Integrating Research and Engineering Education: A Case Study of Undergraduate Research in Orthopaedics

Mary Phillips, Megan Schroeder
University of Notre Dame

Abstract

Integrating undergraduate research with related coursework is an accepted method of piquing student interest, recruiting underrepresented minorities, and retaining students in all fields of engineering. While this is an accepted approach, it is by no means popular. On the one hand, it is generally considered valuable to apply knowledge gained through undergraduate coursework to industrially relevant problems, but such efforts require significant direct industry involvement and cooperation with faculty as well as dedicated students. If any of these elements are found lacking, the value of research in the undergraduate experience is compromised and the academic value of the research experience is limited. This paper presents a case study of orthopaedic research projects and emphasizes the undergraduate student perspective on research, finding projects and faculty mentors. The particular problems addressed include research in strength of woven materials, new applications of braided materials, and optimization of locking plate screw configurations for orthopaedic implant applications.

I. Introduction

It is widely accepted that interactive learning is the best known method for teaching engineering (see for example Felder[1], Foyle[2] and Rosenthal[3]). Undergraduate research which compliments coursework is inherently interactive and can serve to increase student interest in engineering, recruit underrepresented minorities and retain engineering students. While many would agree that this approach is effective, it is not widely used, probably due to the level of involvement required from both faculty members and students. Though it is generally considered valuable to apply knowledge gained from undergraduate coursework to problems seen in industry, without the full dedication of either of the involved parties, the academic value of the research experience is severely limited. This paper demonstrates how the research experience can benefit undergraduate engineering students. Not only does it keep the students interested and excited about their chosen major, but it adds a wider appeal to the field of study, increasing its attraction to those minorities who are generally underrepresented. The undergraduate research experience also lends many valuable life lessons that cannot be learned in a classroom setting. By examining a case study of orthopaedic research projects, the value of such experiences to the undergraduate can be more clearly demonstrated.

The vast majority of literature on teaching and learning in the engineering education literature is written from the perspective of the professor (see for example, the literature review by Niemeier et al[4]). In contrast, the authors of this paper are undergraduate students providing a review of their experiences in research, along with descriptions of successes and pitfalls for other undergraduates to keep in mind.

II. The Value of Undergraduate Research

There is a wide recognition that underrepresented minorities, including women, have not pursued engineering as often as other disciplines. Also, these groups leave engineering in significant numbers to other majors, so that retention is a major issue. Some of the main arguments forwarded to explain this continuing trend are:

- These groups do not have effective role models to encourage them to consider engineering. Thus, young men and women in these groups do not realize that engineering is a rewarding career.
- Once they have selected a field of engineering as a major, they do not have a support network to help them succeed.
- Societal expectations place these groups at a disadvantage when studying engineering.

It is not our goal to examine all of the reasons for a lack of women and underrepresented minorities in engineering, but instead to suggest that recruitment and retention can be improved by the use of research projects within the undergraduate curriculum.

However, we can anecdotally express that we have been recruited and sold, perhaps to excess, by professional society outreach programs since mid-high school. (A question that is sometimes asked by students is `How good of a career can it be if they are working so hard to get us to study it?') We expect that outreach programs have had their main impact to date; high school students are currently well-informed about engineering, and while we are not advocating that outreach programs be curtailed in any form, we do believe that further improvements in underrespresented minority recruitment rely on other approaches.

We also do not wish to imply that all of the shortcomings of the engineering profession that have been addressed in the past decade are solved. We haven't encountered sexist and demeaning attitudes from our professors and student colleagues, but perhaps these still occur at some institutions or departments. For the most part we feel very welcome and secure within the engineering profession. It is an undeniable fact that women are outnumbered by men in every one of our engineering classes; we have become used to these demographics, and it is not considered unusual or oppressive in any way.

One problem that we can relate to is that many undergraduates lack faculty mentors. Many publications have noted the importance of mentors for under-represented groups (Mintz, et al[5], NAS[6]) and for women (Bell[7], Kronik[8]). We appreciate that faculty have many responsibilities, such as teaching, directing graduate student research, writing publications, securing grant funding and participating in administrative duties. Serving as a mentor for undergraduate research projects is an additional burden that few faculty will undertake. The academic environment does not reward faculty for undergraduate research, as the associated projects do not often lead to peer-reviewed journal publications or large grants, so that the rewards to the faculty member are not clear.

We believe that there are major benefits in the integration of undergraduate research into the curriculum, not least of which is the development of a faculty-student mentor relationship. We have been told that faculty expend considerable effort in the recruitment of graduate students, but we would like to opine that this is equally important for undergraduates recruiting faculty mentors. It is very important to identify faculty that you would like to work with, and to recruit them wisely. Some of the important considerations are:

- It is rare for a sophomore or junior to know exactly what area of research they wish to pursue. Some do know, but these are the exception. In fact, it may be unreasonable to expect college underclassmen to make informed decisions about their career directions. The research area you choose can lead to career benefits, but they are not restrictive. The important consideration in choosing a research topic is to find one that will be rewarding. In short, look for research that will be fun.
- Your department web site will summarize the faculty and their areas of research. Many of the faculty will be known to you in your early courses within your major. Perform research and identify faculty members that conduct research that you find of interest. (For us, the design of orthopedic implants was an area of great interest, and we identified faculty who work in this area).
- Speak to your peers. Upperclassmen will generally know which professors are responsive and generally good to work for. Graduate students (often TAs in courses) also offer valuable insight.
- Begin research early. We started during our sophomore years, and maintained a level of activity throughout our undergraduate studies. Faculty that are active in research are more open to working with undergraduates that will be available for multiple years; the learning curve associated with experimental techniques, computer programs and laboratory equipment is significant, and a second-semester senior will not be able to contribute to a research program.
- Be active. It has been related to us that our enthusiasm was a major reason that we were incorporated into a research program. When you have identified a faculty member that you would like to work with, approach them and ask for a research project. Explain that their research program attracted you, and that you have similar interests.

Sometimes an instructor will try to recruit you; it is probably wise to keep these considerations in mind regardless of who initiates the first contact.

As undergraduates, and especially as underclassmen, you should expect that the role you serve in research will be limited. Patience is a virtue; as your demonstrated competence warrants, your duties will be expanded.

Once you begin performing undergraduate research, the curriculum becomes more rewarding. A student that only takes classes can be bored, as well as exhausted. It sounds contradictory, but a good undergraduate research project, even though its time commitment may be greater than a typical course, is more rewarding and easier to include in a course schedule. It is more fun; it is demanding but rewarding, and as a result is an experience that should be pursued by all undergraduate students.

It is especially beneficial if industry involvement in the research project occurs. This ensures a pragmatic focus and provides the additional benefit that the research may be applied to a useful problem. Further, internship opportunities often can result from undergraduate research projects. Both of the authors obtained student internships at the industry sponsor of the research. This too, was a rewarding development, but internships are outside the scope of this paper.

III. Examples of Orthopaedic Research Projects

Research projects examined in this papery were conducted by students at the University of Notre Dame under the guidance of a faculty member. Projects were also completed in collaboration with Zimmer, the leading company in design, development, manufacturing and marketing of orthopaedic implants and related surgical products.

A. Development of Woven Orthopedic Implants

One specific research project focused on inspection methods of woven implants. The task was to determine methods of examining woven constructs to determine whether defects were present. The concern was that the intended use of the woven material could result in damage during surgery, creating a potential for snagging and abrasion of the woven material. This possibility of tears or abrasions of the woven construct could cause the woven to no longer function as the barrier that it was intended, which would ultimately compromise the reliability of the implant. It was determined that the physical property which would most likely affect the reliability of the woven implant was the strength of the fabric. Test methods researched included thermal imaging, acoustic sensing, airflow analysis, optical imaging, and the force needed to produce mechanical failure. After the initial design review, the mechanical pressurization method for establishing burst strength of the woven material was selected. Numerical analysis and laboratory demonstration determined that the best way to quantify burst strength was to position a rubber balloon over a pressurized air nozzle, then place the woven construct over the rubber balloon and secure it around the nozzle base. The pressure inside the balloon was then increased until the woven bag burst, as shown in Figure 1. This maximum pressure achieved was then recorded. This procedure was repeated with woven constructs in which defects were simulated by making incisions using a razor blade or by dragging trabecular metal across an area of the fabric. This research project was completed in one semester and determined a quantifiable method for detecting defects in woven implants.

Figure 1. Woven implant after bursting

B. Experimental Investigations of Cement Reinforcement

Another example research project focused on a new application of wovens to reinforce bone cement augmentation of total hips. The task proposed by Zimmer was to develop a bone cement prototype shaped like a hip stem such as that used in total hip replacement procedure, which integrate woven interfaces over the surface of the device. This would create an increased surface roughness for new bone to grow into and provide increased strength of the implant. Design reviews of the initial concepts determined that the best method to develop the prototype is to heat treat the reinforcement into the desired hip stem shape then place it in a negative mold of the hip stem which is finally injected with bone cement. This research project challenged the students' abilities to transform a design concept into a physical prototype.

C. Optimal Locking Screw Placement in Bone Plates for Femur Fractures

Yet another example is a research project that sought to determine an optimized locking screw placement in fixed angle plates used to treat supracondylar femur fractures. The minimally invasive surgery application of locking plates reduces trauma and disruption of the blood supply at a fracture site. Fixed angle or locking plates are often the preferred treatment for these surgeries since they provide sufficient rigidity and may require fewer screws in attaching the plate to the femur. This research project compared a titanium NCB plate to a stainless steel Peri-Locking plate. It examined three different screw configurations for each plate to determine how many screws are necessary to satisfy the strength requirements for fracture healing. A theoretical beam analysis on the plate was performed to determine which screw configurations should be used in testing. From surgical techniques, a procedure for plate assembly on sawbones was established. Each sample was fixed at the proper anatomical angle and loaded axially as shown in Figure 2. Statistical analysis on the stiffness and gap strain showed that the plates demonstrated little sensitivity to the number of screws used.

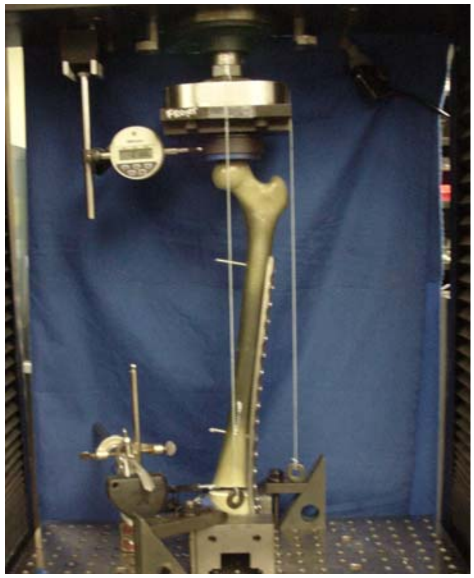

Figure 2. Test setup to determine stiffness and gap strain in bone plates

D. Design of an Interphalaneal Implant

Orthopaedic research conducted over the semester was extended into the summer, as the students continued involvement in orthopaedic engineering with an internship at Zimmer. An example research project completed during the summer was focused on designing and building an interphalangeal joint. After initial benchmarking was completed, concepts of possible implant solutions were generated, incorporating new technologies that Zimmer was exploring. These concepts were narrowed down to the top ideas by discussion with those both in research and in development. Prototypes of the joint were built in order to fine-tune the implant design as well as to demonstrate the design's feasibility. The prototype building process included modeling the features in CAD and generating SLA models as well as testing materials and building molds. Another summer research project completed at Zimmer focused on new applications for woven materials. The benefits of these materials include achieving a higher degree of fixation in fractured bone and the ability to minimize the size of the surgical incision. Applications considered include total hip replacements and improved screw fixation. Each of these were modeled using CAD and were prototyped at Zimmer. Additionally, the improved fixation achieved by each prototype was demonstrated by fixating the device in styrofoam, which acts as the softer cancellous bone.

IV. Discussion

From a student's perspective, each of the research problems described above did much more than solve a given problem or develop an acceptable solution. Though the projects' outcomes had value to Zimmer, the students gained much more during the actual research process. First and foremost, the research experience allowed the students to directly apply the engineering principles learned in the classroom setting to real world problems. This not only showed them the relevance of their classes but also kept them interested and involved in engineering over each semester. The students also gained great leadership experience from their research projects. As project leaders of a student team, they learned valuable lessons in time management, dealing with unexpected problems, and keeping the team interested, involved, and on task.

Not only did the students gain experience writing up the results of their research and presenting these results to faculty and industry collaborators/sponsors, but they also had the opportunity to further present these results at several conferences. Poster papers were displayed at the Orthopedic Design & Technology Conference in Fort Wayne, Indiana and at the State of Innovations in Orthopaedics Summit in Indianapolis, Indiana. Both conferences gave the students a chance to present their findings to a variety of professionals involved in the orthopaedic industry as well as the opportunity to learn about current issues in the orthopaedic field including other research that is being conducted elsewhere.

The projects also allow students to acquire noteworthy milestones for their resumes, whether they will be reviewed by potential employers or graduate programs. Papers, poster presentations and patents are unusual accomplishments for undergraduates, and these can differentiate an applicant.

The value of research in terms of motivating and cultivating enthusiasms in undergraduate students is clear. We encourage undergraduates to perform research. Our experiences have suggested that the following are pitfalls and successes in the undergraduate research efforts that we've been involved in. The following has been formulated as a list of considerations for an undergraduate (freshman or sophomore) contemplating involvement in research.

- Don't be afraid to stay in close contact with faculty members. It can be intimidating to a freshman or sophomore to email a professor or to drop by their office. Don't hesitate maintaining contact, as this is the first step in initiating research. Also, don't assume the faculty are too busy to care about you.
- We don't believe that mentors need to have the same demographic as the student. It's far more important to do something fun than to have a mentor that shares your gender or cultural background.
- Often, departments or the college offers invited lectures. If there is a lecture of interest, don't hesitate attending. Even if the subject matter is part of a graduate lecture series, and even if parts are beyond your current education level, observing faculty interactions with the speaker can help identify a potential mentor.
- Talk to TAs often. TAs can be graduate students or seniors, and they have good insights.
- Join student sections of engineering societies. We have found the Society of Women Engineers, Pi Tau Sigma, National Society of Black Engineers, and the American Society of Mechanical Engineers to be active in the Mechanical Engineering department at Notre Dame.
- We have found that students who obtain their degrees through pure coursework are more likely to pursue other interests after their undergraduate program. They find alternatives in business or the legal profession, as examples, instead of applying their degrees directly. The students that are involved in research maintain a high level of enthusiasm. Therefore, as a retention mechanism, undergraduate research is extremely valuable.

- When the major is selected (during the Freshman year at Notre Dame), students often have a poor understanding of their major. Coursework doesn't give a good understanding of the profession. Performing research (and obtaining internships) is a better approach for confirming that their selection of a major suits their interests.
- As a freshman, we are students in a university offering a wide variety of majors. (Faculty on the other hand, only encounter students within one major and therefore don't appreciate the students situation.) We are often asked by our student peers why we are studying engineering, why we don't switch to other majors, and what our plans are for pursuing other careers after obtaining our bachelor's degrees. This peer pressure is especially sensitive as a freshman or sophomore, and defense of our major is difficult at this time. As freshman, there are no good and apparent answers for these questions. However, when performing research in an area of our personal interest, it becomes very easy to answer these questions with concrete examples, and as a result we feel a greater pride in our profession.

V. Conclusions

The integration of research projects and coursework at the University of Notre Dame and the summer research conducted at Zimmer has indeed increased the students' interest in engineering. The high degree of collaboration between the two institutions has lead to a successful partnership focused on orthopaedic research. The student perspective of this research initiative has concluded that integrating undergraduate research with related coursework is an effective way of increasing interest in their chosen major as well as retaining underrepresented minorities in the field of engineering. The students considered in this case study have chosen to continue their engineering studies by attending graduate school upon completion of their undergraduate degrees.

References

[1]Felder, R.M., "A Longitudinal Study of Engineering Student Performance and Retention: IV. Instructional Methods," *Journal of Engineering Education*, v. 84, No. 4, 1995, pp. 361-367.

[2]Foyle, H.C., ed., *Interactive Learning in the Higher Education Classroom: Cooperative, Collaborative, and Active Learning Strategies*, Washington, National Education Association, 1995.

[3]Rosenthal, J.S., "Actuve Learning Strategies in Advanced Mathematics Classes," *Studies in Higher Education*, v. 20, No. 2, 1995, pp. 223-228.

[4]Niemeier, D., et al., "Integration of Engineering Education and Research: Perspectives from the NSF Civil and Mechanical Systems 1998 CAREER Workshop", *J. Engineering Education*, April 2001, pp. 199-202.

[5]Mintz, L., K. Bartels, and C. Rideout, "Training in Counseling Ethnic Minorities and Race-Based Availability of Graduate School Resources," *Professional Psychology: Research and Practice*, v. 26, No. 3, 1995, pp. 316-321.

[6]*Advisor, Teacher, Role Model, Friend: On being a Mentor to Students in Science and Engineering*, National Academy of Sciences, National Academy Press, Washington, 1997.

[7]Bell, L., "Something's Wrong Here and It's Not Me: Challenging the Dilemmas that Block Girls' Success," *J. Education for the Gifted*, v. 12, No. 2, 1989, pp. 118-130.

[8]Kronik, J., “On Mentoring Women – Then and Now”, *ADFL Bulletin*, v. 21, No. 3, 1990, pp. 1-27.

Acknowledgements

The authors thank Dr. Steven Schmid at the University of Notre Dame for his outstanding support and mentorship as well as Mr. Tony Lozier at Zimmer for his guidance and encouragement.