

## **AC 2010-1861: LINKING SENIOR DESIGN PROJECTS TO RESEARCH PROJECTS**

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# LINKING SENIOR DESIGN PROJECTS TO RESEARCH PROJECTS

## Abstract

Senior design projects form an important capstone for most engineering disciplines and must consist of the realistic application of the engineering design process. Some senior engineering students would like the opportunity to participate in research projects, but cannot give the time to perform research and participate in a senior design project. The authors have served as either faculty or students in combined research and design projects for several years, and have made several observations about this combined approach.

Many research projects offer the opportunity to perform engineering design although recognition of this fact is sometimes overlooked by faculty. Some general cases where design may be needed in a research problem include: design of an experimental system, engineering software design, and design of a process to manufacture experimental test pieces. Once a design aspect of a research project has been identified, the faculty member that will oversee the design project should carefully consider how the project will require the design process, whether multiple alternative designs will be considered, and in what way will the project satisfy multiple realistic constraints. Students in the design group may already be working on the research project and it has to be clear to these students that they will be doing two projects: the research project and the design project. Use of a design proposal that is signed by the faculty member and students can aid in making sure that all involved, faculty and students, know how the project will meet the research program's and ABET's expectations in terms of design.

Our experiences with combined research / senior design projects are discussed in this paper.

## Introduction

This paper is focused on the use of engineering and physics research-related problems used as senior capstone engineering design projects. Capstone design projects must be focused on design and hence are often viewed as incompatible with research projects, which may be discovery rather than design-oriented and without concrete deliverables. In many cases, however, it is possible to find a design-related problem for an engineering or physics research project.

The Engineering and Physics Department (EPD) at the University of Central Oklahoma (UCO) has been using research-related design projects to satisfy requirements for a Senior Engineering Design course for several years. There are two engineering programs at UCO: Biomedical Engineering and Engineering Physics. These programs are recent and developed from a physics program. The programs by their nature are interdisciplinary and have a tradition of sending students to graduate school and to industry. Participation of undergraduates in research-related projects has been common at UCO. It is very difficult for students to complete course

requirements, to carry out research, and to complete a significant senior design project in the last two semesters. A design project related to research allows students to be involved in research and get design experience as well.

### **Engineering Capstone Design Experiences**

Two significant studies<sup>1,2</sup> concerning senior engineering capstone experiences have been conducted in North America since the 1990's. The study by Todd et al.<sup>1</sup> was conducted in 1995 and included a array of 360 responses from engineering departments. There are many interesting findings in the report, including the small number of programs with interdepartmental senior design courses and that a significant number of capstone experiences were individual rather than team projects. The authors suggested two “areas of improvement in engineering education,” including and increased practice of teamwork and involving industry in order to give students preparation for “real-world engineering practice.” There is little doubt that this study impacted engineering programs to use teamwork more and to increase interdepartmental projects as seen by a follow-up survey in 2005 by Howe et al.<sup>2</sup>. A total of 444 programs responded to the survey by Howe et al.<sup>2</sup> and in just over a decade the percentage of individual-based capstone projects decreased from 32% to 18% and the use of interdepartmental teams increased from 21% to 35%. Certainly, the revised ABET criteria for 2000 had some part in this change as influenced by Todd et al.<sup>1</sup> One other note regarding the 2005 study by Howe et al.<sup>2</sup> is that 46% of respondents said the source of their projects was faculty research and 71% said the source of their project was industry. This point was not addressed in the survey by Todd et al.<sup>1</sup>. The types of research projects are not clear except that there must be overlap with the industry sponsorship of these applied research projects. There was a noticeable increase in external projects from 1994 to 2005 as well, as Todd et al.<sup>1</sup> suggested as an engineering education improvement.

Howe et al.<sup>2</sup> received some information that a number of projects were based on faculty research, but it appears many of these projects were industry driven. Industry sponsored projects are a positive in many ways for the programs, industry, and students that may eventually be employed by the business, but they may not serve to prepare the students for graduate research. As an example of the larger U.S. trend, in 2004 Labrador et al.<sup>3</sup> noted that there was a slow but constant decrease of engineering graduate students at the University of South Florida from 1996-1997 to 2004. The National Academies Press report<sup>4</sup> entitled “Rising Above the Gathering Storm - Energizing and Employing America for a Brighter Economic Future” indicates the need for more engineers and scientists trained at the graduate level and emphasizes the fact that access to advanced level science and engineering instrumentation is currently at a deficit. There are a number of studies<sup>5,6</sup> for example, that have found that small group learning, including undergraduate research, improves persistence in STEM (Science Technology Engineering and Mathematics) courses.

There have been some attempts to integrate research and related design into the undergraduate curriculum such as those to integrate nanotechnology<sup>7</sup> or use of engineering clinics<sup>8</sup>. Gonzalez<sup>9</sup> describes the blurring of undergraduate and graduate education at research universities. Students from research universities and regional and other schools should be prepared for a

multidisciplinary educational and research environment for graduate study. Exposure to research experiences for senior engineering students should help attract the resident students that the engineering graduate programs so badly need.

### **Senior Engineering Design I and II at UCO**

There has been a wide variation of the format of senior engineering capstone courses in North America<sup>1,2</sup>. At UCO the arrangement is a two course sequence each consisting of two semester hours. The sequence, entitled Senior Engineering Design I and II (SD-I and SD-II) always begin in the Fall semester. In this sequence there are lectures over topics in engineering design and related issues. Additionally, there are exams used for assessment of engineering science retention and background. The project portion of SD-I and SD-II is conducted as follows:

1. In the first few weeks of SD-I, self-chosen student teams develop a project proposal in coordination with a primary EPD faculty member and potentially other faculty or external sponsors. This project may be a sponsored project (either directly by faculty members or involving local industry) or a standard project which is chosen by the course instructor.
2. Students begin work on the project in SD-I, but have not completed a final design. At this stage the students are still understanding the project constraints and considering how to solve the design problem and basic conceptual design alternatives. Students are required to do planning at this stage from early in the SD-I course until the end of the academic year in SD-II. Gantt charts and other planning tools are standard requirements in project proposals and presentations.
3. The primary faculty sponsor approves the student proposal and by the end of the first semester students participate in a formal public presentation of the proposal and documentation of their progress including the final project deliverables. Standard grades are issued at the end of SD-I based on completion of course forms and reports, lab/project notebooks, professionalism, and peer-evaluated participation within each team.
4. In the second semester in SD-II students choose amongst the design alternatives and construct a prototype. Then the prototype is tested and improved and the design process cycle is carried out as time permits.
5. The final SD-II deliverables are a *final report*, *final presentation*, and a *poster*. The report is reviewed by the instructor and primary faculty sponsor. The presentation is judged by final presentation attendees, which includes faculty, students, and advisory board representatives. The poster is displayed in the hallway near the classroom typically used for SD-I and SD-II until it is taken to a statewide “research day” the next Fall semester.

### **Lessons Learned for Research-Related Senior Design Projects**

Some cases where an engineering design project may dovetail with a research problem include the design of a small scale system for an experimental research problem, the design of software for a computational research problem, and the design of a process to manufacture test pieces or other unique parts needed for an experimental research. For many research projects, identifying

a design aspect of a research problem that will meet the capstone course requirements is possible. The difficulty may be in deciding the scope of the project and whether it is advisable for a team to undertake a given project. Some general questions faculty members should ask to help determine the answer include:

1. Is the the level of the project appropriate for seniors in your program?
  - Some projects just are too complex, require too much of a time commitment, or too long of a time period for a senior design project.
  - Sometimes a project might be broken into pieces such that it would work for senior design. If managing the senior design team or training them to be really helpful to the overall project is not likely, another design project should probably be chosen.
2. What disciplines or other background are needed to perform the design portion of the project and does the proposed group meet these needs?
  - It is a good idea to assess a potential team's chance of success. If a particular background course is critical, then one should be careful to ensure there are not too many team members that will not be taking until their last semester.
  - Are there considerable construction, electronics, shop work, or other technical skills required for the project? If so is the proposed team capable?
3. Is the scope of the project appropriate?
  - This can be difficult to judge, but one should be somewhat conservative to ensure the project can realistically be completed.
  - If a larger or longer term research project is ongoing, the design project can be a smaller piece, or a related research problem that could be investigated in parallel with the main research project.
4. Can the project realistically be completed in the time frame of the capstone course?
  - Estimating the time to complete a project is difficult, but time spent up front to make a reasonable estimate of timing can help ensure the proposed project is not too long for the time period.
5. Is the budget sufficient?
  - If a faculty member has research project funding a budget should still be set so the design team has to meet an economic constraint that is not too different from the other teams in the course.
  - A faculty member without funding could use the senior design project to build a system to make preliminary measurements and apply for a grant.
6. Do both faculty and students understand the differences between the design project and the related research project?
  - It is important for the faculty member know the senior design project cannot be managed as a discovery-oriented research project. The project should be a design project that follows a basic engineering design process.
  - It is also important for the faculty member to make the difference between pure research and design clear to the student team. This distinction can be more difficult when students have been working on the research project prior to enrolling in senior design.

As with any senior design capstone, the make up of the team is important. The survey conducted by Howe et al.<sup>2</sup> in 2005 found that 60% of responding programs had an average of 4 – 6 members per senior design team. The authors' experience indicates a team size of four is the largest to consider. There seems to be a greater chance to have team members that do not participate in groups larger than four. In some institutions the project budget is tied to the team size, but it best to not add team members just to increase the project budget.

The following describes several research-related senior design projects that have been conducted at UCO in the last several years.

The project entitled “Design of a Process to Manufacture Artificial Pore Networks” was carried out in Fall 2006 and Spring 2007. Only one student from the senior design course was involved in this project, but the student worked with faculty and students from a nearby university in this collaborative project. The student designed a process to create small networks milled from acrylic. The networks were intended for fluid flow measurements to validate a porous media research code from a nearby university. The project was somewhat successful, but ultimately, the manufacturing process was not suitable for the intended use. This result was most likely due to poor initial consideration of the project scope, time frame, and design alternatives.

The project entitled “Design of a Low Pressure Measurement System for Small Scaled Fluid Networks” was carried out in Fall 2007 and Spring 2008 by a group of three senior students. The project was aimed at designing, building, and testing a system for use in fluid mechanics research. One author (Lemley) had recently received a three year grant to investigate fluid energy losses in small arbitrary junctions. Some computational work had been carried out on this problem at UCO prior to the senior design project, but the team was to construct and test a system for validation experiments. These students were highly motivated and met most deliverables for the project. This project was an unqualified success. The students even began making initial measurements for research use at the end of the project. Additional system improvements were undertaken after the project's completion and currently the system is being used to make the measurements needed for the research grant.

The project entitled “Design of a Laser Tweezer Apparatus” was carried out by a group of three students in Fall 2007 and Spring 2008. The project was to design, construct, and test a laser tweezer setup, which uses a laser to create an optical trap that may be used to manipulate microscale particles. This apparatus has possible uses in research in a number of engineering areas including biomedical engineering. This project was successfully completed and the students were able to trap microscale cells. The apparatus was set up for future use for other projects.

The project entitled “Design of an Experimental System for Microchannel Junctions” began in Fall 2009 and will continue in Spring 2010. The project team consists of two students. This project is an extension of the research associated with the project entitled “Design of a Low Pressure Measurement System for Small Scaled Fluid Networks.” The student team is to design

a technique to create arbitrary microscale junctions for microfluidics research. This project does not derive funding from an existing grant, but is closely related to this grant in terms of shrinking the size of arbitrary junctions from the milliscale to the microscale. The final design presentation will take place in April 2010.

## **Conclusions**

Although there are challenges to relating to conducting senior capstone design projects that are related to engineering research projects there are ways to minimize the potential issues and have the projects succeed in terms of meeting the capstone design requirement, giving students research experience, and furthering the research project. Possible research-related design projects could include design of small scale experimental systems, design of software for computational studies, and design of processes to produce or obtain experimental test pieces. Before undertaking a research-related design project, faculty sponsors should carefully consider the level, scope, time-frame, and cost of the potential project and whether the project will have the desired impact on the research program. Other considerations should include the team personnel, size, and background. Team members should be carefully evaluated for projects that require any special technical skills.

The most common issue in these dual use projects is the lack of the understanding of the differences between the research and design projects. It is best for the research project and for design experience of the senior students to have the faculty member as a client of the design team. The faculty member should set the needed research needs and specifications of the system, software, or process to be delivered.

After several years of experience of trying research-related senior design projects, the EPD at UCO has an environment where many students implement the engineering design process and get experience in engineering research. Undergraduate research activity in the EPD at UCO is growing every year with student interest and faculty grantsmanship. The design projects described here have created a synergistic effect of preparing graduates for the engineering profession and for graduate engineering study.

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