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Research Experience at an Undergraduate Institution

Abstract

The authors' institution, Ohio Northern University (ONU) is a private, medium-sized university offering undergraduate degrees in Arts & Sciences, Business, Pharmacy, and Engineering, as well as graduate degrees in Law. The College of Engineering at ONU attracts exceptional students. However, because there are no graduate programs within the College of Engineering, engineering students have limited opportunities to participate in advanced interdisciplinary research. This paper describes research activities conducted primarily in the mechanical engineering department by undergraduate students. Projects in biomechanics and biomaterials integrate engineering mechanics and materials science with the life sciences to enable undergraduate engineering students to participate in cutting-edge research. These activities are expected to attract more students, especially female students, to engineering and to expand the future career options of mechanical engineering students.

There are a number of special circumstances that must be considered when developing research projects that are appropriate for undergraduate students. The undergraduate research activities are carefully designed to recruit suitable students and to ensure a positive educational experience. During the freshman year, students are selected and introduced to the research topic. These students enroll in an independent-study course in order to learn basic concepts related to future research work. In the sophomore year, the participating students obtain practical experience in mechanics experiments. During the junior year, the students perform mechanics analysis and more advanced experiments. In the senior year, the students create numerical models using finite element analysis. All the students involved in the research work have good academic standing. These students become more interested in cutting-edge research work and some of them decide to pursue graduate degrees after graduation.

Introduction

A common concern for engineering educators today is that the number of American students entering the engineering field is not high enough to meet future demand.[1-4] In recent years, fewer than one-third of college students have pursued science and engineering degrees[5]. The enrollment of engineering freshman declined from 1985 to 2005, according to data by the Engineering Workforce Commission.[6] As studies have shown, in recent years "the number of engineering Ph.D. graduates has increased very little."[7] Undergraduate research focusing on interdisciplinary projects has been shown to have a positive impact on retention in the engineering majors, enrollment in engineering graduate schools, and the career development of engineering graduates.[8-12] In most research universities, undergraduate research programs are relatively mature, since undergraduate students can easily be integrated into existing research groups, working with graduate students on a variety of research projects. However, for an undergraduate engineering program like that at Ohio Northern University (ONU), this model is not possible. The absence of graduate students severely limits the amount of work that can be accomplished, since undergraduate students generally lack the technical background needed to work independently. In addition, undergraduate students have many more demands on their schedules – both academic and extra-curricular – and are seldom able to commit the amount of time needed to make rapid progress on complex problems.

The first author of this paper has experience as both a graduate research assistant and a post-doctoral researcher in universities with strong engineering graduate programs, where she participated in advising undergraduate and graduate students. After becoming a faculty member in the college of engineering at ONU, the author realized there are several special circumstances that must be considered when developing research projects that are appropriate for undergraduate students. First, unlike graduate students, undergraduates are only able to commit a limited amount of time to research.[12] Second, project schedules must accommodate the changing schedules of individual students during both the academic year and during the summer. Third, due to the limited technical background of undergraduate students, a significant amount of support and supervision is required of the faculty member. Fourth, there is little opportunity for research during the senior year unless it falls within the parameters of the capstone design course or other required courses, since the capstone project demands a great deal of the students' time. Finally, faculty members in a teaching university have extremely heavy loading in teaching and academic advising, and can only commit a limited amount of time supervising undergraduate research.

Since undergraduate students have a learning curve of engineering knowledge from freshman to senior year and tight curriculum schedules, the research projects must be packaged in small modules that are appropriate to changing knowledge levels and/or can be incorporated into their course work. The objective of this paper is to discuss the design of undergraduate research activities in order to ensure a positive educational experience while accommodating the limitations mentioned above. Two undergraduate research projects, used as examples in this paper, have been conducted primarily by undergraduate students. Each project has been tailored into small modules according to students' knowledge level. As students' engineering knowledge grows, the projects are finished module by module, from basic experimental work to theoretical analysis and numerical simulation.

Background

Ohio Northern University (ONU), established in 1871, is a private, comprehensive undergraduate university which has five colleges including Arts and Science, Law, Pharmacy, Engineering and Business Administration. The College of Engineering, with a student population of approximately 470 students, offers degrees in civil, mechanical, electrical and computer engineering, and in computer science. With small class sizes (around 30 students in each class), faculty members have close relationships with students, but also have fairly heavy teaching and advising loads.

While graduate students are often expected to dedicate portions of their time to research, undergraduate engineering students typically have heavy course requirements, part-time jobs, and extracurricular activities - all combining to limit the amount of time available for participating in undergraduate research projects. Similarly, while graduate students have typically already developed the basic knowledge and academic skills required for independent learning, the technical knowledge of undergraduate students develops gradually, and almost always requires significant guidance. In the mechanical engineering curriculum at ONU, technical courses are limited in the first year to calculus and physics; during the second year, students begin to acquire basic engineering knowledge including engineering mechanics, material science, and circuits; in the third year, students take mechanical engineering courses including heat transfer, control systems, and mechanical design; in the senior year, students take higher level engineering courses including finite element analysis (FEA) and computational fluid dynamics (CFD). In addition to this course work, seniors are also required to complete a year-long capstone design project. During the first two or three years, students have little of the technical knowledge required to perform research work independently. By the time students have gained the knowledge, skills, and intellectual maturity required to complete a research project, they are nearly ready to graduate.

It can be expected that advising undergraduate research needs a significant amount of support and supervision from faculty members. However, faculties in undergraduate programs like the Mechanical Engineering Department at ONU have heavy teaching, advising and service requirements. Usually one faculty member teaches six or more courses an academic year in addition to committee service, academic and capstone project advising, lab instruction, and professional development. In addition, due to that absence of graduate students, faculty members also do their own grading, hold office hours, and run their own labs. Therefore, it is difficult for faculty members to also find the time required to closely supervise undergraduate research assistants. However, with proper planning and accommodations, undergraduate research projects can be successful. In the following section, two projects are used as examples to demonstrate how research projects can overcome the limitations described above.

Research project description

While undergraduate students have a learning curve on engineering knowledge, research work needs to be arranged based on education pace. During the freshman year, research work is introduced to some good students through an interdisciplinary independent study course. Some basic concepts related to future research projects are introduced to students. In the sophomore year, students focus on lab work such as material tests. In the junior year, students can perform mechanics analysis and a variety of experiments. In the senior year, students can conduct numerical analysis. The following two projects are used to show details on how to perform the research work.

Project 1: Cool polymer heat exchanger and material enhancement

College of engineering of ONU received indirect NSF support from 2006 to 2011 via participation as an affiliate school of CLiPS program. CLiPS, Center for Layered Polymeric Systems, is a NSF Science and Technology Center that is led by Case Western Reserve University. The center focuses on the research of multilayered polymers. ONU faculties initiated an interdisciplinary educational program to prepare students for research and development of advanced polymers. Students can be motivated by hands-on research experiences in labs. A few projects were designed related to the CLiPS program and polymer heat exchanger project is one of them. The project has been an ongoing project starting from 2007.

Plate heat exchangers are used increasingly in marine environments to save both energy and water. Due to the strongly corrosive effect of seawater, these plate heat exchangers are usually made of very expensive metals, such as titanium and its alloys, which have a high long-term corrosion resistance. Innovative thermally-conductive polymeric materials (cool polymers) are strong candidates to replace metals in these applications because of their excellent corrosion resistance, low cost, and ability to be formed into complex shapes. The cool polymers, which are thermosetting polymers, have good thermal conductivity (comparable to stainless steel) but relatively low ductility and strength. A plate heat exchanger prototype was fabricated from a cool polymer in order to investigate both the advantages and limitations of the material. The low ductility limits the application of the materials as structural materials in industry, but with the addition of other types of polymeric materials, the applications could be very broad. So far, three faculty members and eight undergraduate students have participated in this project. The project is tailored to the following small packages:

- Heat exchanger design and manufacture;
- Heat exchanger performance experiment;
- Numerical simulation of heat transfer performance;
- Material processing;
- Material mechanical properties test;
- Material thermal conductivity test.

A heat exchanger prototype has been designed and machined by a professor and sophomore students. Each plate has grooves as shown in Figure 1. Heat transfer rate and pressure loss has been tested by junior students with the test setup as shown in Figure 2. In addition to evaluating the performance experimentally, a numerical simulation will be completed to predict the thermal and mechanical behavior of the polymer heat exchanger using the ANSYS finite-element software. This analysis allows the thermal stresses within the heat exchanger to be better understood. This numerical simulation work will be done by senior students as a term project in their FE course.

Figure 1: Prototype of cool polymer heat exchanger plates.

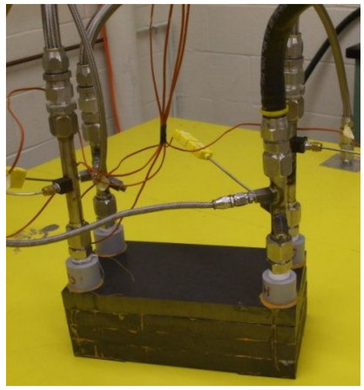

Figure 2: Cool polymer heat exchanger test setup.

The effect of the addition of phenolics is studied to identify the mechanical properties and thermal conductivity of cool polymer materials and the feasibility of producing polymer plates for the heat exchanger. In this application, phenolics allow these polymers to retard most chemicals and heat. In order to attain polymerization between the "cool polymer", phenolic resin was added to the cool polymer in different percentages to gain desired results. Table 1 shows a sample test matrix for the addition of the phenolic resin. The heating time for this set of tests is 8 minutes per cycle. The research team used a Wabash 12 ton compression molding to attain polymer plates for testing. In order to test the mechanical properties, compression tests were conducted on samples with dimensions of 1"x1"x6" using the Tinius Olsen machine. Results are also shown in Table 1. This package was developed as a collaborative effort between the Mechanical Engineering Department in the Engineering College and the Technological Studies Department in the Arts and Sciences College on the campus. Faculty members and students from both disciplines conducted research techniques ranging from compression molding of polymer processing to mechanical and thermal property tests.

Table 1: Test matrix for material processing of the mixture of the cool polymer and phenolic resin and the corresponding compressive strength

Percentage of cool polymer (%)	Temperature out of mold (^{o}F)	Temperature of 5 minutes later (^{o}F)	Compressive strength (psi)
20	340	293	210
30	335	291	205
40	342	288	201
50	356	284	155
60	320	268	187
80	315	262	184

Project 2: Single Screw vs. Double Screw Device for Femur Bone Fracture

This is a biomechanics project collaborating with a physician from the Institute for Orthopaedic Surgery in Ohio. Proximal femur fractures commonly occur between the head of the femur and the femoral shaft as shown in Figure 3. Medical devices are needed to stabilize these fractures. A traditional device which includes a single cylindrical screw is widely used to repair the bone fracture. However, the application of the single screw device still suffers technical problems. The head has potential to rotate about the screw and the fracture surfaces have potential to slide over each other. In addition, force relaxation might lead to inadequate contact between the fracture surfaces. To solve these problems, a new device has been developed by Smith & Nephew Medical LTD. It has two screws that are integrated together creating a figure-of-eight configuration on cross-section as shown in Figure 4. The objective of the study is to provide evidence that torsional stiffness is increased and fracture surface sliding is delayed or prevented with the new device. This project is tailored to the following packages:

- Set up torsional stiffness test including design and manufacture of fixtures;
- Test the torsional stiffness of the fractured femur bone stabilized with the two devices;
- Perform mechanics analysis;
- Conduct FE simulation of the internal stress and deformation.

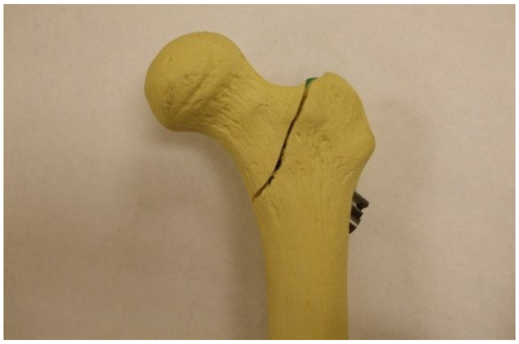

Figure 3: Proximal femur fractures that occur between the head of the femur and the femoral shaft.

Figure 4: Double cylindrical screws device with two screws integrated together creating a figure-eight configuration on cross section.

Three undergraduate students work on this project. They first met with the physician to get familiar with the background of the project. The experiment was setup first including designing and manufacturing the grips as shown in Figure 5. The torsional tests were performed on bone samples with the two devices. The relationship of torsional stiffness with internal friction between the device and bone was analyzed. The FE simulation work was carried out as a term project for the senior FE course. Figure 6 shows the 2D FE analysis results for internal force and stress distributions for the two devices. 3D model of the broken femur was also created using 3D laser scanner and used for 3D FE analysis. A poster regarding this project was presented in the 4th Frontiers in Biomedical Devices Conference and Exposition [13]. The senior students are writing a paper on the project.

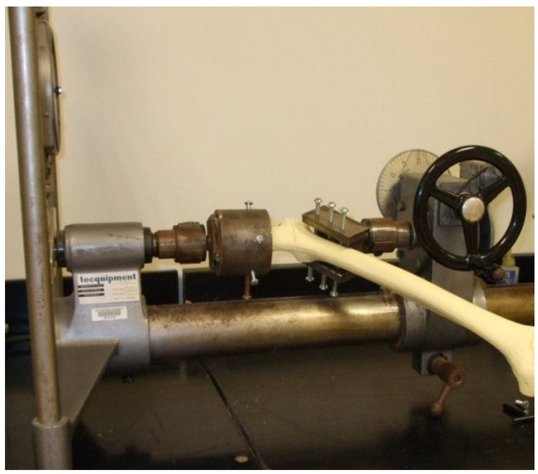

Figure 5: Torsion test to measure the relationship between applied angular rotation and the resultant torque

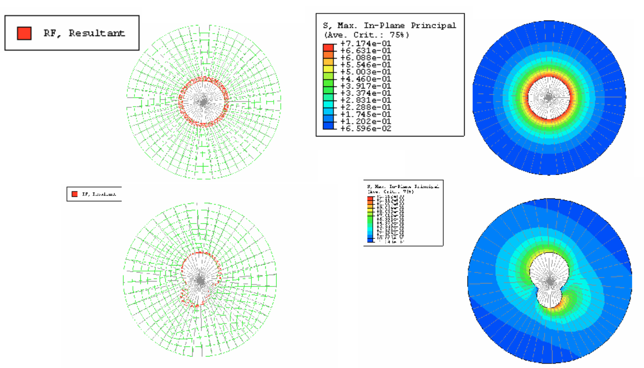

Figure 6: 2D Finite element modeling to study microscopic responses of each device's interaction with the bone

Outcome

All the students participating in the research work have good academic standing. No one has dropped the engineering program so far. The research experience did help the retention rate of undergraduates in the engineering program. While all the involved students are currently juniors and seniors, after participation in the research work, some of them are interested in graduate school. However, due to the small sample size and different levels of involvement of the students, it is hard to show the positive impact of the experience on students quantitatively. It should be mentioned that all the three students participating in the biomechanics project are female students. Two of them are applying engineering graduate programs related to medical devices. They are very interested in applying the knowledge of mechanical engineering and problem solving skills in biomedical field. While female students in particular are attracted by careers that offer social and environmental impact [14,15], the potential for a career in biomedical engineering can be used to attract prospective students, especially female students, who otherwise might not consider a degree in mechanical engineering. These research projects will used as demos for existing outreach programs at ONU. On the faculty side, the research experience helps faculty members to keep their knowledge current and apply their research experience in teaching. For example, through advising the research project on medical devices, a faculty member decided to develop a senior technical elective course on medical devices.

Conclusion

In an undergraduate engineering program, there are several limitations that must be acknowledged while conducting research. Both undergraduates and faculty members have busy schedules due to course work and other activities. In this paper, a model is introduced that enables undergraduate research projects while accommodating these circumstances. Research projects need to be tailored to small packages according to undergraduate students' knowledge level and schedules. These small packages can be completed separately by different students. Some packages are incorporated into course work. Results show that the ability to support undergraduate researchers will provide an opportunity for those students who are strongly interested in engineering research to pursue their interests more deeply. The projects can also serve as demos for outreach activities. On the faculty side, the research work helps faculty members to keep their knowledge current and apply their research experience in teaching.

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