AC 2009-1805: A FULLY INTERDISCIPLINARY APPROACH TO CAPSTONE DESIGN COURSES

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A Fully Interdisciplinary Approach to Capstone Design Courses

1. Introduction

We live in an era with unprecedented changes due to dramatic advances in technology on many fronts. The explosive growth in computing and communication has revolutionized the way we work and live. Increasingly the engineering work force is becoming more diverse with teams working with global foci. These forces of globalization, demographics, and technological advances are changing the role of engineering in society[1], calling for changes in the way universities address the engineering profession and education. It is important for students to gain the skills needed for this changing global economy and working environment. Engineers are increasingly required to be purveyors of technological solutions and must work together with marketing and business components in new product development. While we still must equip our engineers with strong technical skills, proficiency in areas such as communication, leadership, innovation, business and entrepreneurship is also necessary. This requires an interdisciplinary approach to engineering education. Simply adding marketing and business courses to the engineering curriculum often results in compartmentalized knowledge that does not provide experience and intuition into the complex relationships between the business and engineering aspects of product development.

Currently, the capstone experience in the Ming Hsieh Department of Electrical Engineering at the University of Southern California is similar in style and content to most other universities. Using a one semester (15-week) course, students receive loosely-defined design or product objectives either from faculty or industry sponsors, perform trade-off and other design analysis, complete a prototype, and prepare a written and oral presentation for review by panelists from industry or other faculty. In the spring of 2008, the Viterbi School of Engineering and Marshall School of Business piloted a program to integrate an engineering capstone design course (currently in computer and electrical engineering) with a product development and branding marketing course. Teams of engineering and marketing students are given a product to design and select a specific brand. The team works together to define system requirements and features that are consistent with their brand's customer base and pricing, while also performing market research with potential customers. Based on the results, the engineering teams design, implement and test a prototype while having to meet cost and other design constraints. Teams also enlisted help from external designers and artists for product packaging, models, and marketing materials. Results from the initial offering were excellent and the partnership is now expanding to include the School of Fine Arts for the product packaging and design materials. Above all, this pilot program provides a model for other cross-school, cross-departmental ventures in an effort to produce graduates capable of excelling in today's fast-paced, global economy.

2. Motivation and Background

The terms multidisciplinary and interdisciplinary are often used interchangeably, but originally the terms refer to different problem solving approaches[10]. By definition, *multidisciplinary* refers to collaborations of scholars and industry partners whose work is grounded in, and preserves the integrity of multiple established disciplines. However, if teams maintain these boundaries they often reach a point where their problem solving cannot progress adequately. It then becomes essential for team members to stretch beyond the fringes of their own disciplines to formulate

new concepts, research ideas, problem solving approaches, or novel discoveries[3]. It is at this point that interdisciplinary teams emerge and boundaries are blurred and shared. According to Daniel Feller[2], interdisciplinary practice "brings together different disciplines to address complex questions." Integrating the methodologies and analytical approaches of different disciplines changes problem definitions and defines novel solutions. As a result, new interdisciplinary fields emerge. Once these boundaries are crossed, transdisciplinary teams are possible. A transdisciplinary team is an interdisciplinary team whose members have developed sufficient trust and mutual confidence to transcend disciplinary boundaries and adopt a holistic approach across all represented disciplines[5]. Accordingly, transdisciplinary approaches lead to novel solutions and enable innovation. This problem solving and innovation is often at the core of major engineering teams, however without documenting this transformational process and measuring its propensity, transdisciplinary practice is often not replicable and scalable[11]. Figure 1 provides a visual depiction of these contexts and intersects.

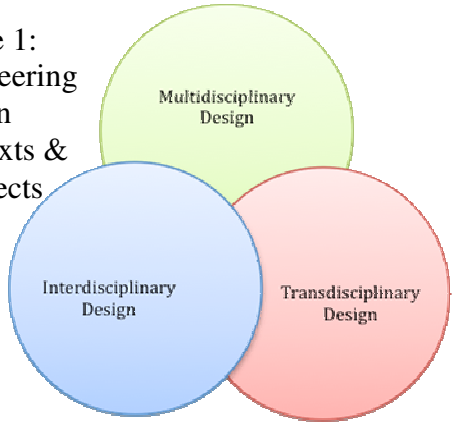


Figure 1: Engineering Design Contexts & Intersects

The Viterbi School of Engineering at USC has strong interest in interdisciplinary research and education. We are led by the following realizations:

- Technology fluency is becoming a necessity for higher education
- To compete in today's global economy requires our engineering graduates to be creators and innovators, finding new solutions to problems of society
- To become innovators, graduates require the non-technical skills needed to work and communicate effectively in interdisciplinary teams

With these in mind, we actively seek collaborations with other schools on campus and outside entities. Since there is strong interest among engineering students to learn about business and entrepreneurship, we wanted to develop a program for engineering students to gain fluency in business concepts, especially product development, as well as the ability to effectively partner with business students. Product development in today's environment must account for many factors other than technology, such as product placement and branding[12]. While students are required to take an "Engineering Economy" course that provides fundamental business and finance concepts, we found that it did not provide an authentic experience of the relationship between engineering abilities, constraints, and product success. This led us to team with the marketing department of the Marshall School of Business to pursue more novel approaches that would facilitate our students working in teams with each other.

Initially, engaging students from different disciplines to work in teams may seem straightforward however, there are many challenges. First, students in each school had little understanding of what the other did and the limitations they worked under. Students were unlikely to take courses in the other school for a number of well-known reasons, including: not having sufficient background knowledge, limited class space, and limited units available in their degree program.

In addition, our university has a revenue center model that would make it unlikely to add requirements for students to take technical electives in another school. Second, we did not want to create more "compartmentalized" knowledge by introducing business and marketing concepts in separate modules, guest lectures, or additional courses, but rather create an authentic experience that would provide skills and understanding rather than knowledge and theory.

To overcome these challenges while still producing an effective, innovative educational experience, we decided on the concept of an "**integrated assignment**" where students collaborate on assignments from their respective courses. In engineering, capstone design courses were natural candidates and the embedded system design course within the Ming Hsieh Department of Electrical Engineering was selected for the pilot program. On the business side, the marketing department created a follow-on practicum course to its "New Product Development and Branding" theory course. Run once in spring 2008, the program is running again in spring 2009, with a third collaborator in the Roski School of Fine Arts. The "Advanced Design Projects" provides product design, packaging, and artistic input and expertise. The following sections summary the approach to teaching these courses along with lessons learned throughout the pilot experience.

3. Approach

Interdisciplinary engineering capstone design courses are becoming more common and have provided helpful insight to effectively running such a course[8,9]. However, these efforts have mainly focused on collaboration between engineering departments. Providing an interdisciplinary experience between engineering and non-engineering students presents new challenges that are addressed below.

Project selection criteria: The selection of a project involves meeting requirements from three diverse groups. For the engineering students the primary requirement is to find a project that is challenging, can be built and debugged with the available facilities and can be completed in a 15 week semester. The students need to be able to go from hearing about the project for the first time in week one, to having it designed, constructed, debugged and documented by week 15. Ideally the project will include elements that require integration of components from several areas of electronics technology with an embedded microprocessor at the core. The project must also have enough freedom in its specification to let students explore several alternative solutions to both technical challenges and user interfaces.

The marketing students have very different requirements. The primary limitation is that the product must be something that can be marketed, preferably to a large number of customers. As part of their work, the marketing students conduct focus groups to gather information about interest in the product and the value consumers place on various features. As students, the only readily available pool of people they can draw from for their research is other students. This limits the potential products to either ones that students would purchase, or ones that they are very familiar with and can envision themselves purchasing in the near future. For example, an advanced irrigation control system for improving water conservation for homeowners is not something that groups of students living in dorms and apartments normally purchase for their own use.

The project requirements as they relate to the design students are not as restrictive as virtually all products need some amount of design input. The goal is to find a product where the design elements can have a significant impact on the consumer's decision to purchase the product.

In the initial offering, a simple seven-day alarm clock with daily alarm times was chosen. Technically speaking, this was less advanced than previous projects but suited the above criteria and allowed for a broad degree of freedom in feature selection and user interface. Surprisingly, we found that the desirable features that resulted from branding and focus groups introduced new technical challenges that required the engineering teams to create more sophisticated designs. Groups added MP3 player control, touch interfaces, and some milled their own PCB's as well as the plastic casing to create an actual, working device.

Class schedule and organization: The traditional engineering capstone course starts with two or three weeks of class meetings to discuss the project. The students are broken into teams with each team producing the same core product though with different implementation choices. In order to help the teams get started, a very general block diagram of the project is discussed with the emphasis on pointing out the places where there are multiple ways to solve problems in the design and encouraging the teams to start discussing the directions they would like to go in. The rest of the semester is devoted to teams working on their own project with weekly office meetings with the instructor. The class meets as a group once in the middle of the semester for a design review presentation in which students present their designs before implementing the prototype. Near the end of the semester, final project presentations are made to the class and a group of outside reviewers. A final written report is submitted.

The inherent collaboration necessary between engineering and marketing courses required altering the traditional 15-week semester schedule as well as synchronizing the start times of each course. Four or five joint sessions were scheduled where all classes meet together in one large classroom. The first is during the second week of the semester where instructors from each course provide an introduction to their field and what their students do along with some of the basic concepts and techniques. This provides each group of students some familiarity and fluency for the tasks of their teammates from other disciplines. It also provides a big picture idea for how each discipline fits into the whole development process. Later joint sessions are reserved for design reviews where teams can learn from each others' approach. This will culminate in final presentations from each team at the end of the semester. Most other weeks provide one class session where the teams of marketing, engineering, and design students can meet and collaborate in one of the three classrooms and another class session for separate meetings of the traditional course.

Team responsibilities and development stages: Each engineering and marketing team is assigned a brand such as Nike, Apple, Sony, or LG based on the market for the specific product. The brand determines pricing, design, and feature constraints that are consistent with the company and their customers (i.e. low-end pricing, "intuitive" interface, etc.) The engineering teams works in conjunction with the marketing team to define features, user interface, and budget.

The product design evolves over a period of several weeks as a result of interaction between the members of the engineering team and by input from the marketing and design teams. As the

results of the market research refine the specification, more and more of the hardware and software are implemented and tested. The goal is to have a "works-like" prototype complete by the eleventh week of the semester with four weeks left. This schedule provides several advantages. The marketing students can take the prototype and test it with focus groups to get more accurate data on the product's marketability. If some changes are suggested there is time to implement them. Meanwhile the design and engineering teams can work together for product packaging and size issues. Some engineering groups will fabricate their own PCB to insert into actual packaging prototypes created by the design students in the machine shop or in Viterbi "fab-lab". The goal is a prototype that works like and looks like the proposed product.

Outcomes: Technically, the results of this interdisciplinary experiment were excellent. Most teams succeed in implementing a prototype that meets a vast majority of the project specifications and expectations while a few still exhibit some bugs and occasionally a few have problems based on earlier design choices that were unrealistic or added too many features too late in the game. Even this "feature creep" provides a valuable education to both engineering and marketing students. Instructors also found that the greater latitude given to the interdisciplinary teams to come up with innovative designs greatly increases the effort and personal time that was invested. Students felt a "pride of ownership" that was much more pronounced than in previous semesters.

4. Assessment

In an effort to measure the impact of the interdisciplinary capstone course, we implemented two measures focused on students' perception of the team approach and their actual knowledge and propensity for interdisciplinarity and eventual transdisciplinarity. The items from the assessment were derived from key recommendations from the National Academy of Engineering's publication, The Engineer of 2020[7]. The "Design Team Structure and Knowledge" index is a three subscale inventory that measures students' knowledge about the importance of team structures and the role they play in workforce preparedness and leadership. The "Design Team Structure Preferences" scale is a four subscale, 6 point Likert-type measure that assesses students' propensity to engage in interdisciplinary and eventual transdisciplinary engineering work[4]. Both metrics are quantitatively focused and are comparable statistically, with large sample sizes. Both measures were administered after the end of the capstone course on both the marketing and engineering students.

Our assessment metrics revealed interesting results. Both groups valued the design team and gained knowledge about the importance of collaboration and leadership to solving engineering problems. Figure 2 provides important information about the knowledge gained about "team" importance, leadership for engineering and marketing problem solving, and for eventual career success. Blumenthal and Grothus[13] recognize that this leadership and problem solving are critical skills needed for global market places. All students scored relatively well on the design team structure and knowledge measure (m=4.7). This indicates that USC senior students are prepared to work in interdisciplinary environments, however diverse their responses to the metrics. The marketing and engineering students had diverse priorities on the propensity for interdisciplinarity scale (results below). As an example, the marketing students far preferred getting the "correct answer" to a problem as a top priority at the expense of engaging in collaborative work in comparison to the engineering students. Additionally, the engineering

students had a stronger propensity for interdisciplinary work than the marketing students, although both groups have relatively strong propensities for interdisciplinary work (m=3.6). Figure 3 illustrates the students' propensity for interdisciplinary and eventual transdisciplinary work. It is interesting to note that the engineering students were far more interested in leadership and cooperation than simply "finding the correct answer" to problems. This suggests a process orientation to their engineering work. Additionally, there were significant differences between the engineering and marketing students' preference for cooperation. We do, however report these results of our pilot study with caution as the total sample size for the study (those taking the post course measurements) was 20 students. Future course offerings will provide a broader assessment process. Current assessments will be run again providing more data and deeper insight to the effect of this course on the interdisciplinary and transdisciplinary preparedness of students.

Figure 2: Design Team Structure and Knowledge

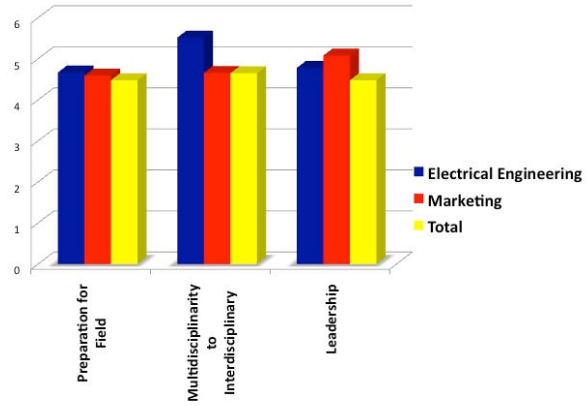
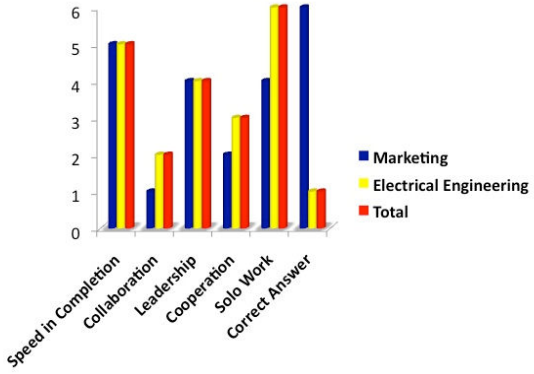


Figure 3: Design Team Structure Preferences: Propensity to Transdisciplinarity



Qualitatively speaking students also showed increased enjoyment of our capstone course. End-of-semester course evaluations are conducted and students are asked to rate the overall course on a scale of 1 to 5. The average over the previous eight semesters was 4.45. In its initial offering, the average student rating was 4.75 which correlated with anecdotal feedback from current students that this offering was unique and valuable.

5. Conclusion and Future Work

The integrated capstone courses were a resounding success. Both marketing and engineering students were more engaged, creative, took greater initiative, and expressed greater satisfaction with both courses. The engineering capstone design course saw an increase in fully functional, completed projects than in previous semesters while marketing students expressed a deeper ownership over the marketing concepts that were taught. Additionally, the metric's results from the course provided valuable information that is aligned to the "soft skill" outcomes required by ABET[6].

With our second offering in spring 2009, we have integrated the art and design course as our third partner and are implementing the approach outlined in earlier sections. With joint course schedules and more time designated for group meetings during class times, we expect our design team assessments will yield a greater appreciation and ability to work in interdisciplinary and even transdisciplinary teams. We are also exploring other partner schools and departments as

well as the adoption of this style of capstone course in our other engineering departments, for which this pilot program will serve as a model to emulate or adapt.

Despite many of the challenges that arose from this integrated, interdisciplinary approach the benefits are clear and persuasive. Our engineering students not only develop the communication, teamwork, and leadership skills needed to excel in their particular discipline but the framework needed to work in interdisciplinary and even transdisciplinary teams that are increasingly necessary in this complex commercial world.

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