Customers on Campus – Building Successful Collaboration between Physics and Engineering through Interdisciplinary Undergraduate Research

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Abstract

The educational benefits of collaborative student – faculty research and real-world design projects in engineering are well known. In particular, engineering students benefit from the exercise of design skills and from working with non-engineering clients to define the technical requirements of their projects. In parallel, individuals from other disciplines can benefit from exposure to engineering problem solving techniques. In this paper the authors present the results of an ongoing effort to integrate the benefits of both student-faculty collaborations and real-world design by incorporating undergraduate engineering students into physics research projects.

Over the course of several years, engineering students at the University of St. Thomas have been incorporated into physics department research laboratories, working side by side with physics students and faculty. These students design, build and test instrumentation and other equipment used in all aspects of the physics research. The problems to be solved are technically challenging and valuable to the client. Students working on these projects receive guidance from both electrical engineering and physics faculty regarding real-world constraints and the implications of the student solutions. The engineering students gain design experience as well as experience working with non-engineering customers to define problem requirements and specifications. In addition to the resulting instrumentation, physics students and faculty gain insight into engineering problem solving techniques. The impact of the experience goes beyond the immediate participants; finding its way back into the classroom through better-informed instruction in both physics and engineering.

Traditional opportunities for students

Many educators have written on the advantages students gain from various forms of experiences in which they can practice the analytical and design skills learned in their engineering coursework, see for example Campbell[1]. A variety of mechanisms have been used to provide these experiences including cooperative faculty-student research projects, inter and intra campus student design competitions[2], on-campus industry sponsored design projects[3], internships and co-op positions in engineering firms[4], and service learning projects[5] in the local community or abroad. Each of these approaches has advantages and disadvantages for different students and the availability of a wide range of opportunities is clearly valuable for a diverse student body with wide ranging development needs. All of these activities have associated costs in terms of space allocation, faculty time, or administrative support. While large engineering programs can maintain the infrastructure needed to support several of these activities and thereby provide the range of experiences needed by their students it is often difficult for smaller programs to maintain the variety of experiences. However, by thinking creatively, smaller programs can benefit from activities that accomplish several goals with minimal overhead. To do this, we consider first, the various benefits of such activities as on-campus research, service learning, and internships to identify core features that might be available in a single activity.

Faculty-student collaborative research is a natural offshoot of the mentoring relationship that is already in place between the professor and the pupil. It is a model that faculty are familiar with from their experiences with graduate students (or their own experience as graduate students). It provides students with the ability to apply their knowledge and skills under the supervision of an expert in the field who knows the student and is able to provide insights into the connections between the current project work and the student's prior coursework. On the other hand, this collaborative research is very different from typical engineering practice that will be experienced by most engineering graduates in that it provides little interaction with non-engineers and the problems being solved are typically well defined by the professor.

Internships and co-op programs provide the student with an experience closer to what they will find after graduation. Such programs provide students with exposure to corporate cultures, policies and procedures and give students a sense of what potential employers are like. Students work in multidisciplinary teams including both engineers and non-engineers and they experience the whole process of problem identification and design. In such projects students must face real world constraints such as cost, manufacturing issues and schedule. They have an additional benefit of helping the student understand their employment options after graduation and in many cases lead to employment opportunities. On the other hand, it is difficult to ensure the quality of internship and co-op experiences without significant administrative support. Furthermore, it is rare for mentors to be available on the jobsite who can provide students with guidance on applying classroom skills to the workplace and employers are less likely to know the student well enough to understand how to make connections between theory and practice.

Service learning projects give students the opportunity to apply their skills in service of others, either in the local community or abroad. Studies have shown that these experiences provide students with a sense of accomplishment and pride that may not accompany typical industrial projects and help the university fulfill its service mission[6]. Like internships, service learning projects expose students to non-technical customers and real world constraints. However, it can be difficult to find projects that have significant electrical engineering content. Because of the community interactions, service-learning programs can require significant effort to monitor and maintain although many schools have offices to support such efforts.

In summary, each of these methods has strengths and weaknesses. Service learning projects provide a real sense of using one's skills to help others, and provide real-world constraints, but often lack significant technical content. Internships and co-ops can introduce greater technical content and employment opportunities at the expense of a greater distance to the ultimate customer but they lack the close mentorship opportunities of faculty sponsored research. Faculty sponsored research provides both the mentorship and technically demanding problems, but it lacks the real world constraints and multi-disciplinary aspects of either.

An Alternative Approach: Interdisciplinary research teams housed in the Physics Department

Several authors have reported excellent results from interdisciplinary work done as part of a normal course or pair of courses[7,8]. At the University of St. Thomas, we have had good success encouraging engineering students to participate in undergraduate physics research teams. These engineering students apply their knowledge and skills to design and build instrumentation for use in physics research projects. Their customers are the faculty and students of the physics department and they must develop products that are acceptable to these customers and fit the budget, schedule, and other constraints of the program. Working outside their home engineering department, they are exposed to the culture of the physical sciences and have the opportunity to see the similarities and differences between engineering and physics. Working side by side with physicists on technically complex and interesting problems, engineering students have the opportunity to work on a multi-disciplinary team and yet because of the close proximity of the two programs, they still receive mentoring from faculty in their home department.

For example, an ongoing series of polarized electron beam experiments provided numerous opportunities for engineering students. The first of these projects was the design and fabrication of an electron gun. Working closely with a physics professor, a mechanical engineering student generated complete dimensioned, detailed drawings for the components and assembly. This project objectified the student's coursework in CAD and manufacturing processes and the portfolio of drawings was later instrumental in the student obtaining a job. Another engineering student designed and built a control system for the vacuum chamber. This controller was responsible for proper sequencing of valves and the roughing and diffusion pumps to avoid catastrophic failure and fouling of the vacuum system with oil due to improper sequencing of controls. Since the student was not familiar with vacuum systems, it was necessary to work with the physicists to understand the requirements for the system and ensure that the controller would meet their needs. Because of the success of these projects, several electrical engineering students are now working on a multi-channel computer controlled high voltage, high resolution, bipolar power supply for use in these electron beam experiments.

In addition to the electron beam experiments, engineering students have also participated in other projects. One student provided control theory and electronic design expertise for the development of the drive electronics for laboratory equipment to investigate the onset of chaotic motion in a deterministic system. Another student has built a real-time polarization imager using field programmable gate arrays to process and combine images obtained with orthogonally polarized illumination. A third student is working on a low noise pre-amplifier for detecting low-level optical signals in the presence of noise.

Physics researchers benefit from the technical skills that engineering students bring to their labs. For example, physics majors may be very familiar with Fourier analysis yet completely unfamiliar with control theory, so the addition of an electrical engineer with this knowledge can improve the performance and stability of apparatus. Similarly, while physics majors may learn digital logic design in an electronics or experimental methods course, they typically are not familiar with contemporary devices such as field programmable gate arrays that can be used to improve the speed, cost, and flexibility of equipment.

How these interdisciplinary projects combine some of the advantages of each of the traditional methods while mitigating their disadvantages is summarized in Table 1 below.

	Internships / Co-ops	Faculty / Student cooperative research	Service learning projects	Interdisciplinary research project
Faculty mentoring of students	Low	High	Medium	High
Technical challenge	Medium	High	Low	High
Direct contact with customer	Low	Medium	High	High
Customer need for technical assistance	Medium	Low	High	Medium
Multi-disciplinary team	High	Low	Medium	Medium
Real-world constraints	High	Low	High	Medium
Industrial Exposure	High	Low	Medium	Medium
Exposure to different culture	Medium	Low	High	Medium

Table 1. Comparison of Different Student Practicum Experiences

Techniques for success

There are challenges to this approach. Some schools will find that it is difficult to initiate and maintain discussions between engineering and physics departments. At the University of St. Thomas we have been fortunate in that a close relationship exists between departments and interdisciplinary work is encouraged. We find that during the school year, few of our students have time to work on projects outside of their coursework. This leaves summers available for this type of project. Furthermore, typically the kinds of skills that students need to be useful in such projects are typically not available until late in their undergraduate career and by that time the students are typically looking for jobs or internships that will lead to jobs.

So how can we overcome these problems that lead to relatively short periods of useful time? First, it is critical to move useful skills as early as possible in the curriculum. This is often done for other reasons such as the improvement of retention rates. By incorporating useful design skills in the sophomore level courses we are able to employ students in the summer between their sophomore and junior year in the design of simple instrumentation. Some of these skills are now being moved to a freshman level course.

Second, regular student presentations on projects help create a sense of camaraderie between students working on multiple projects and give younger students the opportunity to see more advanced work done by upper classmen. This has value at all stages of the project, not just the conclusion, and helps students see the value of teamwork in projects as well as reinforces the value of multiple views and approaches to problems. When done as 'work in progress', this also helps reinforce the blending of theory and applications which is characteristic of these projects.

Third, it is sometimes necessary for a project started by one undergraduate to be continued by another. This is in some ways a blessing in disguise since it forces the students (and faculty) to appreciate the importance of clear and complete documentation. In fact, students who have experienced first hand the effects of poor project documentation have provided guest lectures to underclassmen on the importance of documentation and provided examples of attempting to complete poorly documented projects.

Fourth, faculty must do more project management than is typically needed for graduate student projects. In fact, this can be a form of mentoring for the undergraduates in learning how a large project might be divided into smaller parts and how a project might be managed to reduce risks. All of these projects have been fairly demanding and have increased the students' understanding of the complexity of real-world design. Through mentoring, the physics and engineering faculty provide the student with a safe environment in which they are free to take risks and fail. Many of the students who have participated in these projects have reported that it was their failures that taught them important lessons about the design process, attention to detail, and time management. In each case, the students went on to be very successful in their senior design projects.

Conclusions

These interdisciplinary projects have provided many benefits. Since these projects are housed in and funded by the physics department and the students' home department is engineering, the students benefit from mentoring by both physicists and engineers. This gives the advantage of a customer who is not an engineer, yet is experienced in helping a student understand the nature of the problem. Similarly, the engineering mentor can provide guidance in developing engineering specifications and possible design solutions.

The projects also benefit our students. Through their work in the physics labs, they gain experience with sophisticated instrumentation. They have had the opportunity to practice the skills learned in their engineering classes and to integrate the knowledge gained in different courses. The students improve their writing skills by documenting their design and learn to appreciate the importance of these skills by working with the documentation left behind by previous students. The projects also provide opportunities for students to develop and demonstrate time management skills in the context of real product development. As a result, the projects leave the students better prepared for internships and graduate studies.

Finally, these projects also provide benefits for the University. Physics faculty benefit from the development of instrumentation and learn new skills from interactions with engineering faculty and students. Engineering faculty obtain feedback on the efficacy of the curriculum in preparing students to solve real design problems. Faculty in both programs gain from the increased interaction between departments. This interaction impacts the curriculum of both programs.

Our experiences with this approach have lead to three recommendations to other engineering programs that may wish to try something similar. First, talk to your physics department. Informal communications between departments can lead to productive partnerships. Second, develop laboratory experiences outside of the traditional model; allowing the students to experience the uncertainties of real laboratory and design work. Finally, use your students as workers early and often.

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