2007: MULTIDISCIPLINARY CAPSTONE DESIGN AT THE UNIVERSITY OF HOUSTON

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Multidisciplinary Capstone Design at the University of Houston

Abstract

In this paper we identify some of the issues and problems that we confronted while developing a new, one-semester, interdepartmental, multidisciplinary capstone design course. We implemented the following changes to the pre-existing capstone design course:

- utilized a website to enhance information transfer
- modularized the course and replaced lecturing with facilitating,
- introduced a studio/critique teaching format,
- integrated communications professionals into the teaching of the course, and
- allowed the students to be involved in establishing the final expectations for their project.

The details of the implementation process, the effects of the changes, and the students' responses are discussed.

Introduction

Until 1980 the capstone design experience in the Department of Mechanical Engineering (ME) at the University of Houston (UH) was either

- a series of faculty developed team projects, usually related to developing experiments for the undergraduate laboratory courses, e.g., a low speed wind tunnel and a piping network in which the pressure drops through various pipe runs and fittings could be determined,
- projects related to one of the nation design competitions, e.g., SAE Baja or later high mileage vehicles, or
- student initiated projects.

In 1980 the mechanical engineering capstone course was reorganized. Industry began to provide and sponsor projects. Student teams were set at four and informally "bid" on the projects. The precedent was set that each team was assigned a different project, a practice that has been followed with a few exceptions ever since. Course content began to evolve. Design methodology and optimization were the first main topics. About 1985 the Industrial Engineering (IE) capstone course was combined with the ME capstone course forming the first multi-disciplinary capstone course in the College. The content of the combined course continued to evolve. In late 1980s and early 1990s statistics, project planning, and some instruction in technical communication were added. The faculty member who was responsible for the course and had lead its evolution since 1980 left the University in 1991. Ross Kastor, a retired drilling engineer with 40 years experience in the petroleum industry, was hired as a lecturer and took responsible for the ME/IE capstone course.

The course had always been a one-semester, 3-hour credit course that was offered every fall and every spring on an alternating day-night schedule by a single instructor. The teams of four students were assigned (through a bidding process) a project. This bidding process became more formalized in the 1990s. About 70% of the projects were provided and sponsored by local industry, and a majority of them, at least since 1991 were related to the petrochemical industry. The remainder of the projects were provided and sometimes sponsored by faculty. In addition to the client-provided “engineer-in-charge,” each team was assigned a faculty advisor. Short, weekly progress reports and formal written and oral final reports were required from each team. By the mid-1990s the course also had considerable content, e.g., the design process, oral and written communications, project planning, risk analysis, ISO 9000, engineering ethics, statistics, optimization, present value analysis, and neural networks. Individual homework assignments and short quizzes were given throughout the semester over the lecture material. Officially the course was two hours of lecture and three hours of “lab” each week. However, the class typically met for lectures four to five hours a week early in the semester so that much of the content was covered by mid-semester. Few class meetings occurred during the last half of the semester as students were allowed to concentrate on their projects without much supervision.

In 1998 the Department of Electrical and Computer Engineering (ECE) began requiring the completion of a new capstone design course as part of its BSEE and BSCE (computer engineering) degrees. Through mutual agreement they created a new course ECE 4334 and joined the existing INDE/MECE 4334 capstone design course. Hence all the students from the four programs (Computer, Electrical, Industrial and Mechanical Engineering) were required to take this course. There was a three-year transition to the full implementation of new multi-disciplinary capstone course. The ECE students “in the pipeline” in 1998 were given the option of completing the new capstone for elective credit but few did. The ECE students entering in 1998 and thereafter (freshman and transfers) were required to take the new course. In 2001 Bannerot and Ruchhoeft was assigned to assist in the development and teaching of the new capstone design course. In a previous paper[1] the following capstone course issues confronting the new team of instructors were presented:

Capstone Issues

Problems Associated with the Transition to the New Environment

<u>Enrollment:</u> The IE/ME course enrollment in the mid 1990s was between 30 and 40 students. It was clear that changes would be necessary as the College granted more than 100 BSEE and BSCE degrees annually.

<u>Team Teaching:</u> A plan for the division of labor was needed.

<u>Multidisciplinary Teams:</u> Previously there were no restrictions on the make up of the teams. The guidelines for the combined course required that at least two disciplines be represented on each team.

<u>Multidisciplinary Projects:</u> As noted, the projects in the past had been primarily from the petrochemical industry which was appropriate for a primarily mechanical engineering course in Houston. However, with the new course, enrollment was expected to be primarily electrical and computer engineering students and a larger variety of projects would be required.

Problems Associated with Team-Oriented Design Courses In General

<u>Individual Grades:</u> One of the objectives of the course is to teach students to become “team” oriented and to accept both the responsibility and rewards of team membership. However, grades are assigned to individuals in an academic environment. As an alternative to simply assigning to individuals the grades earned by their teams, we desired to introduce a measure of individual accountability into the grading process while at the same time not burdening the students with “make-work” tasks that had little to do with their projects.

Class Participation: Students tend to become preoccupied with their own projects and pay little or no attention to the other projects. We felt students would benefit from some involvement with the other projects.

Analysis-Based Design Content: The ultimate product of any design process (regardless of the discipline) is an artifact (using the broadest possible definition) that satisfies the constraints and aspirations of the client. One of the aspects of engineering design that sets it apart from design in many other disciplines is analysis. We wanted to assure that our designs were based on good engineering analysis and produced a satisfactory artifact.

ABET Criterion 4 (Professional Content): Although the expectation is that students will be prepared for the capstone experience through exposure to engineering standards and realistic constraints throughout the curriculum, these issues must also be addressed in the capstone course. With teams of students working independently on different projects there appeared to be little opportunity to address these issues except on a team by team basis which seemed very inefficient.

Demonstration of a Successful Design: Validation of the product of the design is an important part of the design process. We prefer projects that result in an artifact that can be tested (validated). The question is what to do about artifacts that fail their "test", about teams that fail to produce a testable artifact and about projects that, by definition, will not produce an "artifact."

Project Completion: A team's inability to satisfactorily complete its project is a frequent problem in general and even more critical in a one semester, last semester, design course. When students have completed all degree requirements except the last design class, it is difficult to hold them up. However, the assignment of an unsatisfactory grade is hardly "satisfactory" for anyone including the instructor. We wanted to develop a process that would make it more likely that projects would be satisfactorily completed on time.

Meaningful Instruction and Feedback in Communications: By the time students reach senior standing one might presume that it would be unnecessary or too late to provide assistance or instruction in writing and oral technical communications. However, we were concerned about the generally poor quality of communication skills exhibited by the students in both their presentations and reports. The students were from four academic programs, each with different communications requirements. In addition, the ethnic diversity of our student body created a wide range of English proficiencies. The large class size prevented individualized instruction that many students needed. Finally, as engineering faculty we were really not prepared to turn this design class into a communications class.

Uniformity of Grading: In a large design class it is impractical for one person to be responsible for grading all the written assignments or all the oral presentations. Also, there is a subjective element to grading written and oral reports and the artifacts of design. How could we be assured that the grading would be fair and uniform?

Class Communication: Communications in a large class with numerous reporting and demonstrating requirements, with numerous scheduling issues, with numerous projects, with potential team dysfunction, etc. would be difficult.

Client Consistency: Clients provide a project description to the instructors. Modifications may be required before a project is approved and submitted to the class for the proposal process. However, the client's objective is seldom the same as the instructor's, so there is usually a little give and take before the project description is accepted. As the project proceeds, new ideas evolve; old ideas are shown to be unacceptable or unworkable; and there is a tendency on the part of the client to modify the project. Personnel changes may occur; a new client's representative may appear. How are the issues associated with a changing set of constraints and goals handled in light of the course requirements, e.g., finish on time, maintain uniform expectations, produce an artifact, validate results, etc?

Quality of Client Consulting: Despite the client's good intentions, many issues affecting his availability and interest may be beyond his control. A common problem is a client's failure to provide promised information, materials, equipment or access in a timely manner, if at all. The student team can not be held responsible for the client's failure to deliver, but neither is it fair to give the team a "free ride" for its project.

Quality of Faculty Advising: The students' ability to access to a busy faculty member and the faculty member's interest in carrying out his advising assignment are variable.

Responses to these Problems

Four changes from the preexisting IE/ME capstone design course were made course that addressed most of the issues raised above. These changes were:

- to modularize the class by dividing it into cohorts and changing the instructor's role from one of "lecturing" to one of "facilitating",
- to integrate the resources of the newly established University's Writing Center into the teaching and evaluating of communications for the course,
- to utilize a studio/critique teaching format, adapted from the visual arts, and
- to replace many of the industrial projects with projects from the College's research laboratories.

These four changes are discussed in more detail below.

Cohorts and the Facilitators: The cohorts developed as a natural consequence of the instructors' decision to reduce the course "content" and focus on a more "hands-on" approach to managing and encouraging the multidisciplinary teams. The "lecture" material was "repackaged" and presented in interactive, cohort meetings. The project teams were grouped into cohorts of four teams or less (16 or less students). In the spring 2004 there were 88 students in the class so each of the three facilitators (a.k.a. the three instructors) had responsibility for two cohorts of three or four teams each. Each cohort had eight, 90-minute, meetings (More information is given below and in Reference 2 on how these cohort meetings were conducted in a studio/critique format.) with its facilitator. Three cohorts met together on a rotating basis for the student oral presentations. Each team participated in four presentation sessions. Its representative gave his/her presentation, and the team listened to ten to twelve other presentations. Hence everyone heard at least one presentation from each of the other teams at some point in the semester. The entire class met together only during the first week. A website (utilizing Blackboard®) was initiated and served as the central contact point for the class. All students and facilitators could contact each other by email through the website. All assignments, discussion materials, grading rubrics (See next section.) were posted on the website. In addition to the hardcopy submissions, copies of all student work (including PowerPoint slides) were submitted to the website.

Writing in the Discipline Program: In 2000 the UH Writing Center was established to provide a campus-wide resource to assist students in their writing. In 2002 a special Writing Center program, Writing in the Discipline, (WID) was initiated. The WID program sought opportunities to actively (by working with the instructors) intervene in courses across the campus in which communications skills were stressed. The rationale for the intervention was that general composition courses cannot adequately prepare students for discipline-specific writing. (More information on the UH Writing Center, its WID Program, and its interaction with the capstone course can be found in Reference 3.) For the capstone course this intervention produced several significant results. With assistance of the WID program a comprehensive set of individual and team communication projects was established. Each team member was personally responsible for the one oral and one (different) written report. These reports could be a proposal, a progress report or a technical report. These two reports represented 15% of the individual's course grade. Five, team-prepared, written Planning Reports were required and reviewed in the cohort meetings. The team was also responsible for a final technical report, a final oral presentation, a poster and an extended abstract. To provide assistance to the students in preparing these documents and presentations, just-in time (JIT) interactive workshops were developed and conducted by Writing Center personnel. A student with the individual responsibility to prepare a specific oral or written report was required to attend the appropriate workshop. These workshops were scheduled about two weeks prior to the submission or presentation. The grading criteria (These rubrics were developed jointly with the WID program.) for these assignments were available for each type of report, were posted on the website, and were discussed in the workshops. Each student also had to attend at least three of the seven optional workshops on the following topics: posters; extended abstracts; abstracts, introductions, & conclusions; mechanics & proofreading; tone in technical communications; effective use of figures and examples; and paragraph structure. The details of the course structure can be understood from the spring 2004 capstone class schedule as seen in Figure1 at the end. In the spring 2004 there were 88 students divided into 22 four-person teams. The 22 teams were grouped into six cohorts, i.e., C1, C2, C3, etc. The meetings were:

- Facilitated Cohort Meetings, FCM, with informal presentations, review of each team's Planning Report, critiques on presented work, etc. There were a total of eight for each team,
- Writing Center Workshops, WCW. Note that the workshops on February 3rd (WCWs #5 and #6) on proposals were two weeks before the proposal presentations on February 17th and 19th,
- Individual presentations and written reports, e.g., February 17th and 19th for the proposal. The student responsible was indicated, e.g., student "A", etc. (On each team each student was assigned to be an A, B, C or D.) Individuals presented to their own cohorts plus two other rotating cohorts about every two or three weeks, and
- Planning Reports, PR, were due about every two weeks.

Each team prepared a poster for its project that was displayed in the engineering building commons for three days and presented a 30-minute oral report on the last Saturday of the semester. These presentations were part of an all day affair and lunch was served. All students intending to take the capstone course in the next semester were required to review (and evaluate) the posters and attend (and evaluate) at least three presentations. Each team must schedule a one-hour "out of class" meeting with the facilitators to present and defend (validate) its project (artifact).

Adaptation of the Studio/Critique Teaching Format:

Introduction: The use of a studio environment in the teaching of engineering design is briefly discussed in Reference 4, and experiences in using the critique in a studio environment for the teaching of introductory engineering design are presented in Reference 5. The critique and the studio environment have been an important teaching tool in the visual arts for much of the last century. In the visual arts, class size is limited to about twenty students, and the object of the design process is being created in the studio under the watchful eye of the instructor. Neither of these conditions was satisfied in our capstone design course. As many as ninety students were enrolled, and the available meeting room provided no work area or storage facilities. Another issue that could interfere with the successful implementation of the studio/critique environment was the difference between the "supportive culture" that normally exists in an art class and the "competitive culture" that many times exists in engineering classes. In spite of these differences and apparent obstacles, we developed a very effective technique for improving the design experience for our students through the use of a modified studio/critique process. This technique required the "modularization" process (forming the cohorts) discussed above so the technique can be contracted or expanded to accommodate (in theory) any number of students (with the appropriate number of instructors). The following sections will provide a brief description of the how these processes were integrated into the course and how the resulting experiences and interactions improved the quality of the final product, team work, and communications. The studio concept and the culture of the critique are explained in detail in Reference 2. Only a brief review is given here.

The Studio and the Critique: The studio is equivalent, but definitely not the same as, the engineering or science laboratory. In the studio paradigm, projects are assigned to or developed by the individual students, and it is assumed that the student will devote a certain amount of time, including time in the studio, to completing the project. It is the critique and the culture of the critique that more than anything sets design education in the visual arts apart from engineering design education. Two or three critiques are usually associated with a given project, so the timing of the critiques is related to the timing of the project. The idea of seeking help from peers and teachers is not new to engineering students. However, what is new is the sharing of ideas and the unsolicited advice. An important aspect of the studio culture is that the student and the instructor work as a team. The studio requires two resources that have equivalents in engineering education: the meeting space or studio (the laboratory for engineering) and the human resource (the instructor for both). The important elements of the studio are that the size of the classes is limited and the completed works of previous classes and other drawings, posters, and artifacts related to the discipline are on "permanent" display. Access to the studio is granted at any time during the class day to any student enrolled in a class using that studio. It is not uncommon to see students of different classes (and academic levels) working side by side in the studio during a class that neither is enrolled in and to see students working alone in the studio when classes are not meeting. The instructor's office is usually adjacent to the studio, and the instructor is usually accessible throughout the day. This picture may resemble the "open lab" concept used in the some engineering programs and in fact it is similar in appearance (except for the electronics and the hardware). The major difference is that in the engineering laboratory there is usually a specific outcome objective, a data collection process and a reporting requirement. In the artist's studio, the objective is usually not as well defined as in the engineering sense. The expected result is a new and unique image or artifact that satisfies to varying degrees an array of preset constraints and goals that are generally based on a "sensing" or "feeling" rather than on demonstrating or illustrating an engineering principle. The instructor's role is also quite different. In the engineering laboratory course the instructor is attempting to help the student find the "right" path; in the studio, the objective is for the student to discover his/her own path.

The Culture of the Critique: As noted above the educational process in the visual arts is more of a team process: the student and the teacher being the team, than it is in engineering education. Of course, in a larger project there could be a "team" of students. In another sense all the students in the art class view themselves as "team members", or at least consultants, on all the projects in the class. Once this "team" culture is accepted, the role of the instructor is much easier. Criticism is viewed positively and constructively. Students welcome the instructor's comments. Over the years of experiencing "artistic" criticism (i.e., sometimes vague opinions and multiple suggestions as opposed to declarations that the work is either right or wrong, along with specific suggestions, rules, or references), the visual art students learn to accept and even relish it because they trust the instructor and acknowledge the "team" aspect of their relationship. It is true that the instructor must eventually "judge" the student, but that judgment is based on more than simply the student's artifact or his/her performance on a few "tests"; it is based on a semester long "working relationship".

Adapting the Studio/Critique Teaching Model to Capstone Design: We decided to use the studio/critique teaching model in the hope that we would be able:

- to achieve a better team effort and final product,
- to increase each team's effectiveness by providing more timely intervention,
- to encourage more discussion of the projects within the teams and among the teams,
- to provide many opportunities for each team member to informally discuss, explain and/or defend his/her project and the design decisions,
- to allow peer questions and challenges,
- to provide an environment for more effective interaction between the facilitators and the students with the specific purpose of improving the planning and communication skills of the students,
- to establish a non-competitive environment in which all teams could benefit from the collective input of peers and facilitators, and
- to discuss (rather than lecture about) a series of design, planning, ABET, and communications topics.

As seen in the class schedule in Figure 1 (at the end), there were eight meetings with the teams in their cohorts. Before each meeting the teams were told (through the website) of the assignment for that meeting, e.g., discuss the team's Gantt Chart, state the team's three most important milestones, be prepared to discuss the impact on their design of the three most important constraints listed in ABET Criterion 4, define the final product of the semester and how the team plans to demonstrate that it is successful (and what is success?), etc. If the team's discussions were not satisfactory, they were told to prepare a written reply to the facilitator. During one team's discussion, questions were posed to other teams present. Teams were always told to bring any artifact (component, subassembly, etc.) if one were available. Several teams will inevitably have common design issues, e.g., fabrication of printed circuit boards, and all teams can benefit from another team's experience.

Use of the College of Engineering's Research Laboratories for Projects

There is a strong feeling by many who teach capstone design that industry should be the source for as many capstone design projects as possible. Under certain circumstances we could agree.

However, our view is that in general industry is not able to provide the consistency in objectives and quality of consulting to assure a satisfactory result. Some would argue that "that's life" and the students will have to get use to it. Our feeling is that we are responsible for providing a realistic and "fair" experience that will be evaluated on its merits. Attempting to account for incomplete (company) information, denied access, late or no promised materials, a change in goals, etc. lead to inconsistency in grading. Too many industrial partners take the approach that "everyone worked hard and did a good job" no matter how unsuccessful the project is. As noted above we still accept industrial projects, but a good number of our projects now come from our research laboratories and from our ideas. Reference 6 presents a list of such projects and provides detailed descriptions of a few.

Short-Term Results

Cohorts and Facilitators
Splitting up the class and eliminating the formal lecturing by itself would not necessarily represent any improvements. However, without this first step, the rest of changes described here would not have been possible.

Collaboration with the Writing in the Discipline Program
We observed a definite improvement in the quality of the writing and the presentations in just one semester. Part of that improvement was probably due to that fact that we have done a better job telling the students what we want. Reference 3 discusses more of this collaboration and presents the results of a student survey which is summarized here. Student used a Likert Scale (5 = strongly agree,…, 1 = strongly disagree) to respond to a series of statements. About 75% agreed or strongly agreed that their skill level in technical communications had increased while only 10% disagreed. For four of the six workshops surveyed, there was over a 70% "approval rate", e.g., at least 70% of the responses agreed or strongly agreed that they were helpful. There was only a marginal increase in the students' "before" and "after" self- assessment of their ability to express themselves clearly. Although the number of students who disagreed or strongly disagreed that they were able to express themselves clearly through writing or speaking decreased from 25% to 7%.

Studio-Critique Teaching Format
Generally all our intents (above) were satisfied, and several additional benefits have also been realized such as (These benefits are briefly discussed in detail below. More discussion can be found in Reference 2):

- An opportunity to review and correct common misconceptions and mistakes based on "live case studies", i.e., the ongoing projects,
- An opportunity to link the planning activities with the development of effective communications,
- An increased emphasis on demonstrated progress (no hand waving or promises allowed), and
- A positive student reception to this process and genuine synergism among the teams.

<u>Live Case Studies:</u> Case studies are commonly used in engineering education to demonstrate best practice scenarios by describing the set of facts and decisions related to the systematic solutions for given problems. Normally "successful" solutions are provided although one can imagine that the discussion of suboptimal solutions in which alternatives are presented would also be

effective. Problem solving is a process that can be learned. However, the process can be abstract and unrealistic when presented "out of context." In the studio environment each team discusses its "real" problem solving process and difficulties. Other teams can relate to the experiences of their peer teams because they are probably experiencing similar issues.

Planning and Writing: Many teams have difficulty in organizing and planning both their projects and then their writing about the projects. We note that two topics often included in capstone design courses are project planning and technical communications. We have found that these two topics are so closely linked that we are able to address both together, sort of "killing two birds with one stone." (See Reference 7 for more details.)

Demonstrated Progress: In the past we had experienced serious disconnects between reality and what many teams state about their progress in our conversations and in their reports. Part of this problem is an honest underestimate of the effort remaining to complete and debug a software program or to fabricate and test a prototype. Sometimes, unfortunately, it appears to be an attempt to deliberately mislead or misinform the facilitators. Requiring that artifacts of the design process be brought to the studio has essentially eliminated this problem.

Synergism among the Teams: As noted above the teams have demonstrated a genuine interest in helping each other. Not only is class morale higher, but the project results have improved. By allowing the teams to "look over each others' shoulders" the less effective or less motivated teams aspire to work harder. The more successful teams tend to work harder as they see others begin to work up to their level. It is a "win win" situation.

From the Students' Point of View

At the end of the Fall 2003 capstone course the students (42) were asked to complete a survey that asked them to rate their level of agreement with statements related to various aspects of the course using the same Likert scale described above. (See Reference 1 for details). The statements were grouped into three categories:

- the students' sense of accomplishment,
- the students' reaction to the cohort format, and
- the students' feelings about whether the course satisfied the various aspects of ABET criteria 3.

All of the statements were "positive" in the sense that agreement with the statement indicated "satisfaction." For all twenty statements at most only 10% of the students "disagreed" or "strongly disagreed." Overall, only 35 of the 807 responses (not all students provided responses to all statements) or 4.3% were "negative" compared to 628 of 807 or 77.8% that were "positive," i.e., either "agree" or "strongly agree." The student sense of accomplishment was high (4.44 mean, [5.0 means all strongly agreed]) with only four of 41 rating their pride as low as "neutral". Therefore over 90% "agreed" or "strongly agreed" that they were "proud of [their] effort in this course." Seven of the ten statements in the first two categories listed above received ratings higher than 4.0 ("I feel that the cohort environment was an effective compromise between team and class meetings for discussion." [4.20];"I am proud of my team's solution." [4.24]; "I am proud on my team's effort." [4.05]; "I liked the fact that I was able to learn about all the other projects." [4.08]; "I liked the fact that we were responsible for demonstrating that our solution 'worked'. " [4.07]; "The facilitator was helpful and interested in the project." [4.03]. (Two students did not pass the course; the grade point average for the course was 2.97/4.0.)

Mid-Term Results (What We Learned about the Capstone Issues)

The resolution and status after two-years (2005) to the Capstone Issues defined at the beginning of the paper are now presented.

Enrollment: The cohorts and the website solved this potential problem. The instructors formed and divided up the cohorts and coordinated their joint meetings for the presentations.
Team Teaching: The three instructors worked well together and were able to resolve all issues.
Multidisciplinary Teams: Under ideal circumstances combining students with different technical backgrounds seemed like a good idea. In practice, it "sort of worked out", but there were far too many situations in which it did not "work out" satisfactorily, for example when there were IEs or EEs on a team with a Finite Element stress analysis project, or MEs and EEs on a team with a factory layout project or IEs and MEs on a team with an autonomous robot with no structural issues project. Rarely did it "worked out" well. The major problem was that the technical requirements for the project rarely matched the technical makeup of the team. More precisely, we really had difficulty finding true multi-disciplinary projects. We could find projects for EEs, for ECEs, for MEs, and for IEs, but not enough that required the knowledge from multiple disciplines. This problem was especially true of the projects from industry, and when we attempted to redefine the projects to include some additional issues, the industry representatives were not too happy for the most part. Even in these "unbalanced" teams there was still the possibility of a benefit, for example, for the IE who learned about FEA. Unfortunately, this scenario was the exception. The usual scenario was that the IE did nothing but write the report.
Multidisciplinary Projects: As noted above, these projects are difficult to develop. Of course, the instructor could make them up. And, yes, many teams could work on the same project, but this approach would take the realism and variety out of the course. It would become a "make work" situation.
Individual Grades: Thirty percent of the grade was based on individual work: a written (10%) and oral (5%) report for the team and the Final Exam (15%). A peer evaluation was used to determine the individual credit for the team grade; about 10% suffered a grade reduction.
Class Participation: The cohorts and the presentations have worked well in this regard. About two-thirds of the Final Exam was over the "other" projects.
Analysis-Based Design Content: To the extent possible analysis was required before construction could begin. However, some projects were simply analysis.
ABET Criterion 4 (Professional Content): The cohorts have provided a good opportunity to discuss these issues even though a single project rarely involves very many. However, when four projects were grouped there was usually sufficient opportunity to discuss most of the Criterion 4 issues. Even if the discussion wandered from the specific projects, the cohort was small enough that a meaningful discussion was still possible.
Demonstration of a Successful Design: Validation was probably the most important innovation in the course. Teams were required at the beginning of their projects to state their expected outcomes and how these outcomes would be demonstrated, e.g., an autonomous device weighing less that three pounds that would traverse the maze, pick up the cube and return within ten seconds. As the semester progresses, teams were allowed to change their expected outcomes with justification and the approval of the instructor. About two weeks before the end of the semester, the expected outcomes became fixed. Teams schedule a 60-minute meeting during the

last week of the semester with the instructor and one or two other faculty to demonstrate their devices. The faculty determine a grade together (for about 30% of the total project grade).

Project Completion: Completion went hand in hand with the Demonstration of a Successful Design. The object was to have a realistic goal which was usually difficult to specify at the beginning of the semester. By allowing the goal (or outcome) to shift, e.g., based on availability of parts, students have a realistic, but not trivial, goal. This exercise helped the students to develop more realistic planning skills, while at the same time allowed them to "finish the project" and not just "end it"

Meaningful Instruction and Feedback in Communications: With the help and cooperation of the UH Writing Center, as described above, improved communication skills was one the great success stories of the capstone course. This collaboration has lead to a new technical communications course initially taught by the UH Writing Center personnel and sponsored by the College Engineering. It is now taught in the College and coordinated by the College's new Director of Technical Communications across the Curriculum and intervention has been established into several other classes in the College. [8-10]

Uniformity of Grading: This issue turned out not to be a problem. The oral reports, the posters, and the validations were team graded. The written reports were graded by cohorts.

Class Communication: The website took care of this issue.

Client Consistency: This issue remained one of the most troublesome. The issues remained the same as presented earlier.

Quality of Client Consulting: We continue to have problems here as well, and it is not just with the outside clients. Undergraduates sometimes have difficulty finding their faculty clients. On the other hand some faculty take this responsibility very seriously and treat the project as a thesis. This problem was particularly obvious when we saw the large disparity in the quality or completeness of similar projects for different clients.

Quality of Faculty Advising: See the comments on client consulting.

Long-Term Results

Effective for the Fall 2005 the three-department, multi-disciplinary capstone course was discontinued. The IE/ME capstone course was reinstituted, and a separate CE/EE capstone course was established. This decision was based on a mutual agreement between the Department of Electrical and Computer Engineering and the Department of Mechanical Engineering. There were some disagreements over the allocations of resources, but in the long run the task of coordinating 25 to 30 projects in a semester was seen as daunting. The good news was that both of the capstone courses are currently organized and run as their three-department predecessor capstone course was. There is even a common poster day for the two classes.

Conclusions

This paper has presented a series of issues and their resolutions associated with the development and implementation of a one semester, multidisciplinary capstone design course involving the seniors from four engineering programs. Additional issues associated with team-oriented design classes in general were also addressed. The significant beneficial changes that were introduced into the new course in 2002 and which continue to be used today are:

- using a web site to enhance information transfer;
- using cohorts to modularize the large number of students and teams;

- using a "studio/critique" teaching environment
  - to encourage open discussion of projects,
  - to provide a less threatening environment which allows student to informally discuss their projects, and
  - to get teams involved in other teams' projects;
- involving a group of professional communicators (initially involving the staff of the UH Writing Center but now the College of Engineering's Technical Communications across the Curriculum Program) in the teaching and evaluating of the oral and written reports; and
- allowing the students to become involved in establishing the expectations for the artifacts of their design process such that the project validation is much more likely to occur successfully.

Two issues that remain to be addressed are

- reducing the variability in client support and technical advisement and
- matching the skill set required for the project to that of the team.

References

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9. Chad Wilson and Richard Bannerot, "Creating a Comprehensive Communications Communications-Across-the-Curriculum Program in the Cullen College of Engineering" 2006-1978, Abstract. Presented at the 2006 ASEE Annual Meeting, June 18-21, 2006, Chicago, ILL.

10. Richard Bannerot, Chad Wilson, and Colley Hodges, "Integrating Technical Communications into an Early Design Course", IMECE2005-79556 presented at 2005 ASME IMECE, Orlando, FL, November 5-11, 2005. available at http://www.asmeconferences.org/congress05/.

Writing Center Workshop (WCW); Facilitated Cohort Meeting (FCM); Due dates in bold. Planning Report = PR	
Tuesdays: 5:30 to 8:30	**Thursday: 5:30 to 8:30**
January 20, 2004	**January 22, 2004**
Course expectations, website, Writing Center	**Apply for projects (due to at end of class)**
Annoucement of Projects, **form teams**	Projects, Teams Cohorts announced via Website
January 27, 2004	**January 29, 2004**
FCM I: C1 @ 5:30 in N376D	FCM I: C3 & C4 @ 5:30 in N376D & N357D
FCM I: C2 @ 7:00 in N376D	FCM I: C5 & C6 @ 7:00 in N376D & N357D
WCW#1&#2 (Abs, Intro, & Concl) @ 5:30&7	WCW #3&#4 (Abs, Intro, & Concl) @ 5:30&7
	PR #1 due from Cohorts 1&2
February 3, 2004	**February 5, 2004**
FCM II: C1 @ 5:30 in N376D	FCM II: C3 & C4 @ 5:30 in N376D & N357D
FCM II: C2 @ 7:00 in N376D	FCM II:C5 & C6 @ 7:00 in N376D & N357D
WCW #5&#6 (Proposals) @ 5:30&7	WCW#7 (Tone in Tech Com) @ 5:30
PR #1 due from Cohorts 3,4,5,&6	
February 10, 2004	**February 12, 2004**
FCM III: C1 @ 5:30 in N376D	FCM III: C3 & C4 @ 5:30 in N376D & N357D
FCM III: C2 @ 7:00 in N376D	FCM III: C5 & C6 @ 7:00 in N376D & N357D
WCW #8 @ 5:30 (Mechanics and Proofreading)	WCW #9 @ 5:30 (Mechanics and Proofreading)
February 17, 2004	**February 19, 2004**
Proposal: Oral (A) and Written (D)	**Proposal: Oral (A) and Written (D)**
C1, C2 & C3 @ 5:30 in W122D3	**C4, C5 & C6 @ 5:30 in W122D3**
WCW #10 @ 5:30 (Progress Reports)	WCW #11 @ 5:30 (Progress Reports)
	PR#2 from Cohorts 1 and 2
February 24, 2004	**February 26, 2004**
FCM IV:C1 @ 5:30 in N376D	FCM IV:C3 & C4 @ 5:30 in N376D & N357D
FCM IV:C2 @ 7:00 in N376D	FCM IV:C5 & C6 @ 7:00 in N376D & N357D
WCW #12 @ 5:30 (Tone in Tech Com)	
PR #2 due from Cohorts 3,4,5,&6	
March 2, 2004	**March 4, 2004**
Progress Reports: Oral (B) and Written (C)	**Progress Reports: Oral (B) and Written (C)**
C1, C5, & C6 @ 5:30 in W122D3	**C2, C3, & C4 @ 5:30 in W122D3**
WCW #13 @ 5:30 (Paragraph Structure)	**PR #3 due from Cohorts 1 and 2**
	WCW #14 @ 5:30 (Paragraph Structure)
March 9, 2004	**March 11, 2004**
FCM V: C1 @ 5:30 in N376D	FCM V: C3 & C4 @ 5:30 in N376D & N357D
FCM V: C2 @ 7:00 in N376D	FCM V: C5 & C6 @ 7:00 in N376D & N357D
WCW #15 @ 5:30 (Using Figs, Examples, etc.)	WCW #16 @ 5:30 (Using Figs, Examples, etc.)
PR #3 due from Cohorts 3,4,5,&6	
March 16, 2004:SPRING BREAK	**March 18, 2004: SPRING BREAK**
March 23, 2004	**March 26, 2004**
FCM VI: C1 @ 5:30 in N376D	FCM VI: C3 & C4 @ 5:30 in N376D & N357D
FCM VI: C2 @ 7:00 in N376D	FCM VI: C5 & C6 @ 7:00 in N376D & N357D
WCW #18 @ 5:30 (Technical Reports)	WC#14 @ 5:30 (Technical Reports)
March 30, 2004	**April 1, 2004**
Technical Reports: Oral (C) and Written (B)	**Technical Reports: Oral (C) and Written (B)**
C1, C4 & C5 @ 5:30 in W122D3	**C2, C3 & C6 @ 5:30 in W122D3**
WCW# 19 @ 5:30 (Mechanics and Proofreading)	**PR #4 due from Cohorts 1 and 2**
	WCW# 20 @ 5:30 (Mechanics and Proofreading)
April 6, 2004	**April 8, 2004**
FCM VII: C1 @ 5:30 in N376D	FCM VII: C3 & C4 @ 5:30 in N376D & N357D
FCM VII: C2 @ 7:00 in N376D	FCM VII: C5 & C6 @ 7:00 in N376D & N357D
WCW #21 @5:30 (Progress Reports)	WCW #22 @ 5:30 (Progress Reports)
PR #4 due from Cohorts 3,4,5,&6	
April 13, 2004	**April 15, 2004**
Progress Reports: Oral (D) and Written (A)	**Progress Reports: Oral (D) and Written (A)**
C3, C4 & C5 @ 5:30 in W122D3	**C1, C2 & C6 @ 5:30 in W122D3**
WCW #23 & #24 @5:30&7(Posters)	WCW #25 & #26 (Posters) @5:30&7
	PR #5 due from Cohorts 1 and 2
April 20, 2004	**April 22, 2004**
FCM VIII: C1 @ 5:30 in N376D	FCM VIII: C3 & C4 @ 5:30 in N376D & N357D
FCM VIII: C2 @ 7:00 in N376D	FCM VIII: C5 & C6 @ 7:00 in N376D & N357D
WCW #27 & #28 @5:30&7 (Extended Abs)	WCW #29 & #30 @ 5:30&7 (Extended Abs)
PR #5 due from Cohorts 3,4,5,&6	
April 27, 2004	**April 29, 2004 ***
Set up Posters by noon	**Poster Session 1 to 4:30**
	Final Presentations on May 1st
May 4, 2004	**May 6, 2004**
Schedule Demontration	**Final Technical Report Due**
May 11, 2004	**May 13, 2004**
Final Exam	

Figure 1: Capstone Design Schedule for Spring 2004