2007: INVOLVING INDUSTRAIL PARTNERS THROUGH THE CAPSTONE DESIGN COURSE

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Abstract

The Mechanical Engineering curriculum at the FAMU-FSU College of Engineering features a capstone one-year senior design course in which students work in teams tackling engineering problems provided and sponsored by industrial partners. This paper describes the evolution of the capstone course over the last eight years. As the course matured, the department has been able to attract more and more industrial sponsors; today almost all the senior projects are sponsored by industry. This high level of industrial participation allows us to draw some important conclusions on what constitute "best practices" for capstone design courses.

Introduction

The Department of Mechanical Engineering at the FAMU-FSU College of Engineering adopted an integrated curriculum in the late 90s. Major themes within the discipline are grouped in two-semester sequences with a corresponding laboratory (e.g., thermal-fluids, mechanics and materials, etc.). The teaching of design has been integrated to the curriculum by devoting a certain fraction of the coursework or labs to open-ended design problems. The curriculum is capped with a one-year senior design project in which the students work in teams to design and implement products or systems under the sponsorship of an industrial partner. This paper briefly chronicles the evolution of the capstone course, and describes in detail the format and mechanisms used at the present time. We will stress aspects related to industrial participation..

Evolution of the Capstone Design Experience Course

It has been recognized that capstone design courses represent an excellent vehicle to round out a good engineering education and they provide the appropriate platform for students to apply design thinking and transition into a professional career[1]. Many universities have adopted this model for their engineering curricula[2,3,4] .At our department this course was first introduced as a one-year sequence within an integrated curriculum in the 1999 academic year, undergoing both gradual and year-to-year significant changes.

Evolution in Capstone Course Format

When this capstone course was first introduced in 1999 it was conceived as an integrated lecture plus project course. The course spanned the Fall-Spring semesters worth 4 units each semester (8 units total). The mechanics involved traditional lectures twice a week (75 minutes each), although since projects were running concurrently, approximately every three weeks the lectures would give way to student presentations (design reviews). The rationale behind the lectures was to introduce, "just-in-time", material relevant to the phase in which the projects were at the time of the lecture. For instance, early in the first semester, most lectures would deal with subjects such as team dynamics, the design cycle, or concept generation and selection. As projects made progress, the lectures would attempt to follow the design cycle as best as possible. When the teams were ready to produce the first major design report, the lectures would feature a module on technical writing or graphics in engineering.

This approach of "just-in-time" lectures worked well early during the early weeks of the course, however it is not possible to cram all project-relevant material in the first semester (much less early in the first semester). As a consequence, some topics that could be useful during the early design phases of the project, could not be covered until the Spring semester, and by that time most projects had already completed the design and had moved to implementation and testing. Subjects such as optimization and engineering-economics could never be covered in time to be applied in the design stages of the project.

It was also our observation that it was difficult for student to stop behaving like "students" and start behaving as "project engineers", and they would place more emphasis on the lectures, homework, and tests than they would on the projects. Since grading had to be done combining the lecture portion (tests and homework), with the project grade, it was observed that some students (especially the strongest students boasting the highest GPA) would spend the effort into doing well on the tests, getting high grades, so that they could 'coast' on the project. The end result was lackluster performance on many of the projects, without reaching the level of expectation set by the department or our industrial sponsors.

After delivering the course as an integrated unit of lectures plus project for three years, it was decided to split the lectures into a separate (Fall semester) course, with traditional delivery and grading, and leave the capstone design experience as a two-semester, project-only course (3+3 units) and combine all lecture materials into a Fall semester course (3 units). Since going to this new format we have observed a marked improvement in the level of priority the student teams give to successful project delivery since the entire course grade is based on project performance.

Growth in Enrollment and Industrial Participation

Since its inception in 1999 the senior design course has seen steady growth in enrollment as well as in industrial participation, this growth is shown in Table I. Since the capstone course is a required part of the curriculum, enrollment perfectly tracks graduation numbers for the department. We have seen a slight dip in numbers this last year, but expect significantly larger classes for the next two years and beyond. We recruit enough projects during the summer aiming to have about 4 students per project team (but we sometimes cannot properly estimate enrollment and have to adjust the number of students per team). We have consistently increased that percentage and today we are running close to all projects with an industrial sponsor (about 90%). We feel this is the limit and will not try to achieve 100% of industrial sponsorship. There are many instances of valuable projects that we would like to pursue with the class that do not involve industry, such instances include service-oriented projects (community-based), projects involving spin-offs from research activity by our own faculty, or student-based organizations such as SAE or ASME.

Table I – Evolution of industrial participation in the capstone design course

Academic Year	Student Enrollment	Number of Projects	Avg. Number of Students per Team	Fraction of Industry-Sponsored Projects
99-00	56	17	3.3	12% (2/17)
00-01	40	12	3.3	25% (3/12)
01-02	56	18	3.1	44% (8/18)
02-03	46	13	3.5	54% (7/13)
03-04	47	13	3.6	54% (7/13)
04-05	60	15	4.0	80% (12/15)
05-06	65	16	4.1	88% (14/16)
06-07	52	14	3.7	93% (13/14)

Current Course Structure and Mechanics

Project Harvesting

Since the entire pedagogical premise of the capstone experience revolves around engineering design projects, and great effort goes into mimicking as much as possible the conditions encountered by engineers in industry, the quality of industrially-sponsored projects is paramount[5]. Very significant effort goes during the summer prior to the beginning of classes to "harvest" enough quality projects from industry to staff enough design teams including the entire graduating class. The projects must be somewhat meaningful to the industrial partner, yet not be mission-critical, and funding must be available to construct prototypes or other hardware as required by the project. The task of securing enough projects to feed the capstone experience course, although always daunting, has become somewhat easier in recent years due to two important factors:

- Active involvement from the Mechanical Engineering Department's Advisory Council (MEAC), representing industrial partners, which has been very pro-active at helping us secure participation from divisions and engineers from their home organizations, and
- A significant fraction of "repeat business" with many companies returning in subsequent years to sponsor more projects after realizing the benefits of their involvement

Team Assignment and Formation

Once projects are identified and selected for the academic year, the next challenge is to make the team assignments. Since one of the main motivations behind the capstone experience is to expose students to team-based design and procedures, the make-up of each team is very important. We have used slightly different techniques to assign teams and over the years we have learned what works best. It is fair to say that if students were allowed, they would make their own teams based on friendship and level of comfort. There would also be a tendency for teams to cluster by GPA (with some teams nucleating all class overachievers, while other teams would be composed of students with low GPAs). We clearly observed this during the first year of the course in which we offered some latitude for the student to choose projects.

Beginning with the second year of the capstone course we have limited the ability of the student to choose projects and instead the instructor assigns the teams and forces students to work in group without the comfort level of picking teammates. The process is somewhat complicated because certain constraints need to be observed:

- Allow members of students chapters (e.g., SAE, ASME) to work on specific projects sponsored by such organizations
- Allow students on the BS-MS (co-terminal) track to work on projects sponsored by certain industrial partners that also serve as hosts for summer internships
- Consider the student's career interest or objectives as much as possible
- Ensure teams are composed by students from both universities represented at our college: FAMU and FSU

Aside from these constraints, the method used to assign teams is rather straightforward. Each student in the class is assigned to one of four groups according to GPA (top quartile, second quartile, etc.). Each team is given four 'slots', one from each GPA quartile group, and a random drawing is used to pick a student's name and then allow him/her to pick a project with a n open 'slot' for the GPA group the student is in. Even though prior GPA is not at all a good indicator of performance in the capstone course (in fact most of the top performers in senior design come from the second quartile group, and not the top), the method ensures a uniform distribution of GPA among all teams and indeed project execution and performance tends to be quite uniform for the entire class.

Periodic Reviews, Staff Meetings, and Deliverables

Another major thrust of the capstone experience is to expose students to industrial projects and to the methods and procedures engineers employ in industry to solve problems and carry out projects. Therefore, the capstone course is structured so that students execute projects in a very consistent and well-documented manner. The aid the teams in that respect, the course follows a schedule of frequent design reviews and written deliverables as outlined in Table II. During the "staff meetings" the course instructor meets one-on-one with each team for about 20-30 minutes to discuss project-specific problems or issues. The teams also have frequent meetings with support faculty, as well as meetings and/or teleconferences with the industrial sponsor. This high frequency of contact among all stakeholders ensures projects can stay on track despite the distractions of other courses, team dynamics, busy schedules, etc.. In addition, there are six major design reviews in which each team presents progress to date and plans.

During the first semester all projects go through a design cycle that is fairly independent of what product or system is being developed. It is appropriate to utilize a "template" of deliverables applicable to all. However, during the second semester projects diverge considerably in their direction as they move to an implementation phase. In addition, we do want students to develop a sense of ownership of the project and develop the time-management skills that will bring projects to a successful conclusion without the need for artificial milestones set by the instructor. Most teams develop that culture by the second semester.

Table II – Typical schedule of project activities and written deliverables

Week	Activity	Deliverable (Reports)
Fall – Week 1	Project introductions/Team assignments	
Fall – Week 2	Team building and project kickoff	Team-building activity report
Fall – Week 3	Staff meetings	
Fall – Week 4	Introduction to scheduling	
Fall – Week 5		Needs assessment Project scope
Fall – Week 6	Staff meetings	Product specifications Project schedule and procedures
Fall – Week 7	Review #1 (preliminary design)	
Fall – Week 8		Concept generation and selection
Fall – Week 9	Staff meetings	
Fall – Week 10		
Fall – Week 11	Review #2 (mid-point)	
Fall – Week 12	Staff meetings	
Fall – Week 13	Thanksgiving break	
Fall – Week 14	Staff meetings	
Fall – Week 15	Review #3 (final design review)	Final design reports Spring semester proposals
Spring – Week 1	Mini-review (scope and schedule)	Scope and schedule report
Spring – Week 2	Staff meetings	
Spring – Week 3		
Spring – Week 4	Review #4	
Spring – Week 5		
Spring – Week 6	Industry week activities	
Spring – Week 7	Staff meetings	
Spring – Week 8	Review #5	
Spring – Week 9	Spring break	
Spring – Week 10	Staff meetings	
Spring – Week 11		
Spring – Week 12	Staff meetings	
Spring – Week 13	Review #6: Final Project Open House	Final report and web page
Spring – Week 14	Exit interviews/Course evaluation	

<u>Open House</u>

At the conclusion of the academic year the capstone course features a final review/open house for the teams to make presentations describing the project and the results obtained, as well having an open house with posters and the actual hardware produced by the teams. Engineers from industry (both project sponsors and MEAC members) serve as a panel of judges and give feedback not only to the student teams about their projects, but also to the department on any strengths and weaknesses gleaned from the capstone design projects. This input from industry is extremely valuable to the department as part of our ABET2000 self-evaluation process[6,7] .

Grading

Grading and evaluating student progress in a team-based capstone courses is always difficult and has been the subject of much thought among educators[8] . There is always the trade-off between the need to encourage team behavior by rewarding performance as a group, versus the need to identify students that are not contributing to the team effort and do not deserve full credit. This balance needs to be achieved without overburdening the team with peer evaluations that sometimes may have negative effects on team dynamics and ultimately destroy the spirit we are trying to foster when teams are assembled. All grades earned are based on team performance. The only grades based on individual performance are those earned during design review presentations (when both a team grade and an individual grade are given), or at the end of the semester when we evaluate peer review feedback to assign a teamwork grade. We only use the input from these team evaluations to intervene in extreme cases of poor team dynamics, or to warn individual students when their performance is not matching team expectations (we evaluate teams at least twice during the semester). Otherwise, we avoid differential individual grades as much as possible and prefer to reward/punish a team as a whole. In our experience, only about 10-15% of the teams exhibit either poor dynamics or a single non-performing individual warranting intervention from the instructor and a separate individual grade.

Industrial Involvement

As important as defining good projects for the students to work on is the industrial liaison that will work with the students and serve as "customer". In a large class with only one faculty acting as instructor/coordinator, the quality of mentorship offered by our industrial partners is of critical importance for the success of the project. Having strong backing from management is not enough if the individual mentor does not "buy into" the concept of capstone project sponsorship. He/she needs to perceive the value of industrial involvement and the benefits of the work done by the student teams, however minor they might be in the context of the organization's goals. These benefits could be direct, in the form of project results, data, or prototypes; but they could also be indirect, such as potential recruitment targets, image creation within the entire graduating class, or development of industrial-academic contacts.

The relationship between the department and the industrial sponsor needs to occur at more levels than just the student team/mentoring engineer. Most of the companies that routinely sponsor our projects also have a representative in our advisory council (MEAC). These MEAC members tend to be drawn from management positions within the corporations so that there is good visibility and access to resources within the corporation. These MEAC members become "champions" of our capstone program within their organizations and help us recruit projects each year. We further integrate them into our program by scheduling one of the semi-annual MEAC meetings to coincide with the capstone course open house in the Spring (see above). Many MEAC members attend the capstone design open house prior to the council meeting, help us judge the projects (which is then reflected in the grades), and give us feedback on what they see as strengths and weaknesses in the course and in the graduating class. This feedback, along with the student exit interviews we conduct as part of the capstone course become part of the

ABET2000 feedback/improvement cycle for our curriculum. We have found it is a very effective of not only involving industry with our program, but actually a very effective way of improving our curriculum with each passing cycle.

We recently expanded the scope of industrial participation with our capstone design course and curriculum development in general. We called a two-day forum on the subject of systems engineering, and how to best integrate it to the teaching of best design practices. Some of our industrial partners sent representatives to speak to faculty and students on the subject. During the second day, a break-out session was devoted to address how to best introduce systems engineering concepts throughout our undergraduate curriculum, the capstone course, and eventually at the graduate level as well. The action plan stemming from this forum is another example of the great benefits our department has derived from involving industry through our capstone design course.

Conclusions

The capstone senior design course in the Department of Mechanical Engineering at the FAMU-FSU College of Engineering has proven to be an excellent vehicle to educate our students in team-based design, and the application of engineering fundamentals to real-world problems. The program has evolved over the last seven years and reached a high level of maturity. In eight years we have worked over 100 projects and graduated nearly 400 mechanical engineering majors, while also involving nearly 50 students from other majors. A complete record of projects and their sponsors is compiled in the course website[9]. This capstone course has allowed us to create a good foundation for attracting industrial partners that provide project ideas, funding, and mentorship to turn the experience into a much more realistic platform for educational delivery. These relationships continue to grow and are an effective way of keeping industry involved in fashioning our curriculum, helping us produce high-caliber engineers that become sought-after by these industrial partners and other corporations.

Acknowledgement

The authors wish the thank all the industrial sponsors that have supported this capstone experience with their projects, time, and funding; of special note are those organizations that have repeatedly sponsored our students: AFRL at Eglin AFB, Lockheed-Martin, Cummins, Shell, Boeing, Sandia, Talla-Tech, as well as many other companies and organizations that were involved at one point with the senior projects.

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