Reinventing Capstone Design "On-the-Fly"

Cameron J. Turner[1], Candace Sulzbach[1], Jeff Schowalter[1]
[1]*Colorado School of Mines*

All courses change – either by plan or by necessity. When changes must be made by necessity, the transition can often be abrupt, leading to disruptive but transformative change. One cause of such change can be the unexpected changes in the management of such a course. These unanticipated opportunities can be used to address a wide variety of issues within courses, ranging from student concerns, faculty and curricular concerns and client desires. While planned changes and implementations would be preferable, the time for change is when an opportunity appears. This paper describes a set of changes made to the senior design program in the month leading up to the Fall 2009 semester and during the first semester when an opportunity for change asserted itself. Many of these changes have been successfully implemented and received, although a few remain works in progress. In the end, the only constant is that change will continue to happen.

Corresponding Author: Cameron Turner, cturner@mines.edu

Introduction

The Engineering Senior Design Program at The Colorado School of Mines is a two-semester course sequence, including students majoring in civil, electrical, mechanical and environmental engineering. The average enrollment of the course has risen by 10% in the last three years to approximately 250 students per year. Enrollment is predicted to continue to rise toward 300 students per year during the next few years.

An unexpected change in the senior design program management afforded the Engineering Division an opportunity to reconsider the state and direction of the program in light of emerging feedback from the existing course customers. These customers included the faculty managing the course, the faculty in the department, the students enrolled in the class, the external project sponsors, the major specialty programs utilizing the course (Mechanical, Civil, Environmental and Electrical Engineering) and an associated Humanitarian Engineering minor program. The course is a two-semester sequence with projects that are both paper and hardware in nature.

Unfortunately, the initiator of the change was unplanned, and led to an "on-the-fly" implementation of a revised senior design curriculum. While disruptive, this implementation has had a transformative effect upon the program and its perception by students, faculty and project clients.

Drivers of Change

The reasons for changes to the course came from many sources. While prior changes to the course have increased project satisfaction from the project clients (who sponsor the project and provide the real-world tie for the design teams) [1], other issues have emerged from both faculty and student customers as a response to these course changes.

Information provided by current students and recent graduates identified several areas of course concern from the students. These concerns included:

- A general lack of coordination between different faculty advisors leading to disparities (either real or imagined) between students working with these faculty members. Simply put, many students felt that it mattered more which faculty advisor was assigned to mentor students, that what work they did in the course.
- A course structure that led to students executing design methodologies on projects that were not useful or appropriate for the particular project; which in turn was interpreted as an inefficient utilization of the time and resources of the students on their projects.
- A lack of structure for the course that enabled teams to "crash" the project. Thus, some projects were seen as inadequate to be completed within the two-semester course sequence.
- A significant number of graduates who either did not desire to continue to learn about design as a science, or who were inadequately prepared to participate in the design community at a graduate or professional level and thus gravitated to other areas of engineering.
- A requirement for multidisciplinary design teams that led to design projects with contrived elements to engage a disparate set of technical backgrounds.
- A lack of specialized technical support and involvement from the engineering faculty to help the students with individual projects.

Discussions amongst the Engineering Division faculty also revealed additional concerns with the structure of the course and the direction of the design program. Amongst these concerns were:

- An apparent focus on design as an art, without appreciation for the design with a scientific basis.
- A lack of requirements for the application of engineering analysis in design. The use of engineering analysis being what distinguishes engineering design from craftsman or artistic design[2]. This was exemplified by a number of projects, which failed to meet the customer requirements, often due to a lack of design analysis on the part of the project team.
- A number of design projects that did not contain appropriate material for a capstone design experience and/or emphasized non-engineering aspects such as the development of marketing materials and business plans.
- Concern for the demands made by the course upon the supervising course faculty, the faculty advisors (who are typically adjunct faculty but could also be teaching assistants), the students and different program customers.
- An increasing focus of the class on project management and paperwork issues instead of on engineering design.
- A lack of integration with the engineering curriculum and the senior design experience.

Implementing Change

A change in the leadership of the design program in the summer of 2009 brought many of these issues to the forefront and ultimately led to a reinvention of the course. In a half-day workshop in July 2009, the Division of Engineering faculty agreed that changes to the program were necessary, and a new leadership structure emerged.

The new leadership structure includes three faculty members, representing the mechanical, electrical and civil engineering specialties (including about 95% of the students in the course), replacing the single faculty member responsible for the entire program. These three faculty members engaged in a course redesign exercise in August 2009 that was executed for the Fall 2009 semester. Currently, these appointments are permanent, although a rotational structure has been proposed.

The first outcome of the summer exercises was to reconsider the course goals. The original course goals included:

- To practice open-ended problem solving skills through a hands-on, technical project
- To participate in a multidisciplinary design team
- To improve written and oral communication skills
- To interface with the "real world", and
- To develop a professional work ethic.

These goals in turn were derived from the ABET criteria[3] which include:

- The ability to design a system, component or process to meet desired results
- The ability to function on multidisciplinary teams
- An understanding of professional and ethical responsibility
- An ability to communicate effectively
- The broad education necessary to understand the impact of engineering solutions in a global and societal context
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Many of these goals were not controversial, but others revealed that the faculty desires were not adequately represented either. For instance, the requirement for multidisciplinary design teams was often interpreted as a need to place civil, electrical, environmental and mechanical students on a design team, without sufficient concern for the technical requirements of the project. As an example, an electrical engineering major was assigned to a civil engineering project to provide a wiring plan for a light necessary for their project. The electrical scope of work in the project was not adequate in the eyes of the Division of Engineering faculty for a senior design project.

In response, the Engineering Division faculty chose to interpret this program goal differently. Project quality was emphasized over the multidisciplinary design team requirement. This would enable the program to accept quality design projects even if they did not include all represented disciplines and also enabled the program to more effectively staff design projects with appropriate skill sets. Projects are now reviewed extensively before being accepted, with scope and deliverables negotiated with clients before the project is accepted. As a result, projects accepted for the Fall 2009 semester and beyond often include a subset of appropriate disciplines, rather than trying to include other disciplines.

The last ABET requirement also received renewed attention. The previous senior design course had evolved into a "just-in-time" delivery of a limited set of design methodologies. The limited scope of these methods did not satisfy the desire of the Division of Engineering faculty to teach a broad set of design skills that would support the ABET criteria. However, they also expressed concern that teaching a broader set of design methods would require additional time-

investments by the faculty and students in the course, which was already an issue of concern for both parties.

In implementing the new course, the senior design leadership adopted a dramatic solution that offered several curricular benefits.

The first eight weeks of the course were set aside to teach a broad ranging set of design methodologies, including techniques and results recently published in the research literature[5]. These methods include customer needs, functional analysis, ideation methods, decision-making approaches and project management techniques. During this portion of the class, students are assigned to a multidisciplinary design team to engage in a reverse-engineering project. During the course of the project, they are introduced to and apply a number of design methods. At this time, while we have an interest in adopting a course text, we have not done so.

By introducing this material in advance of the senior design project, students are more willing to use the methods during the first portion of the course, knowing that the assignments are intended to develop skills that they may use in the senior design portion of the class. A consequence of this model is that the time for the senior design project itself is reduced from approximately 30 weeks to 21 weeks. However, during this time, students are expected to use methods appropriate to their particular design problem to support their design efforts. The students have positively received this reduction in "busy-work", and the clients have been positively receptive to this change as well.

There are two additional by-product benefits observed from this change. First, the course now requires the students to propose how they will apply design methods learned in the first portion of the class to their project beginning in the second half of the first semester of the course. This is much like a real-world design activity where an engineer needs to tailor their approach and methods to the specific design problem. Students develop and propose this plan in a new writing assignment due about 12 weeks into the first semester. As a part of the same assignment, students also are asked to explain how their engineering coursework will be used to execute their design process. This activity provides a strong link between the content of the course, the degree program, and the engineering design project. This in-turn reinforces the idea that continuous learning will be an element of their engineering careers.

The second benefit observed from the new first semester course structure is that the students obtain two design experiences. The first is through the reverse engineering project, which is a unique design activity in its own right, but also uses teams formed using Myers-Briggs-Test Indicator (MBTI) results and techniques advocated by Wilde[4]. This team experience teaches students to work in assigned teams, and students often have a realization that their peers "see" problem solutions differently. These teams are also often multidisciplinary, and thus reinforce the ABET criteria and program goals without the problems associated with forced integration of multidisciplinary content into projects.

We have adopted a different team formation strategy for the senior design project compared to the reverse engineering project where the students are assigned by MBTI results. For the senior design project, students self-identify design teams and competitively bid for their choice(s) of design project. To be competitive, students need to identify the necessary skill sets for the project(s) that they intend to bid on, and recruit from their peers students with the necessary skill sets. This is a promising entrepreneurial experience for the students and brings a real-world aspect to project selection.

Learning from the Students

As the new senior design course has been implemented, the course faculty communicated with the students about the changes we have made, why we are making them, and the need for their active participation in the process of change. Encouragingly, the students have responded by communicating with the faculty a number of innovative modifications that will be adopted in subsequent semesters. The faculty encourages communication by demonstrating a willingness to make changes in response to their comments.

Since the first day of class, the concerns of the students were openly addressed and the plans to change the class were explained. For instance, student perception of an inconsistent grading basis were addressed through several approaches, including:

- The use of grading rubrics, which are available to the students as well as all faculty advisors
- Regular meetings with all course faculty and faculty advisors to develop a common point-of-view with respect to grading
- A statistical comparison of the grades of individual faculty members, and
- Finally, assignment of students to different faculty mentors during each phase of the class.

Ultimately, the goal of these approaches is to establish a transparency of grading and consistency of course administration that the students did not believe existed within the course.

In addition, the course faculty has taken a significant role in the solicitation, development and acceptance of design projects. A targeted scope for the projects has been developed, and a focus on engineering design activities has been emphasized. Projects that do not initially meet these criteria are first refined with the client in order to be compatible with the course. Once

accepted, the projects are also assigned a Technical Consultant from the Engineering Division faculty, to encourage and assist the team with substantive engineering analysis to support their design work. This extra involvement has more closely tied the engineering faculty to the design program and is addressing the student concerns with respect to project scope and technical support. Project descriptions accepted in 2009 are available at the program website[6].

Learning from the Faculty

The increased involvement of the Engineering Division faculty with the senior design program revealed previously unidentified customers. Some faculty use the program as a portion of their research activities. Others have minor and other degree programs that assume specific content is delivered within senior design. Still others act as external project consultants while a few are involved in developing and delivering the curriculum. The evolution of the program had not served or even recognized all of these customers, and they have now found a new voice and interest in the future of the program.

Identifying these previously unidentified customers has been both beneficial and problematic. The increased interest has made change more attractive to the Engineering Division faculty, but the increased number of interested voices has also made it much more challenging to find satisfactory compromises. What works for one customer is often seen as a disadvantage to another customer.

However, the emergence of a substantial curricular component based on established and emerging design methodologies has been well accepted by the Division of Engineering faculty. Raised standards for project development and acceptance have also been well supported. The increased emphasis on engineering analysis and consequently a reduced emphasis on project management also has been enthusiastically received. Each team is now assigned a technical consultant, an Engineering Division faculty member who is responsible for encouraging and assisting the team in performing rigorous engineering analysis. This new faculty function also has engaged many more Division of Engineering faculty into the program.

The demands on the time of the students, the reduced time-scope of the projects and the changes to the course which have resulted in a perception of increased demands upon the faculty advisors (in particular) continue to be items of considerable concern, despite efforts to mitigate the impact of the course changes in these areas. These are issues that will require continued implementation of new changes to the existing course and to the expectations of the customers involved.

Conclusions

Abrupt course changes are rarely the preferred method for implementing new changes into a course. However, when driven by external forces, an abrupt change in the delivery of a course is an opportunity to redesign the course in light of new and emerging concerns and customers. Such opportunities also can lead to considerable enthusiasm for changes that would be difficult to sustain during an incremental course transformation.

At the Colorado School of Mines, a transformative change in the structure of the senior design program has been accomplished by identifying the program customers and their concerns and needs for the program. This complex tapestry of interwoven goals and needs makes the on-the-fly redesign of a capstone program a challenging iterative process. While substantial changes can improve a program from semester-to-semester and year-to-year, ultimately continuous change and improvement are essential to any program. The occasional opportunities for transformative change due to external factors should ultimately be seen as a positive opportunity for improvement, instead of a reason to stay with the status quo.

References

1. Skokan, C., Burczyk, R., Munoz, D., and Sutton, D. (2007). "Assessment and Evaluation of Engineering Senior Design at Colorado School of Mines," *Proceedings of the 2007 National Capstone Design Course Conference*, Boulder, Colorado, June 15-17, 2007.
2. Eder, W.E. (2009). "Why Systematic Design Engineering," *Proceedings of the 2009 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, DETC2009-86067, San Diego, California, August 30 – September 2, 2009.
3. ABET. (2008). *Criteria for Accrediting Engineering Programs*, 2009-2010, ABET Inc., Baltimore, Maryland.
4. Wilde, D. (2009). *Teamology: The Construction and Organization of Effective Teams*, Springer Verlag, Berlin, Germany.
5. Saunders, M., Seepersad, C. and Otto, K. (2009). "The Characteristics of Innovative Mechanical Products," Proceedings of the 2009 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC2009-87382, San Diego, California, August 30 – September 2, 2009.
6. CSM Engineering Division Senior Design Website, http://engineering.mines.edu/research/senior-design/, Last Accessed April 28, 2010.