

10-5-2020

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Recommended Citation

Pramounmat, N., & Renner, J. Improving Student Preparedness for Entering the Workforce: A Hands-On Experience in Project Management for a Graduate-Level Protein Engineering Class. *Chemical Engineering Education*, 2020, 54(4), 222-229.

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IMPROVING STUDENT PREPAREDNESS FOR ENTERING THE WORKFORCE: A HANDS-ON EXPERIENCE IN PROJECT MANAGEMENT FOR A GRADUATE-LEVEL PROTEIN ENGINEERING CLASS

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INTRODUCTION

Reports in the journal *Science*, as well as the 2017 National Science Foundation (NSF) Survey of Doctorate Recipients, show that over the past 20 years, the percent of US-trained PhD graduates in science and engineering employed in the private sectors has increased by 11 percentage points (to 42%) and is now close to the employment levels in educational institutions (near 43%).^[1,2] Additionally, a study published in the *Monthly Labor Review* of the US Bureau of Labor Statistics concludes that there is a surplus of available STEM workers vying for tenure-track positions in academia.^[3] In light of the shift in employment where more PhD graduates are entering the private sector, graduate programs are considering curriculum adjustments to provide students additional training.

Many universities have already begun to creatively adjust their programs to provide graduate students training in the private sector. For example, when the decrease in academic tenure-track positions for doctoral students in the biomedical field was realized, the Graduate Student Internships for Career Exploration (GSICE) program was implemented for doctoral students in life science at the University of California, San Francisco and the University of California, Davis. The GSICE program offers students internship opportunities during their PhD training years. One survey result showed that despite the challenge the students faced in asking their research advisors for time away to do internships, the number of students who were very confident in their career choice increased from 20% of the students being very confident before the program to nearly 60% being very confident after the program.^[4] Another example of a graduate program curriculum adjustment is an industry PhD (iPhD) program launched by the University of New South Wales Sydney.^[5] By collaboration with the Com-

monwealth Scientific and Industrial Research Organization (CSIR), the iPhD program allows PhD students to work on industry-focused research to bridge the gap between academia and industry with applied research. Within the four-year candidature, the students also have a six-month internship opportunity. The internship training is intended as an incentive for local businesses to employ STEM researchers.^[5]

While the knowledge exchange between industry and academia through experience outside of the institutions provides a great opportunity to prepare doctoral students for the private sector, the time commitment outside the institutes still poses some challenges.^[4] Challenges to outside internship experi-

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Dr. Julie Renner started as an assistant professor at Case Western Reserve University in 2016 and was honored with the Climo Assistant Professorship in 2018. Her group works at the interface of polypeptide engineering and electrochemistry. Prior to becoming a professor, she spent four years conducting industrial research initially sponsored by an ASEE/NSF Small Business Postdoctoral Diversity Fellowship. She completed her PhD as an NSF Graduate Research Fellow at the Purdue School of Chemical Engineering. Author's ORCID: 0000-0002-6140-4346

ences include delay in graduation and securing funding during the internship. Ideally, similar professional skill development would also be available in the core education programs. Project management is an important transferable skill that graduate students can practice in school before entering the private sector. Project management is critical in industry and business where people from different backgrounds work together on the same project, and well-defined goals and awareness of risks and constraints are the keys to a successful project. The purpose of project management is to plan, organize, and integrate resources and tasks to achieve the organization's goals.^[6] Therefore, to provide doctoral students some exposure to tools used in the private sector during their training within an academic institution, a research experience featuring project management was implemented in a graduate elective course. Further, adding an active-learning aspect to an engineering class has been shown to improve students' self-efficacy in engineering^[7,8] as well as their grades.^[9]

Herein, we implemented an engineering project plan (EPP) exercise (or module) that introduces project management as part of a hands-on design and characterization project that PhD students conduct as part of a class. Specifically, an EPP is a project management tool that consists of a concise, formal, approved document used to guide both project execution and project control. The primary uses of the EPP are to document planning assumptions and decisions, facilitate communication among stakeholders, and document approved scope, cost, and schedule baselines. Generally, EPP-driven projects are team-based, and teammates are selected to have a diverse background. The class selected to implement the EPP exercise was a graduate-level protein engineering class, which typically has students from different technical majors. The EPP tools used in this study were provided in the forms of template documents for students to fill in. Educators who wish to utilize the EPP tools demonstrated in this study or see an example of the class assignments and schedule, can find the resources at case.edu/engineering/labs/renner or by contacting Dr. Julie Renner at jxr484@case.edu. This class was also a good candidate because until recently, polypeptides were prohibitively expensive to manufacture and test in the amount of time for a typical semester-long class. This limitation has resulted in students performing conceptual protein designs with little to no hands-on experience, therefore missing some of the benefits of active learning.^[9] With advances in peptide synthesis technology, a substantial amount of custom peptide (generally less than 50 amino acids long) can now be delivered within two weeks for a reasonable cost.

The pedagogical approach in this study is a blend of lecture and project-based experiences. With this approach, we enabled a learner-centered education in a graduate-level course. It has been shown previously that the combination of the instructor-centered and learner-centered approaches results in a more positive learning experience for the students com-

pared to the sum of the individual approaches.^[10] In our class format, the students obtained knowledge from the technical lecture part of the course and actively applied the knowledge to the hands-on projects where the EPP is utilized as a tool. The EPP is expected to help graduate students understand how the project management aspects may be used in the private sector and improve their confidence in their ability to execute design projects. As such, the activities and components of EPP are expected to facilitate the development of specific skills shown in Figure 1. The skills listed in Figure 1 are common project management skills found in project management textbooks.^[6,11,12] Note that the skills listed in Figure 1 are not exclusive and does not cover every skill found in the project management literature.

To evaluate the EPP implementation in the graduate protein engineering class, we utilized a validated survey instrument^[13] to reveal the self-efficacy (an expectation that one can accomplish certain tasks necessary to produce a desired outcome) of the students in conducting, planning, and communicating engineering design before and after the EPP module. High self-efficacy means that the person believes they possess capabilities to perform a certain task successfully. When the person has low self-efficacy, they believe that they do not possess the necessary capabilities to perform well in the specific task. Literature generally suggests that self-efficacy is positively related to academic achievement, persistence, and engagement/involvement in work.^[14,15] Thus, this validated self-efficacy instrument is a suitable tool to begin to measure success in implementing the EPP exercise in the course. Overall, the EPP exercise intends to provide a new way to give PhD engineering students additional transferable skills during their academic years without disrupting their funded research projects and risking the extension of time to graduate. In this study, we specifically wish to discover if students who complete a hands-on project developing an EPP gain confidence and lower their anxiety in performing engineering design.

IMPLEMENTATION

Course and Module Description

The overall goal of the peptide design project was for students to utilize an EPP to design a peptide with a specific function and propose and conduct tests for that function. At the end of the project, students were asked to make logical conclusions about the data gathered and suggestions for improvement, culminating in a final report and presentation at the end of the class. The goal was met by all student groups. By combining hands-on polypeptide engineering with project management, this module provided students with a unique opportunity to gain technical research skills and professional skills.

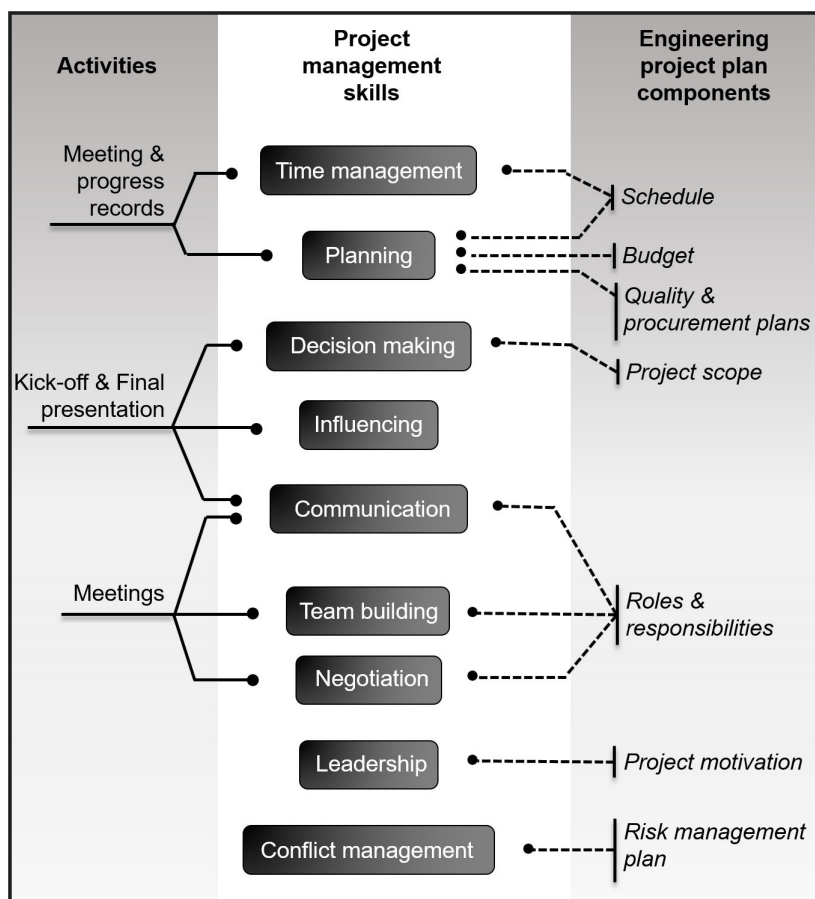


Figure 1. The activities (left column) and EPP components (right column) provided for the graduate students in this protein engineering class are expected to help students develop the listed project management skills (middle column). Each activity and each component are expected to facilitate the development of project management skill(s) they are connected to with the solid lines (for activities) and the dashed lines (for EPP components).

The course where this module was implemented was a graduate-level protein engineering course offered yearly. Graduate students from all levels participated across a variety of fields (chemical engineering, biomedical engineering, macromolecular engineering, biochemistry, and physiology). Undergraduates at the junior and senior levels were allowed to take the course with permission from the instructor.

Throughout the semester, lectures were provided on foundational protein/polypeptide engineering approaches, their applications, and new research in the field. The EPP-based module started around the fourth week of the semester, such that 1) sufficient background information could be provided in lectures to begin peptide design, and 2) there was enough time (the remaining 12 weeks of the semester) for design, peptide ordering, and shipment as well as experimentation and analysis to be completed before the end of the semester. The module accounted for 25% of the grade, other assign-

ments accounted for 65%, and attendance/class participation accounted for the final 10% of the grade. Due to the workload from the assignments and module, there was no exam for the class.

Specifically, students were given a lecture on the elements of an EPP and a problem statement explaining they were at a company where their job was to find potentially profitable peptides. In this protein engineering class there were 2-3 students per group and a total of 3 groups per class. Students were provided with templates for reports and presentations and required to draft an EPP as part of the assignment. Elements of the EPP included motivation (potential profitability of the proposed peptide), project scope, product/peptide design, a test plan/matrix, a schedule for tasks, a budget plan, team roles and responsibilities, a risk management plan, a communication plan, a procurement plan, and a quality plan. After the first four weeks of discussing initial ideas with each other and the instructor, students were required to give a ten-minute presentation on their first drafts of the EPP at a “kick-off meeting” and receive feedback from the class.

Team meetings occurred throughout the module. Student groups were asked to meet outside the class (without the instructor) to make plans and discuss the project at least once every two weeks throughout the duration of the EPP module. They had freedom to choose the time and frequency that were suitable to their schedules. For every meeting, they were asked to record meeting minutes using a provided template of what they discussed, as well as keep track of the project progress. They provided meeting minutes as part of the grade for the EPP module. The meeting-minute reports were important to track decision making and to ensure team members were well aware of the roles and responsibilities assigned at the meetings. Further, the meeting minutes were helpful for the instructor to observe the team dynamics and the pace of the progress. The instructor could then give suggestions on both technical and project management aspects of the project. This feedback could be provided after the updates were turned in upon grading and/or at in-person meetings with the instructor during class which took place formally twice per semester, once before the peptide design was due, and once before the final report was due.

After the kick-off presentation where students received feedback from the class and instructor, their peptides were ordered from a company (GenScript). The students were

advised to choose the purity of their peptides based on their needs. The higher the purity, the longer it takes for the manufacturing process, and the more expensive they might be. During the experimental part of the project, the students provided their test plan to a lab technician who prepared all samples in a laboratory. The students then took samples to be analyzed via user facilities on campus. They were advised to choose appropriate equipment and characterization techniques as they saw fit to remain within the budget and achieve the goals set forth in the EPP. The instructor provided a list of the variety of Case Western Reserve University resources including the Swagelok Center, Molecular Biotechnology Core, Molecular Biophysics Core, and Center for Applied Raman Spectroscopy. The common equipment that students used for their peptide characterizations and functionality tests included circular dichroism, dynamic light scattering, and isothermal titration calorimetry. Students were asked to provide another 12 to 15-minute presentation on the execution of their EPP goals, as well as final results, conclusions, and suggestions. In addition, a final report on the achieved goals, results, conclusions, and recommendations was submitted at the end of the semester. The timeline of assignments is outlined in Figure 2. A copy of the assignment, EPP lecture, assignment templates, and a description of the overall class assignments and schedule are available at case.edu/engineering/labs/renner or by contacting Dr. Julie Renner at jxr484@case.edu

Module Evaluation

A validated survey was used to determine if students had higher self-efficacy in applied engineering after completing the EPP module.^[13] The surveys were given before and after

the project. The validated survey is designed to evaluate self-efficacy toward nine engineering design tasks. One task pertains to a general task called “conducting engineering design” and the other eight tasks pertain to specific tasks associated with engineering design that include “identifying a design need,” “researching a design need,” “developing a design solution,” “selecting the best possible design,” “constructing a prototype,” “evaluating and testing the design,” “communicating the design,” and “redesign.” The students were asked to rate their confidence, motivation, expected success, and degree of anxiety for each task on a scale of 0 to 100 with 10-point intervals. The ranking of 0 represents the lowest and the ranking of 100 represents the highest self-efficacy. Statistical analysis of the difference in rating before and after participating in the EPP module was conducted by performing a paired t-test with $\alpha = 0.05$ using Minitab 19. Data were gathered over two semesters of implementing the module with a total of $n = 11$ students.

Cost

Each group was given a budget of \$1,000 for their proposed project. The student projects were initially funded by the Case Western Reserve University Center for Innovation in Teaching and Education through a Glennan Fellowship. Funds from a National Science Foundation grant supported student projects in the following year. Students managed their budget for every aspect of the engineering project including peptide synthesis, characterization, tests, and training for equipment use or fees for getting the results from shared facilities. The approximate average cost distribution per group is listed in Table 1. The students were encouraged to remain under budget, but to spend as much of it as they deemed appropriate to achieve their goals. Most groups remained under the \$1000 budget. A lab technician was paid \$10/hr to prepare samples such as mixing the peptide with solutions of interest and diluting solutions to the desired concentrations. These prepared samples were then taken by the students to shared, pay-for-use, facilities on campus. The use of a paid laboratory technician avoided the need for separate laboratory space and laboratory time.

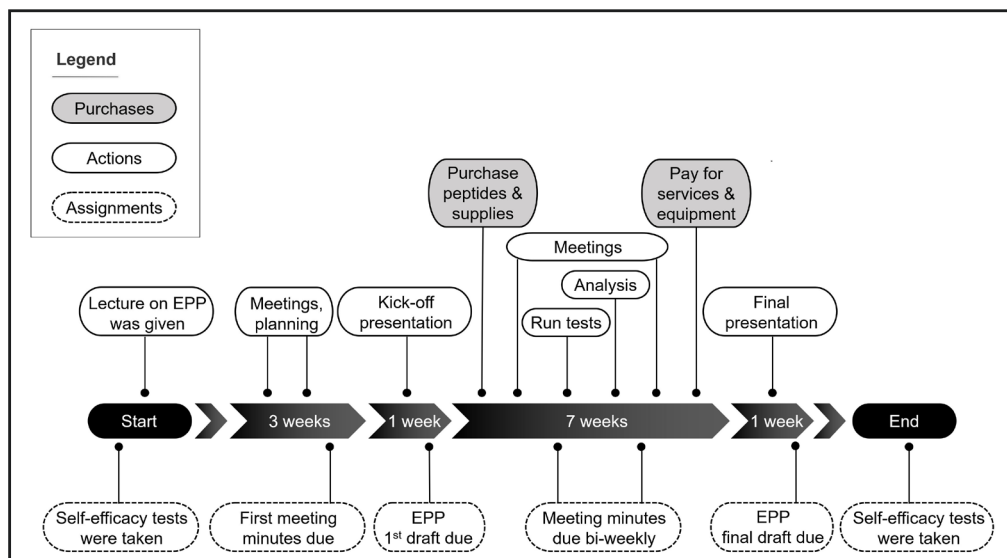


Figure 2. Timeline of assignments, purchases, and activities for the EPP-driven peptide engineering project.

| Type of cost | Average amount spent/group | % of total cost |
|---|----------------------------|-----------------|
| Peptide synthesis (+handling and shipping) | \$300 | 30% |
| Equipment training and peptide characterization | \$400 | 60% |
| Sample preparation (by lab technician) and reagents purchased for project | \$100 | 10% |
| Total | \$800 | 100% |

Results

The results collected from the validated self-efficacy survey are illustrated in Figure 3 showing the average ratings of students' self-concepts (confidence, motivation, expectation of success, and anxiety) on all engineering design tasks. The students rated themselves significantly more confident in all tasks except "constructing a prototype" and "redesigning." For the self-concept of motivation, students reported significantly higher motivation in performing the general "conducting engineering design" task, while no significant differences were observed in other specific tasks. A similar result occurred in the students' self-concept of how successful they would be in performing engineering design tasks. The students felt they would be significantly more successful after the EPP module in the general "conducting engineering design" but not significantly more successful in other specific tasks except for "constructing a prototype." The survey also revealed a significant decrease in student anxiety levels for the general "conducting engineering design" task, and for most specific engineering design tasks except "constructing a prototype" and "communicating a design."

DISCUSSION

Survey Results

The goal of this study was to determine if students who complete a hands-on project developing an EPP will feel more confident and less anxious in performing engineering design. For the general "conducting engineering design" task, the students experienced an increase in expectation of success and felt significantly more confident, more motivated, and less anxious. The results from the validated survey also showed a statistically significant increase in student confidence in performing many specific tasks in the engineering design process. The survey also showed an overall lower level of student-reported anxiety in specific engineering design tasks. Our results of decreased anxiety and increased confidence, motivation, and expected success parallel previous results

showing that a correlation between these self-concepts exists.^[13]

The survey results indicate that the EPP module is one way to positively impact graduate students' self-perceptions in engineering related tasks in the classroom. The positive impact on student self-perceptions is important because it has been previously shown that students' self-perceptions are correlated with performance in classes as well as career aspirations.^[16] One way the EPP module may be encouraging positive self-perceptions in gradu-

ate students is via the experience of collaborative learning (the opportunity to observe behaviors modeled by others). A previous study with undergraduate students showed that collaborative learning was positively associated with gains in confidence.^[17] The EPP module provides an opportunity for students to not only work as a team but also consistently interact with the instructor and their peers both inside and outside their groups. Therefore, the EPP could be considered a form of collaborative learning. The previous study also showed that higher clarity and organization in assignments were positively correlated with students' self-perceptions.^[17] The EPP implemented here may have provided students with organization and clarity for the completion of the open-ended design projects which could lead to the resulting positive self-perception. A study at the University of Nevada showed the same trend in results where significant increases in student self-perceptions of confidence and success were observed over a semester with the project-based learning in an engineering statics class.^[8]

In contrast to the University of Nevada study where a significant decrease in anxiety overall was not observed^[8], our results showed a significant decrease in the anxiety of students in every engineering design task except "constructing a prototype" and "communicating a design." The non-significant change in anxiety associated with "constructing a prototype" task may be due to the fact that project-based classes where students are allowed to construct their own prototypes and communicate about them are not prevalent in graduate-level education. The students also did not feel significantly more confident or motivated in "constructing a prototype," but their expectation of success in this task increased significantly after the EPP. Gaining confidence and motivation and lowering anxiety in the "constructing a prototype" task may require more experiences in performing the task. The non-significant change in anxiety associated with "communicating a design" was accompanied by non-significant changes in motivation and success; however, students did feel significantly more confident in "communicating a design" after the EPP. The

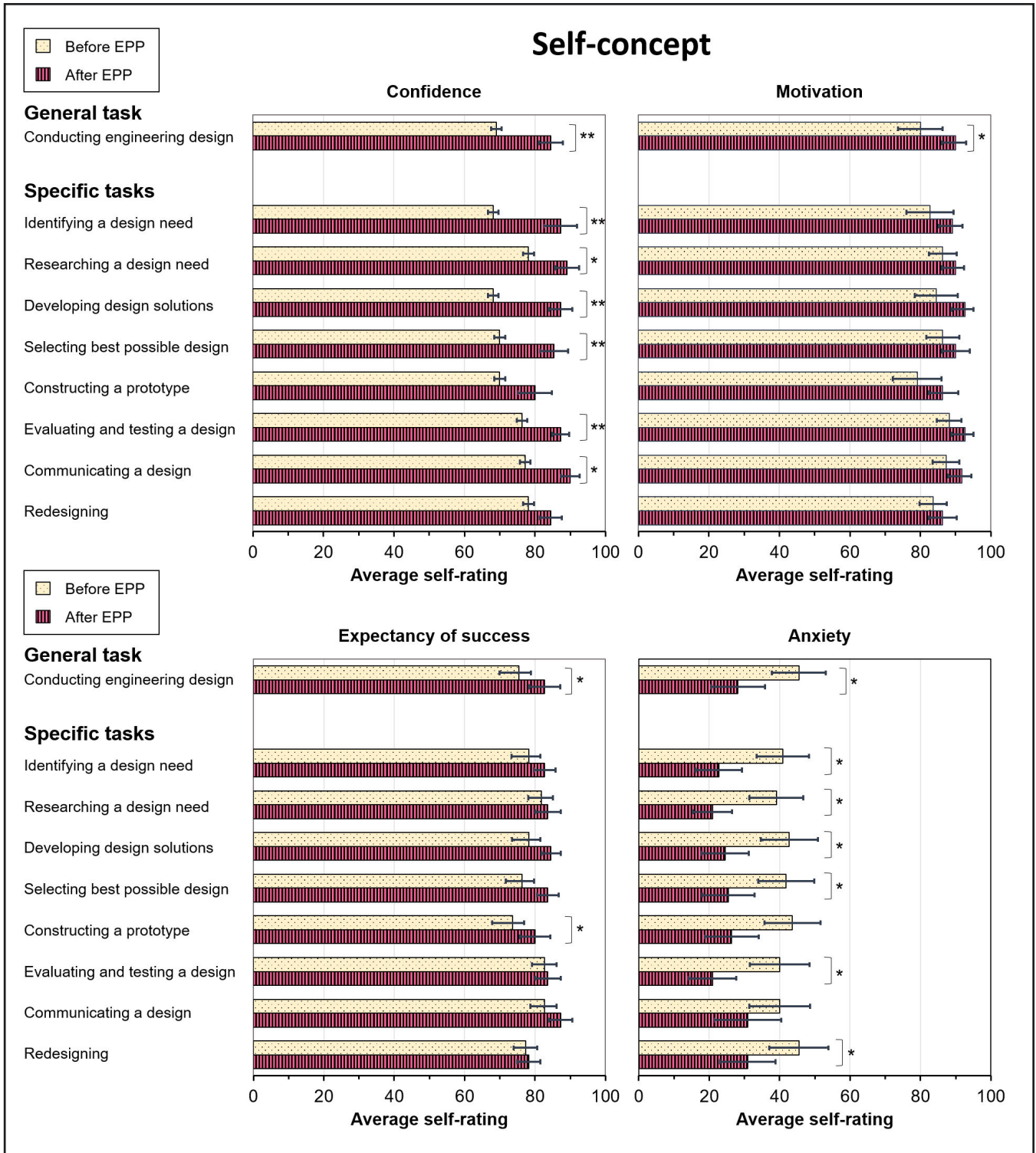


Figure 3. Average ratings of self-concept regarding confidence, motivation, expectancy of success, and anxiety in general and specific engineering design tasks before (light bars filled with dots) and after (dark bars filled with stripes) the graduate students have participated in the EPP module. A paired, 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 ≤ 0.01) For access to the data used to generate this figure, please email jxr484@case.edu. Data requests will be honored pending the privacy of students can be maintained.

fact that they had an experience communicating their designs to the class at the kick-off meeting, team meetings, meetings with the instructor, and final presentation may have made them feel more confident about “communicating a design” task. However, the tools provided in the EPP may not have included components that would specifically help students feel more comfortable or motivated to present their ideas to the peers and classroom.

For the “redesign” task, students did not report significant increases in confidence, motivation, and expected success. Yet, the overall anxiety for the “redesign” task went down significantly after the EPP. The mix of results is not surprising considering the students were allowed to conceptually redesign their peptides and EPP throughout the semester prior to peptide ordering; however, once the peptides were ordered, the peptide design was fixed, and the students shifted their focus to characterization and completing the test matrix. Since the short timeframe of the semester did not allow students to include a physical redesign task in the EPP, students may not have felt significantly more confident, successful or motivated for “redesign” compared to other tasks. The students may have felt less anxious in redesigning after the EPP module because they were able to conceptually redesign their peptides leading up to project kick-off. Our result where students did not feel they would be more successful at the “redesign” task is supported by previous studies where students felt their engineering design projects would have been more successful if they received enough time for a redesign.^[8] We suspect that the self-rating on the “redesign” task is highly dependent on the structure of the EPP module implemented in the class, where conceptual redesign was possible, but there was not enough time for physical redesign.

In summary, a hands-on polypeptide engineering experience that focused on project management was developed and implemented in a graduate-level course. A validated survey revealed that students’ self-efficacy in general “conducting engineering design” and in many specific engineering design tasks increased, while their anxiety in general “conducting engineering design” and in many specific design tasks decreased. We found literature that points to aspects of the EPP module that may be contributing to the increased student self-perceptions, such as the opportunity for collaborative and project-based learning, as well as the perception of high assignment organization and clarity. The increase in confidence, expectancy of success, and motivation and decrease in anxiety generally in performing engineering design tasks will help students feel more prepared for the tasks they will be performing in the workforce. Even though the careers students choose may not be directly relevant to engineering design, the project management tools provided in this EPP module will familiarize students with common practices in the private sector and are transferable to academia as well as government sector jobs.

Implementation Challenges

While it was challenging to complete a project that involves designing a peptide and testing design functionality within the time frame of a one-semester course, we showed in this study that it is possible, particularly when combined with EPP concepts. We found that care must be taken when ordering peptides. Peptides need to be designed and ordered in time for characterization and testing. Each peptide takes roughly 7-16 days to manufacture excluding the shipping time, depending on the peptide length and the purity of the product. Students were encouraged to consider their timeline carefully and to be prepared for any delay in the project that was covered in the risk management portion of the EPP. The class benefited from keeping the purity of the synthesized peptides low (>80-90% rather than >98%) to make sure their projects could be completed in the span of the semester. The design phase also started very early in the class timeline.

A limitation of this EPP format is that the project goal is one dimensional. Specifically, we focused on peptide design, characterization, and testing, which are important components of industrial research and development. Focusing on one project could give a false impression that students will only have responsibilities associated with a single project without the responsibilities of other on-going and potentially non-research projects in an industry setting. An earlier study of an undergraduate-level project management course has indicated that such impression exists.^[10] In the light of this consideration, the EPP could be used in other courses in parallel to expose graduate students to other types of projects. Other possible disciplines that the EPP could be applied to are process scale-up, plant design, intellectual property, business, and marketing. The EPP can generally be a handy tool for effective project-based courses.

CONCLUSIONS

- The EPP-based module utilized in this class introduced project management concepts in conjunction with a hands-on polypeptide engineering experience. Based on the statistically significant increase in confidence and decrease in anxiety levels in most of the engineering design tasks, the implementation of the hands-on EPP module had a positive impact on students’ self-perception regarding their engineering design skills. This type of assignment has the potential to provide students with transferable project management skills relevant to private sector, government and academic jobs without delaying graduation.
- There was no significant decrease in students’ anxiety associated with the specific “constructing a prototype” task which, we believe, is due to the unconventional method of teaching that the EPP module brings to the

graduate-level class. The students may not be familiar with engineering prototype construction as a component of a graduate-level course while conducting their thesis studies. The continuation of implementing the EPP-based module in graduate-level classes may help decrease the anxiety that students have toward “constructing a prototype” task. While implementation of the EPP is encouraged for other graduate-level classes, instructors are suggested to consider the workload of other class components planned such as assignments, other projects, and the lectures that need to be delivered.

- The EPP module did not significantly increase confidence or lower anxiety in communicating engineering design. Future iterations of the class would benefit from more formalized or defined training in communication of design that is relevant to non-academic settings. The finding also encourages future incorporation of tools to help students be more prepared and confident in presenting their ideas to the class and among their teams, which is an important aspect of the engineering design process in both academic and non-academic careers.
- The 12-week EPP implemented in a one-semester class did not allow enough time for physically performing the “redesign” task, which resulted in non-significant changes on self-perceived confidence, successfulness, and motivation in the redesign. An opportunity exists for physical redesign to be implemented in a class sequel where the one-semester class is a prerequisite for another one-semester class the following semester. Alternatively, as peptide synthesis technology becomes more advanced and allows for shorter production time, it may be possible to include a redesign component in a future one-semester class. A conceptual redesign component could be added as part of the final EPP report to give students the opportunity to practice and potentially gain more self-efficacy in engineering redesign.
- The EPP has the potential to be applied in other technical and non-technical disciplines of study (e.g. process scale-up, plant design, intellectual properties, business, and marketing). The demonstration of an EPP in this study was done in a focused polypeptide engineering design project where the project is one of the components in the course. Care should be taken, especially regarding timeline, when the EPP is applied to other disciplines or other graduate-level courses.

ACKNOWLEDGMENTS

We thank the Case Western Reserve University Center for Innovation in Teaching and Education who supported this work through a Glennan Fellowship to Dr. Renner. We also

appreciate the support from the National Science Foundation (award number 1739473). We extend our gratitude to all graduate students who participated in this classroom module. Finally, we sincerely thank Dr. Julie Liu who developed the graduate-level protein engineering class on which this class was based and who shared valuable teaching materials.

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