

AC 2007-2296: BIOMEDICAL ENGINEERING PROJECTS: INTEGRATING THE UNDERGRADUATE INTO THE FACULTY LABORATORY

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Biomedical Engineering Projects: Integrating the Undergraduate into the Faculty Laboratory

Abstract

Opportunities for undergraduate students to become involved in faculty research and design projects can vary widely by institution. We have developed a senior projects sequence that enables students to complete a yearlong faculty sponsored project that immerses the student in the laboratory. While a majority of our students express interest in volunteering and gaining experience in laboratories, they often encounter significant hurdles in reaching the goal of project completion. As undergraduates, their time is not dedicated to research work as one finds at the graduate level. Students are often fully loaded with classes and responsibilities related to undergraduate life or employment. The most important objectives for a sponsoring faculty member is to set achievable outcomes for the project, to provide a detailed schedule for completion, and to ensure that the expectations are communicated. Clear objectives will also raise the student's commitment and thus increase the likelihood of a positive outcome.

For the past seven years, we have explored variations on the faculty-sponsored project with increasingly positive results. In addition to developing clear expectations, the students are required to develop a project proposal, complete significant literature research, peer review fellow student projects, orally present and defend their written proposal, and ultimately compose a technical article and present that work at a poster session. The entire sequence provides students with the opportunity to explore the forefront of biomedical engineering, develop their communication skills and their ability to critically analyze technical work, and to develop the skills and confidence to complete a demanding project.

Over the past two years we have added steps to improve the course by providing alternative pathways for students with less interest in laboratory work. These students are generally more motivated by design oriented team projects that focus on developing skills for immediate employment following their baccalaureate. For laboratory-focused students, we have added a preliminary sequence of junior level independent research courses that provides them with more time to explore the project and to reach more rewarding objectives. This approach also improves collaboration within the laboratory, as students overlap from year to year, and provides additional peer training and feedback.

In order to assess the success of these projects we look at several measures. From 2002 to 2005 the number of graduates that continued on to some type of graduate program was 56%. The number of national awards presented to our undergraduates is also significant, ranging from BMES and Society for Biomaterials Undergraduate Awards and Sigma Xi grants to various poster and paper recognitions at the local, regional, and national levels. The ability to have continuous projects where students can easily pass on their work to underclassmen has also been improved thus leading to an increase in overall scholarly activity in the laboratory and a more positive experience for the undergraduate.

Introduction

While capstone design courses are at the core of all engineering disciplines, the depth of exposure to practical, hands-on experiences within the overall academic environment can vary widely. At Saint Louis University, the biomedical engineering (BME) department was developed around a program offering solely undergraduate degrees. The faculty developed the senior projects course around the concept of immersing students in a faculty lab to give them an in-depth exposure to solving open-ended engineering problems. Depending on the investigator, the range of topics could range widely and also included external faculty advisors with a need for biomedical engineering design solutions.

The two-semester course sequence has evolved over the past seven years to further emphasize design theory, expand the ethical topic coverage, adding a comprehensive exam to address program level outcomes, and various other enhancements and refinements. However, the immersion experience remains an integral component of the course and is highly regarded by alumni as a valuable experience that provided a strong foundation for their next career step. To better prepare students for joining a faculty laboratory, the students are normally required to join the lab prior to their senior year in order to facilitate the development of multi-year projects and to improve their overall experience during the senior year.

This paper discusses the current status of the senior projects sequence and the development process following the initial student involvement in the lab to their project culmination. Results related to various measures of student achievement, namely award recognition and graduate school enrollment, are presented.

Senior Projects Course Description

As defined in the course syllabus, the senior projects course objectives are as follows.

- The primary objective is for students to integrate their knowledge through the completion of the capstone design project. In addition to the basic principles of design, students will develop team skills, communication skills, and an understanding of the overall design process. Students will also review case histories and issues related to biomedical ethics.

The first semester of the sequence involves the fundamentals of design based to a large degree on one of the few texts covering the topic from a BME perspective ¹. Concerns regarding design content are often raised in discussions of BME curricula ^{2,3}. The relationship between design and research in the development of the capstone course and the need for design with regards to accreditation is certainly recognized within the field ⁴ as well as this institution. Projects are selected and approved only if there is a significant design component. In practice, beyond the theoretical aspects covered in class, students are required to apply design practices and concepts to their specific projects. These include, but are not limited to, basic design topics such as establishment of need, consideration of social and ethical aspects, case studies ⁵, market analysis, development of multiple solutions, specifications, and testing. As a measure of overall basic engineering knowledge, a comprehensive exam covering core topics such as computing, signals,

transport, materials, and mechanics has been administered the past two years to assist with program level assessment, similar to the motivation behind utilizing the fundamentals of engineering exam for seniors.

The development of communication skills has long been an important component of the course sequence. Written reports include feasibility and design proposals as well as progress reports and a comprehensive final report. Oral presentations include the proposal and design reviews and a culminating poster session. This emphasis on communication prepares students not only for their career but also for the conferences that many attend while still undergraduates. Students are also required to critically evaluate their peer's work through written assessments and during group sessions. In addition to the technical aspects of their work, students lead discussions on ethical topics, based on assigned readings, ranging from basic science perspectives to the political implications of biomedical developments. Lastly, students are required to attend a seminar series on biomedical research and design topics with a variety of invited speakers. Through these lectures students are exposed to current topics within the field and are able to develop their ability to evaluate and question the work presented. In addition, some seminars have focused on career development and preparation for graduate school ⁶.

Independent Research

Students that seek a classic design project experience are not required to join a laboratory prior to their senior year. These students work on teams that often include students from outside the discipline, e.g., electrical or mechanical engineering. These teams offer students the ability to develop practical experiences working with team dynamics and expectations ⁷. The course master primarily supervises these students although supplemental assistance from various faculty members is common. Students that wish to pursue a project in a particular laboratory are required, with rare exceptions, to complete a one or two semester sequence of independent research courses in order to be prepared to complete their senior project under the guidance of that faculty member. The objectives of the independent courses include:

- Training the student with regards to relevant safety and laboratory techniques;
- Development of the student's ability to apply mathematical concepts, scientific principles, computer tools, measurement techniques, and basic engineering heuristics to the design of solutions to biomedical engineering problems;
- Development of the student's ability to design experiments as well as understand and analyze biological data;
- Development of the student's ability to understand, interpret, and present current research relevant to the project as well as develop their own realistic proposal and plan.

Students that join a lab prior to their senior year are able to develop a broad, hands-on skill set that complements their in-class studies. These students become part of a lab team that not only shares general lab responsibilities, but also provides the mentoring and support system found in a successful organization ⁸. All students taking the two semester independent research sequence are required to submit a proposal (including goals, background, preliminary data, methods, and

budget), develop a timeline, design experiments to achieve their goals, troubleshoot problems as they occur, and collect and analyze data. At the end of the sequence, students are required to submit a final paper in journal format and present their work in a 45-minute public seminar. Based on previous studies⁸ as well as course surveys, a key to success is that clear expectations are defined and that the faculty advisor is closely connected with the student and their progress. Depending on the lab, students may be required to complete a variety of tasks ranging from preliminary design and testing to the submission of proposals for external support. The early involvement of students in the lab clearly prepares them to develop their project skills in advance of the capstone course and to “hit the ground running” as seniors. Similar approaches have been taken at other institutions in the form of sophomore or junior level introduction to design courses^{9,10} that focus more on the design process as opposed to actually committing to a laboratory.

Assessment

Indicators of the student success, during or following their experience embedded in the faculty research lab, include the number of students recognized through awards and the percentage of students that have continued to graduate school.

Of all 120 program graduates through December 2006, the percentage of students enrolled in full time graduate programs, or having completed a graduate degree, was 51%, with an additional 5% of students identified as part time graduate students while employed. The number of students working in faculty labs has decreased over the last two years as the course has developed more team oriented and cross discipline projects. This transformation was instigated in part due to discussions with our student advisory board and was deemed vital by our external advisory board.

In May 2005, there were 13 students in faculty labs and 11 of these went to graduate programs while the remaining two were employed by industry. Of the five May 2006 graduates that were embedded, four went directly to Ph.D. programs while the remaining student entered the Peace Corp. This year there are four students working in faculty labs, all with the intention of pursuing graduate studies. The decrease in the population of students working in faculty labs may simply reflect the timeline introducing new opportunities as well as variations in the makeup and character of relatively small senior classes (18, 30, 14). There has been no negative impact on the student understanding of design topics between students that work in faculty labs and those that do not. Specifically, in the last two years, exams covering specific design concepts show equivalent or significantly better (t-test, $p < 0.05$) scores for students that have completed the junior level independent experience prior to their senior project.

Students completing the combined junior level independent research and senior projects courses were asked to provide self-assessment of the sequence. Sample comments included (* note that actual names have been replaced):

- *Conducting in depth research my junior year definitely helped with senior projects. I knew my way around the lab and was more confident in my lab skills by the time I got to senior year.*

- *It has helped me fulfill my objectives for my senior project because at the start of my senior project I didn't have to get comfortable with working in lab and didn't have to learn how to organize/plan experiments, only how to organize/plan the general project. After spending junior year on the project, I was prepared with the equipment and protocols I had used, to continue to solve problems and learn new protocols and how to use other equipment to complete my tasks.*
- *Huey*, Louie*, and Dewey* taught me the basics of laboratory research (i.e.- chick surgery) and then I got to teach some of it to Thelma* and Louise*. Having to explain something well enough that someone else can do it ensured that I really knew what I was doing. Furthermore, it gave me a 'teaching experience' that I'm sure will be helpful in grad school when I have undergrads working under me.*
- *I learned a great deal from other students and professors working in lab. By working around other students and professors I was able to get advice from them about solutions to certain problems/obstacles and how to improve my lab techniques and make my experiments more effective.*
- *Junior year gave me the lab skills to go into senior projects and begin work immediately, instead of wasting time senior year learning lab basics. Since I plan on going to grad school, the combined two years will not only make me a better applicant but also give me more lab skills to apply to my thesis work.*
- *My junior year research helped me understand what goes into being an academic researcher (grants, budget, papers, etc) and in the same way prepared me for possible research/lab work in the future.*
- *When I first started I didn't really know what I was doing... I knew what I did in lab but didn't fully understand where that fit into the broad range of research and I found it difficult to explain my work to others. However, the 45min presentation at the end of junior year really helped me be able to explain my project to others. Since my senior project was built on my junior project, I feel I was better able to explain what I was doing than some of the other teams.*
- *Over the course of my junior and senior year projects, through writing proposals and papers, presenting the research, and reading papers, I feel it has become easier and more effective for me to communicate the background and work of my project.*

During the past five years, six of the program's students have received national undergraduate research and design awards from the Biomedical Engineering Society. All of these students were working on their projects in a faculty lab. In addition, students have received undergraduate poster, paper, or presentation awards from the Society for Biomaterials, ASME Summer Bioengineering Conferences, the American Chemical Society, the Society for Advancement of Chicanos and Native Americans in Science, the Materials Research Society, Sigma Xi. Furthermore, seven students have received support through the Sigma Xi Grant-in-Aid of Research program.

Conclusions

While a small program has inherent limitations in the breadth of opportunities presented to undergraduates, the ability to immerse students in a faculty lab has proven to be beneficial to students and faculty. Students gain from the opportunity to develop hands-on experience while being exposed to open-ended design challenges. When implemented with appropriate oversight and with the necessary mechanisms in place to carry over projects from year-to-year, faculty are able to successfully incorporate the undergraduate into their lab with confidence and long-term successful scholarly results. Overall, the combination of courses described herein serves to integrate the student's theoretical studies with practical experiences in an environment that is both supportive and professional as well as well designed to prepare students for the next phase of their career.

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