Initiating and Sustaining an Interdisciplinary Capstone Design Course

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Recognizing the complexities of modern engineered products and systems, a current engineering graduate should have knowledge, skills and attitudes from multiple disciplines as well as in-depth knowledge of a specific discipline. Additionally that graduate should be able to work in teams with those from a variety of disciplines in an interdisciplinary fashion. Since 2008, the College of Engineering at California Polytechnic State University has been offering a three quarter Interdisciplinary Senior Design Project course available to all students in the college of engineering. This paper describes the course and its interdisciplinary (not multidisciplinary) implementation. The course has evolved over the years and has become a fixture in the college of engineering with participation from students from nearly all 13 engineering majors and faculty from seven of the majors. This last year a new director of interdisciplinary projects has been established to maintain course continuity and to oversee its growth into the future.

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Introduction

Recognizing the complexities of modern engineered products and systems, a current engineering graduate should have knowledge, skills and attitudes from multiple disciplines as well as in-depth knowledge of a specific discipline. Additionally that graduate should be able to work in teams with those from a variety of disciplines in an interdisciplinary fashion. A more concrete and immediate requirement that new engineering graduates have multidisciplinary skills comes from ABET criteria 3(d) and (h): "an ability to function on multidisciplinary teams" and "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context."[1] Other influential reports such as *Rising Above the Gathering Storm*[2] and *Educating the Engineer of 2020*[3] have called for greater interdisciplinary outcomes from undergraduate engineering education. An ideal platform to create interdisciplinary outcomes is the capstone design project course that is found in the curriculum of most engineering disciplines. By the time students reach their capstone class, they have obtained substantial disciplinary knowledge and skills and identify strongly with their major.

In engineering, the capstone design class integrates the knowledge and skills attained in all previous undergraduate courses. The college of engineering at California Polytechnic State University-San Luis Obispo (Cal Poly) offers an Interdisciplinary Senior Design Project (Capstone) class that is open to any student from the 13 engineering majors offered by the College. Cal Poly as a university has a long history of requiring all students to complete a senior project. Historically, this was an individual activity under the guidance of a single faculty advisor that might or might not have significant design content.[4] Heeding calls from industry and ABET and due to increasing numbers of students, many engineering departments started changing to team-based design projects to fulfill the university-wide senior project requirement and improve student outcomes after the year 2000.[5] For the 2013-2014 academic year, seven of the 13 degree programs allow for team-based senior projects. Three of the programs require the senior project experience be team-based and have formal class and laboratory meeting times. The remainder of the programs have faculty meet with their senior project students informally at mutually arranged times (Note that most majors have a team-based design experience elsewhere in the curriculum other than the senior project). The courses with formal meeting times generally involve less faculty members, have more formal outcomes, and focus on transferrable design skills while the classes meeting at informal times tend to involve more faculty members and the focus is on the specific skills necessary for a particular project (design or research).

In 2007, a committee including representatives from all nine of the engineering departments met to develop a new Interdisciplinary Senior Design Project course centered on the design and construction of an artifact to satisfy an external client's requirements by a team of students from at least three different majors within the college of engineering. The course also has a rigid structure of meeting times (one lecture and two – three hour lab meetings each week) and spanned a full academic year. These represented a significant departure from the traditional Cal Poly senior project format and thus represented a significant change in the educational culture within the college. Not only would departments lose control over the direct course content, the students would be restricted to both a team-based and a design-process driven senior project experience. Additionally some faculty would potentially lose the ability to select students to work on their research projects if those students participated in the class. Overcoming these and other faculty concerns were major barriers to initiating the class.

Much of this concern was based on a disciplinary view of the senior project experience and a general distrust of change. For example, some faculty were concerned that students would not learn enough about their own discipline by taking the class as a substitution for their home department's senior project. Others were concerned that the design projects themselves would not contain enough disciplinary-specific content. Other ongoing concerns were that the design skills learned in the class were not as valuable as those learned in the department's own senior project course. These concerns largely originate from looking at the value engineers bring to a complex project from a multidisciplinary instead of an interdisciplinary standpoint. As posited by Borrego and Newswander[6] and further discussed by Richter and Paretti[7], when students work on a multidisciplinary project, they come together, contribute from and learn about their discipline and leave at the end of the project unchanged. This is contrasted with an interdisciplinary experience where the students will come together to work on a common problem, interact across their disciplines, and come away changed in some way with a design that is more than the "sum of its parts." Bradbeer[8] and DeZure[9] both point out that multidisciplinary learning is a process where each discipline adds to the whole as opposed to interdisciplinary learning which involves synthesis of ideas and creation of new knowledge. For the creation of the new course at Cal Poly, the focus was on interdisciplinary outcomes supported by the belief that interdisciplinary skills were more valuable than additional discipline-specific skills for senior level engineering students.

Course Content and Format

At the heart of an interdisciplinary design course is the focus on the design process. The application of this

Fall Quarter
• Design Process and Methodology • Specification Writing • Teamwork: Theory, Skills and Practice • Creativity and Idea Generation • Idea Selection and Decision Schemes • Project Management • Technical Presentations • Product Safety
Winter Quarter
• Material Selection in Design • Design for Manufacturability • Sustainable Design and Technology • Human Factors in Design • Intellectual Property • Global Perspectives in Engineering • Professional Ethics • Product Testing and Validation
Spring Quarter
• Cost Estimation • Ethics Case Studies • Corporate Culture and Professional Practice • Product Documentation • Entrepreneurship • Product Reliability • Global Competency • Life-long and Self-Directed Learning

Table 1: Course Content by Quarter

process is the primary transferrable skill attained by students. In the Cal Poly Interdisciplinary class, the student teams are guided by faculty advisors through all steps of a general engineering design process. The process begins by working with the client on developing a comprehensive list of engineering requirements. During this stage, the students go through the process of separating customer requirements and quantifiable engineering requirements. They also benchmark existing products, construct a QFD house of quality, and generate a project proposal document that is approved by the project sponsor (client). From here the students enter a creative phase where different concepts are generated using several creativity techniques. Emphasis is placed on idea generation as a team process where individual student disciplines are not a factor.

By the end of the first quarter, the students engage in a preliminary design review where they present their chosen concept that they believe will best solve the sponsor's problem. During the second quarter of the class the students perform detailed design work and have a critical design review with their sponsor. After this review the students begin in earnest to construct, test and modify their designs before finally presenting them at a public design expo. While the design projects provide an application of the design process, other professional and interdisciplinary skills are presented and practiced, such as project management, profession ethics and responsibility, global competency and intellectual property. Table 1 contains a list of discussion topics for lecture and supported by laboratory activities by quarter.

Projects

Projects for the course are proposed by external clients from industry, the local community or from faculty not associated with the class that need hardware to support their research. They are selected by the organizing faculty based on several criteria: First, the projects must be presented as problems which require the design and construction of a physical artifact for a solution. No preferred conceptual solutions are presented to the students as the students must determine the best configuration and approach. Second, the problem must require expertise in three or more engineering disciplines. All student teams consist of three or more students with at least three disciplines represented on each team. Third, the project must have an external sponsor/customer. As the primary role of the faculty member is to advise the students on the design process, it is not appropriate for the faculty member to have a personal interest in the success of the project. Finally, funding for the materials to construct the prototype must be provided by the sponsor. In addition to providing funds for prototype construction, there is a small project sponsorship fee associated with the class that can be waived for service projects. In all cases sponsors are not promised a successful outcome, only that the students will work hard on their problem and use a formal design process. The three faculty members teaching the course are responsible for obtaining the projects. Typically six to eight projects are undertaken each year with approximately 40 students enrolled in the class.

Example projects include:

- Spin bike power meter
- A neonatal medical device
- A beach wheelchair
- An adaptive feeding device
- A system to detect distracted driving
- A solar power light for developing countries

Student teams are formed based on their interest in particular projects and their discipline. They are provided dedicated laboratory space in which they could work on and store their projects. Feedback from external sponsors has been uniformly positive, and project outcomes have been generally excellent.

Making it an Interdisciplinary Experience

One key to the success of the class is to immerse the students into interdisciplinary thinking at the beginning of the course. The first 10 weeks of the class are devoted to activities where the students are forced to work across disciplinary boundaries to achieve project goals. For example, during the first week after assigning students to teams and generally organizing the class, the newly formed teams participate in a 1-hour design challenge. This is typically a fun event where the students are required to design and build a device out of a fixed set of materials to achieve a goal. An example would be to design a marshmallow launcher given a set of rubber bands, paper clips, Popsicle sticks, and the like. Immediately it is clear that no particular discipline has an advantage in creating the best designs. A discussion of group design process and the power of interdisciplinary thinking follows.

Next the students undergo teamwork training and activities including team problem solving and communication exercises. A discussion of Social Styles[10] and Tuckman's[11] stages of team development are followed by students writing a formal team contract. Next the students embark in earnest on their projects. As a guide to their project work, they are required to use a general engineering design process starting with determining customer requirements and engineering specifications. Again these are team activities with little in the way of necessary discipline-specific skills. The students quickly realize that the process of writing an engineering requirements document is a team function and not a specific disciplinary function. Next the students enter the creative phase and are coached to ignore disciplinary backgrounds during the conceptualizing process. For example, if a particular project requires a mechanical subsystem, it is perfectly reasonable for the electrical engineering on the team to come up with the best mechanical concept. Students are often overheard using examples from their own disciplines to conceptualize in a different disciplinary area. By the end of the first quarter the teams must select and present their best concept, and by then it is clear that the team has used an Interdisciplinary approach as opposed to Multidisciplinary approach to create their concept. Key to keeping the teams in this mode is substantial time spent in class with their faculty advisor guiding them as they follow the general design process. Typically the instructors are with the students in laboratory six hours per week. Clearly having adequately trained instructors is a prerequisite for successful interdisciplinary outcomes.

Sustaining the Course

Structurally the Interdisciplinary Senior Design Project class at Cal Poly exists outside any particular department. Since its inception in 2008, the course has been staffed by interested faculty given permission from their department chairs to participate. Each year new faculty members organize and run the class. This system was intended to bring new and more disciplinary viewpoints into the course structure and provide for an expansion of the number of students and faculty involved. By 2012, faculty members from Aerospace, Biomedical, Computer, Electrical, Manufacturing, and Mechanical Engineering had all participated in team teaching the class. Students from 11 of the 13 engineering majors had also participated by this time. Although the class had been successful in bringing faculty and students from different majors, the number of students enrolled had not raised much past the original offering of 36 students. The high turnover in faculty had the intended effect of spreading knowledge of the class throughout the college, but unfortunately the lack of continuity had resulted in some loss of the intended student experience. For example, some faculty who came to teach the class for one year, tended to treat the class in a similar manner as their own department's senior project, which did not include much formal content or supporting activities. They merely advised the students on how to complete their individual projects without emphasizing the broader transferrable interdisciplinary skills.

Another result of the lack of faculty continuity was the choice of projects. Often faculty members who volunteered for the course did so because they had specific projects that they personally wanted to see accomplished. Some of the projects where not presented as design problems to be solved, were continuation projects, or did not require the requisite three different disciplines. Instead the faculty viewed the class as a vehicle to achieve a project results irrespective of the course goals.

To address the lack of continuity and to also provide a platform to grow the course, a Director of Interdisciplinary Projects position within the college of engineering was created in 2013. One responsibility of the director is to oversee the staffing and course content of the Interdisciplinary Senior Design Project course. Changes for the 2013-2014 year also included the removal of the lecture portion of the class and including that information in the more active-learning based lab sections. The director will also oversee the screening of projects for the class to make sure they are good fit for the intended student experience. The director is also currently tasked with determining how and when the course should expand to include more students and how to train faculty new to the class.

Discussion and Future Directions

After six years of experimentation and tuning, the Interdisciplinary Senior Design Class at Cal Poly has reached a state of maturity and is considered a permanent and valuable addition to the college of engineering. Engineering students learn interdisciplinary design skills which make them valuable additions in industry. With the recent creation of the Director of Interdisciplinary Projects within the college, the class will now have the necessary continuity and maintain a vision to grow and improve. As of this academic year, only 40 of the more than 1000 engineering graduates are enrolled in the class. It is expected that under the leadership of the new director, this number will grow as more students and faculty see the value in the class. Another future direction is to better include students from Civil and Environmental engineering as well software engineering into the class. To date those students have been underrepresented.

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