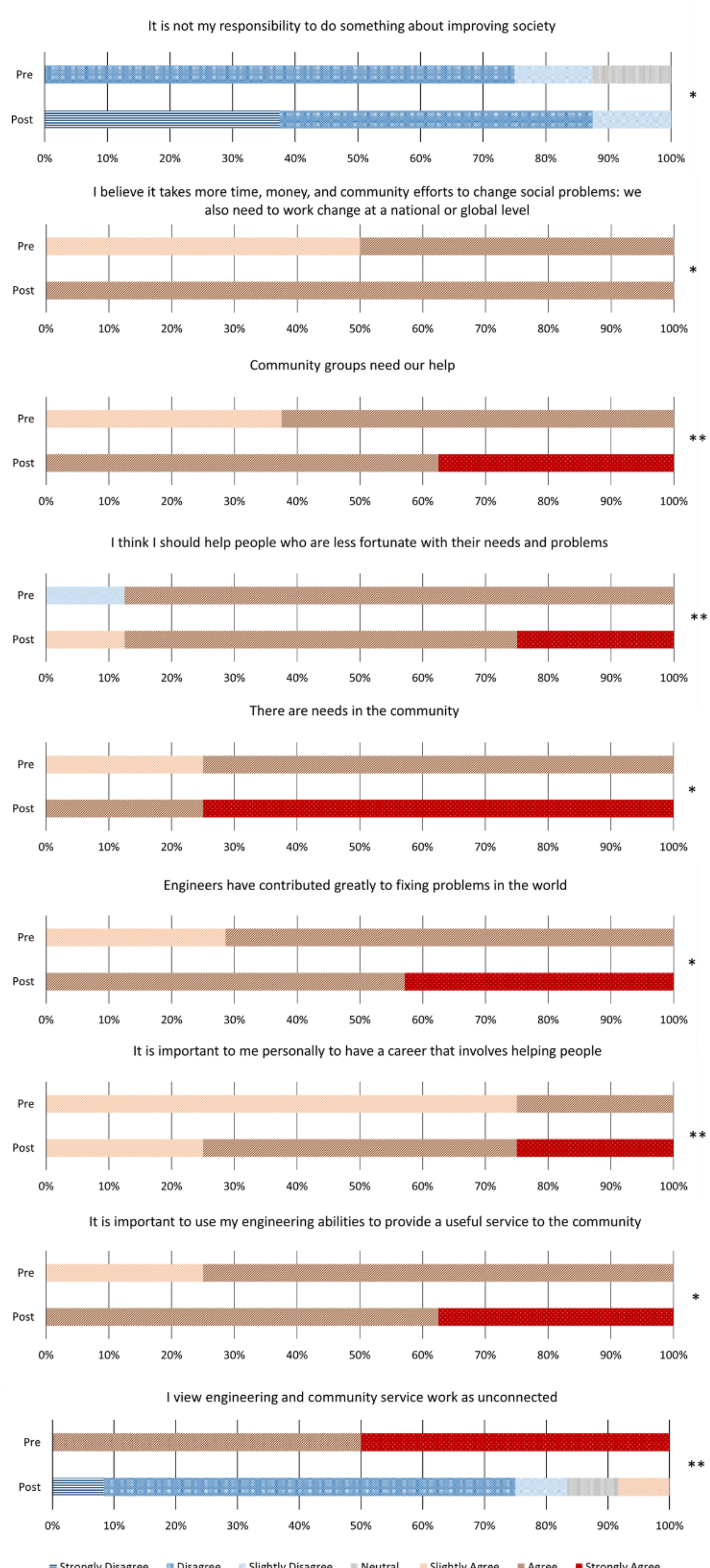


Figure 7. Average ratings of self-efficacy regarding confidence, motivation, expectancy of success, and anxiety in engineering design task before EPP and after EPP among the undergraduate and graduate students participated in the modified EPP module in the protein engineering class. A paired, two-tailed, t-test was performed for each engineering design task to reveal statistical difference between the average self-rating before and after the EPP (** means p-value ≤ 0.05 and * means p-value ≤ 0.1) These surveys were generated with a group of n=12.

We also used a validated survey to assess the impact of the service learning aspect of the module on college- and graduate-level students' social responsibility attitudes.[39] The survey was administered to quantify the social responsibility attitudes of undergraduate and graduate students before the module and at the end of the module. The survey consisted of 47 statements to which the students responded on a 7-point Likert scale. The data were analyzed via a paired t-test, and several statements had significant differences in responses before and after the module, shown in Figure 8. We note that in this analysis, students who had marked the highest responsibility scores in the pre-survey statements were removed, since their scores could not go any higher. It was found that undergraduate and graduate students who came into the class with lower social responsibility attitudes about the community and helping people had higher social responsibility attitudes after the class. Importantly, the course module helped students view engineering and community service as connected and shifted their attitudes toward thinking it is important to use engineering abilities to provide a useful service to the community. In addition, it made students more aware of community needs. Other programs like ENACT (engage, navigate, anticipate, conduct, and take action) have been shown to increase social responsibility.[44] The study of

ENACT showed that allowing students to explore a social scientific issue, develop the solution, and share with the community is a great way to increase social responsibility. It has also been found that engineering curricula can fail to cover the ethical component of engineering knowledge which causes students to not fully comprehend the social and ethical aspects of their profession.[45] In the revised ABET accreditation program, more emphasis has been given to the social and ethical aspects of engineering. It therefore would be beneficial to introduce opportunities for students to learn and practice social and professional ethics, such as in our modified service learning EPP module, for their holistic intellectual and professional growth.[46]



It is not my responsibility to do something about improving society
Pre
Post
*
I believe it takes more time, money, and community efforts to change social problems: we also need to work change at a national or global level
Pre
Post
*
Community groups need our help
Pre
Post
**
I think I should help people who are less fortunate with their needs and problems
Pre
Post
**
There are needs in the community
Pre
Post
*
Engineers have contributed greatly to fixing problems in the world
Pre
Post
*
It is important to me personally to have a career that involves helping people
Pre
Post
**
It is important to use my engineering abilities to provide a useful service to the community
Pre
Post
*
I view engineering and community service work as unconnected
Pre
Post
**
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Strongly Disagree
Disagree
Slightly Disagree
Neutral
Slightly Agree
Agree
Strongly Agree

Figure 8. The perception of undergraduate and graduate students about social responsibilities before and after the protein engineering course EPP module. A paired t-test on the difference in response was performed for each question at the start and end of the course (** means p-value ≤ 0.05 and * means p-value ≤ 0.1). Data were tabulated on a 7-point Likert scale (e.g., strongly disagree = 1 and strongly agree = 7). These surveys were generated with a group of n = 12. The students whose survey results were removed due to having the highest responsibility scores varied from question to question. After removal of highest responsibility scores, n ranged from 4 to 12.

CONCLUSIONS

A module that allows undergraduate and graduate students in a protein engineering class to practice biomolecular engineering design and project management skills was modified for service learning. The projects generated in the protein engineering class were later used to provide high school girls with valuable hands-on laboratory experience in the WOWS outreach program. During the outreach program, high school students also had an opportunity to learn more about chemical engineering.

The survey analysis during the WOWS outreach program shows a significant increase in high school students' self-reported knowledge about chemical engineering and thus, the program was successful in helping them make informed career decisions. The survey results also showed that the science self-efficacy of the high school students improved upon the completion of the program. They felt more confident in understanding science topics and performing in the science activities. In addition, the integrated service-learning module in the protein engineering class helped undergraduate and graduate students view engineering and community service as linked and were more aware of community needs. Undergraduate and graduate students also felt it was more important to use engineering to provide a useful service to the community after the class with the service-learning component. Overall, the combination of high-school community outreach with service learning at the undergraduate and graduate level has a synergistic positive impact on self-efficacy and social responsibility.

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