Capstone Senior Design at The University of Alabama

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Abstract

The mechanical engineering program at the University of Alabama has had a two-course capstone design sequence (the Design Clinic) since the late 1970's. Although several changes have been incorporated over the years, the use of external industry-sponsored projects has remained a constant. Students participate in a common, competitive design project during the first two-thirds of the first course (ME 489). During the last third of the first course and the entire second course (ME 490), each team of three or four students works on a single, extended external project. This paper focuses on the extended design activity.

The overall organization of the course sequence and projects, including faculty support options and the process used to select student project teams, is outlined. We describe our various sources of projects, along with some of the possible advantages and disadvantages of each. Financial considerations for the course sequence and the impact of finances on project selection are also covered.

Finally, brief descriptions of several recent projects are given. Interested faculty members should be able to use these suggestions in the development of their own senior design courses.

Introduction

Senior "capstone" design courses have become an integral component of undergraduate engineering education, and are currently mandated by the engineering accrediting agency, ABET. Looking to the future, the ABET guidelines now being formulated for the year 2000 are incorporated in a draft document entitled *ABET Criteria 2000* that is circulating through the engineering community. Although the wording may change in the final document, the draft document clearly states ABET's expectations for a capstone design experience:

> *The curriculum must prepare students for engineering practice culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufactur-ability, ethical, health and safety, social, and political.* [1]

In both its present and proposed future guidelines, ABET does not specifically define the number of credit hours that must be assigned to the capstone course.

A capstone design course or course sequence requires senior-level students to apply knowledge gained from previous engineering science, design and laboratory coursework in accomplishing an extended design task. It is our hope that the capstone design sequence facilitates the student's transition from an academic to an industrial environment. The capstone course sequence also provides an opportunity to teach and allow students to apply some important topics not covered in traditional engineering science or lab courses, such as ethics, teaming, technical writing, public speaking, and the other topics listed above in the draft version of *ABET Criteria 2000*.

An ***ideal*** project has these characteristics. First, it requires the student team to go through the complete design sequence: (1) identify the problem and constraints, (2) perform a detailed background search, (3) brainstorm to generate a host of potential solutions, (4) develop and apply a procedure to rank potential solutions, (5) build/ program/complete a working model of the best solution or best two or three solutions, (6) test the solution(s) to identify problems, and (7) redesign and retest until a good working model of the solution is developed. Included in the selection process (step 4) is a detailed engineering economics analysis and, if appropriate, statistical analysis. Furthermore, all of the considerations mentioned in the draft version of *ABET Criteria 2000* are made. So that the grading is fair, all projects both during and between semesters are of equal difficulty. Finally, all projects are "real world" industrial problems.

A compromise clearly must be struck between achieving as many of these objectives as possible and actually being able to secure projects. If money is not an issue, then a class-wide, competitive project can be devised that accomplishes most of these goals, although the time available for step 7 above is limited by the length of the semester. A project idea can be solicited from industry and in some cases, if costs are reasonable and a good relationship exists with a large company, then a single industrial sponsor can be found to finance an entire course project for a semester. Another simple solution is to limit the project to, for lack of a more contemporary term, the “pencil-and-paper” variety. This keeps the expenses of teaching the capstone design courses similar to those of other engineering lecture courses, although more faculty time is probably required.

Many universities use one of the above models or a similar variation to meet the ABET capstone design experience requirement. At the University of Alabama we have decided that actual industrial projects are desirable, but we do not have individual industrial benefactors routinely willing to bear the entire $10,000 per semester non-faculty, direct costs of our program. Consequently, we solicit projects from a number of industrial clients each semester. Using actual industrial projects from a number of sources necessitates that some of the other features of the “ideal” capstone course be sacrificed, as discussed later.

Design Clinic Course Sequence Overview

At the University of Alabama a two course sequence of three semester hours each is devoted to capstone design. The first course is described in detail in [2]. A variety of other topics are also covered in this course, including engineering economics, literature searches, patents, ethics, and environmental regulations.

A major component of the first course is an 8-week competitive, build-and-test design project. Each team of three to four students works on an identical design problem. For the last several semesters, these projects have involved wheelchairs and handicapped access. Complete project descriptions, photos, and videos of some of these projects are available on our Web site at http://www.me.ua.edu/medc. The students are required to present their project efforts potential clients, faculty, and staff engineers and shop personnel. The presentations to the clients are particularly competitive, since the students are trying to "sell" their design to a customer. These presentations have received considerable interest from the local media, and have resulted in a great deal of publicity for the department and the university.

After the competitive design project, but still during the *first* capstone design course, the students are introduced to their final projects. These projects are usually sponsored by external clients, although some internal projects and national design competitions have also been used. For example, we have competed in the SAE Mini-Baja West competition with Design Clinic teams in 1995 and 1996. We also competed in the DOE-sponsored Natural Gas Vehicle Challenge competition in 1991-1993. A representative list of some of our recent projects is provided in a later section of this paper.

At present, the final course of the capstone sequence (ME 490) is structured so that the class as a whole (about 30 students on average) meets for an hour each week, each team meets once with their faculty advisor for about 45 minutes each week, and each team works together or as individuals for the remaining time. At the weekly class meeting, information on upcoming deadlines, purchasing, reimbursements, etc., is distributed. The remainder of the time is taken by 10-15 minute team presentations updating the class on progress and soliciting help with problems. Each team makes 4 of these interim progress reports per semester, and each presentation is evaluated by the students and the instructor(s). Each team member submits a written memorandum to their faculty advisor the morning of their meeting, and the team as a whole maintains a design notebook that bundles together all design work and records of team activities [3].

Near the end of the semester each team submits a formal final report that is reviewed by the faculty advisor and an independent writing specialist. At the same time, each team makes a 30-minute presentation to a three person jury made up of faculty *not* participating in ME 490. Finally, the students revise their final reports, submit them to the client and to the faculty advisor, and then make a 30-minute final presentation to a client jury (typically five engineering employees of the client) at the client’s site. The course grade is computed as bi-weekly progress (25 percent, faculty advisor), four progress reports plus attendance (15 percent, advisor), final written report (15 percent, advisor), faculty jury (20 percent), and client jury (25 percent). There are no tests or homework.

Initially and for many years afterward, the final Design Clinic course was supervised by one professor, who might act as faculty advisor to one or two teams, but the large majority of the project teams were farmed out, one per faculty member, to various faculty in the department. There were several problems with this arrangement. First, the grading and workload standards varied from professor to professor, which always left some students feeling they had been treated unfairly. Next, the relatively minor assignment of advising a design team did not instill a sense of course “ownership,” loyalty or responsibility in some professors, so they tended to minimize their efforts in advising.

Recently we have modified the faculty staffing so that two faculty members are in charge of all aspects of the course, including team advising. This minimizes complaints about varying work level and grading standards. The two faculty are each accorded the same level of credit as they would have received for any other typical course (25 percent full-time equivalent (FTE) per course). If the same size class had been taught previously, the coordinator would receive 10 to 20 percent FTE credit and may well have had to teach two additional courses. Other faculty advisors would receive 5 percent FTE credit and would have taught two other courses. In short, the current staffing method reveals that the department is now teaching one or two courses that would have been virtually invisible (e.g., to the Dean's Office) under the old system of staffing, even though the total FTE allocations are almost identical.

The selection of team members and the assignment of teams to individual projects are not trivial issues. In the first course of the Design Clinic sequence, the faculty form the teams. Teams are usually formed of 3 or 4 members, depending on the size of the class. All students are given a personality typing evaluation (similar to the Myers-Briggs form) to use as input in the team selection process. The students are also given a personal inventory form where they indicate other relevant information, such as courses attempted, grades, hobbies, and most importantly, practical experience. The faculty member then forms the teams by providing a mix of these elements among the team members. The primary constraint in the team formation is to insure that at least one member has some practical background for the "build" component of the design process. This process does not guarantee the formation of equally competent teams. One of the points we stress in this first course is that teams in industry rarely get to choose their members and that learning to work with someone you do not know (or like) is a valuable skill in itself.

All teams work on the same project in the first course of the Design Clinic, so project assignment is not an issue. In the second course we have tried a variety of ways to both form teams and assign projects. No single method is perfect, but reliance on some form of a "bid" system seems to work best. One faculty member allows existing teams from the first course to select projects in the priority of their first project grades, i.e. the team with the best grade on the first project gets first choice of the different external projects. Another faculty member gives each student 100 bid points. They can use these points to select for (or against) an individual project or another student. Both of these methods work well for selecting all but the last team and the last project. There always seems to be one project and a few students that no one else wants to work with!

Design Clinic Project Constraints

Finding "good" senior design projects is perhaps the most significant challenge in the continuing operation of the program. First of all, because the Clinic sequence consists of normal, academic year courses, our timing requirements are rigid. We start the project entering the final month of one semester and finish at the end of the succeeding semester, so projects can take more than eight months to complete (spring + fall semester projects). We have missed out on a number of opportunities over the years simply because the prospective client calls wanting to fund a project starting *now*, but we are not starting a new set of students out until three months from now.

Next are financial constraints. There are always plenty of opportunities to do interesting projects "for free," but the financial burden of these projects can become overwhelming. We finance the bulk of Design Clinic activities through client fees. This money pays for project materials, machine shop time, communications, and travel associated with the projects. It also covers most of the cost of the ME 489 competitive design projects. Finally, the client fees pay for half of the salary of a half-time "Associate Director of the Design Clinic" who handles most of the abundant paperwork associated with the two Clinic courses. Funds from elsewhere within the University pay for the other half of the Associate Director's salary.

Our present Design Clinic fee is $750 per project plus actual direct costs, which average about $400 except for projects that involve major hardware purchase or fabrication. We suspect that our fee is on the low end of the spectrum for programs of this sort. Another long-standing program similar to ours charges $6500/project [4]. Faculty involved with this more expensive program point out that the high price buys both attention from industry and commitment to a quality job from the department sponsoring the clinic program. Despite the fact that we prefer "paying" customers, the Design Clinic does one or two *pro bono* projects most semesters at a greatly reduced (or no) cost to the client.

Once the financial and time constraints have been met, the proposed project must still measure up as "good" for meeting the educational needs of the students. Many local industries will suggest projects that may not be sufficiently challenging for senior engineering students. We have, on occasion, agreed to a project that essentially required only a phone call to the appropriate vendor (which the client actually knew all along!). We have also encountered the opposite problem - clients that expect 4 engineer-years worth of Ph.D. level effort from four seniors taking a three hour class! It requires a good bit of experience and discretion, plus a well-polished crystal ball, to be able to tell after a brief discussion with a prospective client if the proposed project possesses most of the desired attributes described previously. We have made mistakes; some projects simply turn out to be poor educational experiences.

It is desirable that each project satisfy as many as possible of the ideal project criteria cited above. Because of the vast variety of industrial engineering activities, and because of pressures on Clinic faculty to enlist enough projects to cover the course enrollment (and costs), compromises must be made in project selection. Not all clients want the students to "build, test, redesign and retest." A large fraction of our projects require industrial equipment or process design where implementation of the design will cost hundreds of thousands of dollars– "build" is not practical within the time or financial constraints of the course. Nevertheless, many of these projects are highly representative of typical entry-level industrial design work and are solid capstone design experiences.

Sources of Projects

Although earlier Design Clinic faculty tended to rely on "cold" calls to industries to recruit projects, in recent years we have found that former Design Clinic students are our single best source of projects. We have made contact with some former students via professional society meetings and with others by targeted phone calls. Chance encounters with former students visiting campus during homecoming or other events have also resulted in Design Clinic projects. These former students know many of the faculty involved in the capstone course, have first-hand knowledge of the level of student capability and effort available, and often need only a little "hint" before they request or generate a project. Many of these alumni work with large firms within a few hours drive of campus, but we have also had success with former students at very small firms and with firms in other regions.

Another good source of Design Clinic projects that we have only recently exploited has been the students themselves. Many of our students participate in co-op or summer internships. Once we announce that they can generate their own project, many of them will contact their co-op employers and develop a project. During one recent semester, three of the eight Design Clinic projects were initially proposed by the students. Students prefer these projects because they already have good experience and have developed a good relationship with their client.

Over the years we have worked on several projects that were never solicited– the clients contacted us with a potential project. Often these clients have contacted someone else in the University who knows about our program and directs them to us. These requests often require careful screening, since many come from individuals with "a really good idea!" However, we often get one or two projects per semester from this method.

Some Recent Projects

- A three-student team designed, built, and tested a prototype miniature iron for quilting and doll clothing applications. The client (an individual) is presently investigating the commercial possibilities for the design. The fee was halved for this project.
- A four-student team designed, built, and tested a process for precisely rotating cartons of fruit drinks for a large national manufacturer. This project was particularly challenging since the students were not able to visit the manufacturing site, which was located several hundred miles away. All of their interaction with the client occurred by telephone conference calls, e-mail, and videotape.
- A four-student team investigated coal loss in a large electric utility's coal pulverizer. After considerable on-site and background research, the team built and performed initial tests on a dynamically similar scale model of the pulverizer inlet. Next semester a follow-on team will complete the project by devising and testing appropriate modifications to the inlet flow.
- A three-student team designed a fiber recovery system for a set of five large paper machines at a paper mill in the state. The team measured fiber wastage rates, designed the piping, tanks, pumps and controls for a recovery system, and performed an economic analysis that indicated a short payback time. Based on the team's recommendations, the paper mill is investing several hundred thousand dollars in a fiber recovery project.
- A two-student team continued a competitive project from ME 489 and designed, built, and tested a device to aide in the loading of a wheelchair in the trunk of an automobile. This project was done at the request and for the benefit of one of the judges for the previous semester's course (for $100 + materials). Projects done for a private individual (especially a non-engineer) carry their own special set of difficulties and opportunities.
- A four-student team designed and built a device to simulate a common physical therapy procedure for a local clinic. The students had no special knowledge of the medical or physical therapy terminology and procedures before the start of the project. They found working with non-engineers in a field far removed from their experience to be particularly challenging.

References

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