Challenges and Solutions in Developing a Three Department Interdisciplinary, Capstone Design Course at the University of Houston

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Abstract *— In 1998 the Department of Electrical and Computer Engineering at the University of Houston began requiring the completion of a new capstone design course as part of its BSEE and BSCE degrees. Through mutual agreement the ECE students were required to enroll in the existing capstone design course, required of all students in the Departments of Industrial Engineering and Mechanical Engineering, resulting in an almost tripling of enrollment in that class. Traditionally, the course had drawn most of its projects from local industry, primarily companies working in the "oil patch." However, since the enrollment in the new course would be dominated by EE and CE majors, additional sources of projects would be needed. This paper describes the specific problems (due both to the specific challenges of teaching a large, multidisciplinary, design course and to team-based design courses in general), the changes, i.e., solutions have been implemented in the course, and the students' response to them. The following is a list of the most significant changes: a change from a lecture format to facilitated, cohort structure in a studio/critique environment, an involvement with the University of Houston Writing Center to provide support for both written and oral communication issues, a web based communication system to "run" the course, an increased reliance on projects from the university's research laboratories, an increased individual student accountability for understanding the projects, a project "ownership" policy requiring students to specifically define their end-of-semester deliverables by mid-semester, and a validation process requiring that the students formally and explicitly state the expectations for the performance of their "solution", develop the specifications for the "testing" of their artifacts, and then demonstrate that they have been successful.*

Index Terms *— Capstone Design, Communications, Multidisciplinary Design, and Studio/Critique Format.*

INTRODUCTION

The capstone design course in the Department of Mechanical Engineering at the University of Houston (UH) has existed since the 1960s and had remained essentially unchanged since 1981 until just recently. In 1998 the Department of Electrical and Computer Engineering began requiring the completion of a capstone design course as part of its BSEE and BSCE degree requirements. Through mutual agreement they created a new course, ECE 4334, and joined the existing INDE/MECE 4334 capstone design courses, required of all students in the Departments of Industrial Engineering and Mechanical Engineering. Transfer and freshman students starting in the fall of 1998 and thereafter began entering the combined capstone course in 2001. The INDE/MECE 4334 casptone course had been taught by Ross Kastor, a lecturer in the Department of Mechanical Engineering and a retired drilling engineer with 40 years experience in the petroleum industry, since 1991. Two faculty members, Richard Bannerot (ME) and Paul Ruchhoeft (ECE), were assigned to help develop and then teach the new multidisciplinary courses. Two major issues were anticipated: an increased enrollment from 35 to 90 a semester and a need to develop new sources for projects appropropriate for the new mix of disciplines. In addition, there were a long list of issues associated with the teaching of team-based design classes in general, e.g., grading, communications, participation, etc., that the new team of instructors wanted to address. This paper lists and discusses these "capstone challenges" and our responses (changes to the course).

THE PRE-EXISTING COURSE

The pre-existing course was 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. Teams of four students were assigned (through a bidding process) a project. About 80% of the projects were provided and sponsored by local industry and a majority of them were related to the petroleum and process industries. 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 were submitted to the course instructor. Formal written and oral proposals and final reports were required from each team. There were also several other individual "reporting documents." 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, and present value analysis. 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 four to five hours a week early in the semester so that much of the content was covered by mid-semester. Few formal class meetings occurred during the last half of the semester as students were allowed to concentrate on their projects.

CAPSTONE CHALLENGES

Challenges Associated with the Transition to the New Environment

Enrollment: The course enrollment was about to triple from around 35 students a semester to about 90.

Team Teaching: Faculty would work together to teach the course.

Multidisciplinary Teams: Previously there were no restrictions on the make up of the teams. The new course would stress multidisciplinary projects for the multidisciplinary teams.

Multidisciplinary Projects: As noted, the projects in the past had been primarily from the petrochemical industry, and they were 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.

Challenges Associated with Team-Oriented Design Courses in General

Individual Grades: One of the objectives of the course is to teach students to become "team" oriented and to accept both the responsibilities 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 three academic departments, 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.

RESPONSES TO THESE CHALLENGES

Five changes were made in the capstone course that addressed most of the issues raised above. These changes were:

- to modularize the class by dividing it into cohorts and change the instructor's role from one of "lecturing" to one of "facilitating",
- to utilize a studio/critique teaching format [1], adapted from the visual arts,
- to integrate the resources of the newly established University Writing Center [2] into the teaching and evaluating of communications for the course,
- to require that all teams have representation from at least two of the three academic departments, and
- to replace many of the industrial projects with projects from the College's research laboratories [3].

Cohorts, Facilitators and Individual Accountability

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 has been reduced and "repackaged" and is now presented in interactive, cohort meetings. The project teams are 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 [1] 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 10 to 12 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 (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, and grading rubrics were posted on the website. In addition to the hardcopy submissions, copies of all student work (including PowerPoint slides) were submitted to the website.

Individual accountability was increased by both student (peer evaluations) and instructor (due to close observation of individuals in the cohort meetings) inputs on the final grade. Also, a final exam was administrated with approximate coverage of 50% for ones own project, 30% for projects in ones cohort, and 20% for the remaining projects.

Adaptation of the Studio/Critique Teaching Format

Introduction: The use of a studio environment in the teaching of engineering design is briefly discussed in [4], and experiences in using the critique in a studio environment for the teaching of introductory engineering design have been presented in [5]. The critique and the studio environment have been an important teaching tool in the visual arts for much of the last century. Class size in 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 is satisfied in our capstone design course. As many as a ninety students are enrolled, and the available meeting room provides no work area or storage facilities. Another issue that could interfere with the successful implementation of the studio/critique environment is 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 have developed a very effective technique for improving the design experience for our students through the use of a modified studio/critique process. This technique requires 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 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 [1]. 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 students, and it is assumed that the students will devote a certain amount of time, including time in the studio, to completing the projects. 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). An important element of the studio are that 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 several different classes (and academic levels) working side by side during a class 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 some engineering programs and in fact it is similar in appearance (except for the electronics and the hardware). The other 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 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 "sensing" or "feeling" rather than 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 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.

Before each cohort 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 is 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.

Writing in the Discipline Program at the University of Houston Writing Center

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 is 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 [2]) 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 were established. Each team member is 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 represent 15% of the individual's course grade. Five, team-prepared, written Planning Reports are required and reviewed in the cohort meetings. The team is 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, a series of 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 is required to attend the appropriate workshop. These workshops are scheduled during normal class time about two weeks prior to the submission or presentation. The grading criteria (These rubrics were developed jointly with the WID program.) for these assignments are available for each type of report, are posted on the website, and are discussed in the workshops. Each student must also attend at least three of the ten 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 Course Structure and Schedule

The details of the course structure can be understood from the spring 2004 capstone class schedule as seen in Figure 1. In the spring 2004 there are 88 students divided into 22 four-person teams. The 22 teams are grouped into six cohorts, i.e., C1, C2, C3, etc. The meetings are:

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

Each team prepares a poster for its project that is displayed in the engineering building commons for three days and presents a 30-minute oral report on the last Saturday of the semester. These presentations are part of an all day affair and lunch is served. All students intending to take the capstone course in the next semester are 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 its project (artifact).

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. Grades cannot be based solely on sponsors input since too many industrial partners take the approach that "everyone worked hard and did a good job" no

UH Writing Center (WC) plumb; Facilitated meetings green; Group due dates red; Individual due dates blue	
Tuesdays: 5:30 to 8:30	**Thursday: 5:30 to 8:30**
[redacted]	[redacted]
Attendance Required in W122D3	Attendance Required in W 122D3
Course expectations and philosophy	Apply for projects (due to at end of class)
Website, Projects, UH Writing Center	Projects, Teams Cohorts announced
Informal mixing; form teams	
January 27, 2004	**January 29, 2004**
Cohort Meetings I, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings I, N376D: C3 @ 5:30, C5 @ 7
WC#1 @ 5:30, WC#2 @ 7 (Abstracts, Intros, & Conclusions)	Cohort Meetings I, N357D: C4 @ 5:30, C6 @ 7
	WC #3 @ 5:30, WC#4 @ 7 (Abstracts, Intros, & Conclusions)
	Planning Report #1 due from Cohorts 1 & 2
February 3, 2004	**February 5, 2004**
Cohort Meetings II, N376D: C1 @ 5:30; C2 @ 7 in N376D	Cohort Meetings II, N376D: C3 @ 5:30; C5 @ 7
WC #5 @ 5:30 (Proposals) C2, C5, & C6	Cohort Meetings II, N357D: C4 @ 5:30; C6 @ 7
WC#6 @ 7 (Proposals) C1, C3, & C4	WC#7 @ 5:30 (Tone In Professional Communications)
Planning Report #1 due from Cohorts 3,4,5,&6	
February 10, 2004	**February 12, 2004**
Cohort Meetings III, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings III, N376D: C3 @ 5:30, C5 @ 7
WC #8 @ 5:30 (Mechanics and Proofreading)	Cohort Meetings III, N357D: C4 @ 5:30, C6 @ 7
	WC #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
WC #10 @ 5:30 (Progress Reports) C4, C5, & C6	WC #11 @ 5:30 (Progress Reports) C1, C2, & C3
	Planning Report #2 from Cohorts 1 and 2
February 24, 2004	**February 26, 2004**
Cohort Meetings IV, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings IV, N376D: C3 @ 5:30, C5 @ 7
Planning Report #2 due from Cohorts 3,4,5,&6	Cohort Meetings IV, N357D: C4 @ 5:30, C6 @ 7
WC #12 @ 5:30 (Tone in Professional Communications)	
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
WC #13 @ 5:30 (Paragraph Structure)	Planning Report #3 due from Cohorts 1 and 2
	WC #14 @ 5:30 (Paragraph Structure)
March 9, 2004	**March 11, 2004**
Cohort Meetings V, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings V, N376D: C3 @ 5:30, C5 @ 7
WC #15 @ 5:30 (Using Figures, Examples, etc)	Cohort Meetings V, N357D: C4 @ 5:30, C6 @ 7
Planning Report #3 due from Cohorts 3,4,5,&6	WC #16 @ 5:30 (Using Figures, Examples, etc)
March 16, 2004: Spring Break	**March 18, 2004: Spring Break**
March 23, 2004	**March 26, 2004**
Cohort Meetings VI, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings VI, N376D: C3 @ 5:30, C5 @ 7
	Cohort Meetings VI, N357D: C4 @ 5:30, C6 @ 7
WC #17 @ 5:30 (Technical Reports) C2, C3, & C4	WC#18 @ 5:30 (Technical Reports) C1, C5, & C6
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
WC# 19 @ 5:30 (Mechanics and Proofreading)	Planning Report #4 due from Cohorts 1 and 2
	WC# 20 @ 5:30 (Mechanics and Proofreading)
April 6, 2004	**April 8, 2004**
Cohort Meetings VII, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings VII, N376D: C3 @ 5:30, C5 @ 7
WC #21 @ 5:30 (Progress Reports) C2, C3, & C4	Cohort Meetings VII, N357D: C4 @ 5:30, C6 @ 7
Planning Report #4 due from Cohorts 3,4,5,&6	WC #22 @ 5:30 (Progress Reports) C1, C5, & C6
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
WC #23 @ 5:30, WC #24 @ 7 (Posters)	WC #25 @ 5:30, WC #26 @ 7 (Posters)
	Planning Report #5 due from Cohorts 1 and 2
April 20, 2004	**April 22, 2004**
Cohort Meetings VIII, C376D: C1 @ 5:30; C2 @ 7:00	Cohort Meetings VIII, N376D: C3 @ 5:30, C5 @ 7
WC #27 @ 5:30, WC #28 @ 7 (Extended Abstracts)	Cohort Meetings VIII, N357D: C4 @ 5:30, C6 @ 7
Planning Report #5 due from Cohorts 3,4,5,&6	WC #29 @ 5:30, WC #30 @ 7 (Extended Abstracts)
April 27, 2004	**April 29, 2004**
Set up Posters by noon	Poster Session 10 to 5:30
May 4, 2004	**May 6, 2004**
** Semester Over **	Final Technical Report Due

FIGURE 1
CAPSTONE COURSE SCHEDULE, SPRING 2004

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. A recent paper [6] presents lists of such projects and detailed descriptions of a few.

DISCUSSION

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.

Studio-Critique Teaching Format

Generally all our intents have been satisfied, and several additional benefits have also been realized such as (These benefits are discussed in detail below.):

- 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),
- a genuine synergism among the teams, and
- a positive student reception to this process.

Live Case Studies: 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. For example, consider the issue of working in parallel paths. For some team members, using the team meetings to assess progress and to establish and assign parallel tasks so that team members can work alone and still be effective is difficult to accept. They may feel more comfortable working as a team on individual tasks and proceeding on a serial path. Using one team's activity as a "real" example and presenting scheduling aids, such as Gantt charts, we can work toward a solution to their problem. By the time this process has been repeated for the second team, the remaining teams can "take care of themselves," and all members have seen the process work several times, i.e., been presented live case studies.

Planning and Writing: Many teams have difficulty in organizing and planning both their projects and then writing about them. 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." For example, we have each team prepare material for the cohort meetings such as: a list of goals for its project, the project deliverables, a statement of work, or the context for the project. Experience has demonstrated that there can be misunderstanding concerning the meaning of these phrases. The teams are required to email their material to the facilitators (and sometimes to all members of the cohort, e.g., when we are talking about the statement of context or abstracts) the day before the meeting. (As previously noted the course is organized through a website which provides a variety of communication options among class members and the instructors.) At the cohort meeting they write their material on the board or provide a PowerPoint slide. We present a short introduction to the topic, e.g., what are goals or milestones?, and begin to seek clarification (from the team) and alternatives (from the other teams) about the goals or milestones listed on the board. Most of the time there a "misconnect" between our expectations and the material provided. For minor problems teams may rewrite material on the board. In cases in which significant revision is needed, the team will be assigned to rewrite the material after class and resubmit via email. This exercise provides many benefits as listed below:

- Students are often confused about the specific goals (or context, or deliverables, etc.) of their project. By forcing them to prepare a concise list of goals not only is their writing about the project more effective and organized, but their planning process is also greatly improved. We find this discussion format preferable to simply "correcting" submitted written documents since our comments can be extended or contracted depending on the student responses, and we can address the issue with the entire cohort, not just the writer of the document. Also, alternative wording can be discussed, but not actually provided in detail so that it can be copied in future documents.
- This studio environment allows the students to think about these issues in a non-threatening situation. ("Participation" points are recorded for the studio meetings, but are not figured into a student's final grade unless he/she becomes a "chronic non-participant.") By working through the process together, e.g., to establish the project

goals, the students will be better prepared to establish the goals for their next projects. In any event they will be more prepared than if we simply stated the goals for them or just "counted them wrong."

- For the specific example of goals, once goals are established the project is dissected into several smaller problems and the planning and documentation processes become more organized and logical. Following each goal through the process, accomplishments, and results phases for a technical report or through the methodology, progress description, and scheduling phases for a progress report is usually easier than attempting to describe the whole project as one big "problem."

<u>Demonstrated Progress:</u> In the past we have experienced serious disconnects between reality and what many teams state about their progress in our conversations and report in their oral and writing documentation. 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. In either case, the result is a project behind schedule and likely to be incomplete at the end of the semester. As noted above, failing students in a course in their last semester is not desirable and steps should be taken to attempt to avoid it while not lowering standards. It is one thing to work with a team all semester providing continuous feedback that their efforts and results are unacceptable and then assigning a failing grade, but quite another to accept and not question inadequate progress and results throughout the semester and then assign a failing grade when the final results are, as expected, inadequate. In order to reduce the probability of this disconnect, we frequently require that artifacts of the design process to brought to the studio. These artifacts are demonstrated and discussed by the entire cohort. This activity closely parallels that experienced in the visual arts studio when the artist's in-progress artifacts are "critiqued." We had hoped that a supportive atmosphere among the teams (rather than a competitive one) would develop for this activity and we were not disappointed. The students enjoy showing off their work and seeing the work of their peers. Many times useful suggestions from the cohort (not thought of by the facilitators) have resulted in significant improvements in the project.

<u>Synergism among the Teams:</u> As noted above the teams have demonstrated a genuine interest in helping each other. Not only is class morale higher, but the project results are 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 work harder as they see others begin to work up to their level. It is a "win win" situation.

<u>Student Response:</u> At the end of the fall 2003 course (but before grades were known) the students were asked to complete a survey to rate their level of agreement with statements related to various aspects of the course. The results from that survey are given in Table 1. The statements are listed on the left exactly as they appeared in the survey. All responses are recorded in the first five columns, e.g., for the first statement, 22 of the 41 (N in the sixth column is total number of responses to that particular statement) students "strongly agreed" with the statement, "I am proud of my efforts in this course." (Note that on the questionnaire only the five columns appear, and all columns have the same width.) The "mean" is the weighted average response for each statement calculated by multiplying the number of responses in each category by the "value" of category (e.g., 5 for "strongly agree"), summing over the five categories and dividing by the total number of responses, N. The standard deviation, σ, for the responses is given in the last column. The questions are grouped in three categories in the table:

- the students' sense of accomplishment,
- the students' reaction to the cohort format, and
- the students' feeling 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 each of the 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 (4.44/5.0 mean) 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." (Two students received non-passing grades in the course; the course grade point average was 2.97/4.0.) The students reacted positively to the cohort environment (4.20/5.0 with none disagreeing), and it was clear that the students liked the interaction with the other teams (statements 2 and 6 under the cohort format). Perhaps most surprising is the positive response to statement 5 (liked being responsible for demonstrating that their solution "worked"): 4.07/5.0 with only one "disagreement"). The lowest ranking statement (3.54/5.0), among those related to the cohort format, was modest agreement with the statement, about receiving help from other teams. With the possible exception of the statements related to professional issues and design of experiments (but even these were well supported), all the ABET Criteria 3 statements were "agreed" to. Overall, the students supported our contention that the course was successful, and we believe that the cohortformat in the studio/critique approach contributed significantly to that success.

Please select the numbers: 5: strongly agree; 4: agree; 3: neutral; 2: disagree; 1 strongly disagree.
that best characterize your opinions of the following statements.

The survey form had columns of uniform width.

#	Statement	5	4	3	2	1	N	mean	σ
	The students' sense of accomplishment								
1	I am proud of my efforts in this course.	22	15	4			**41**	**4.44**	**0.66**
2	I am proud of my team's effort in this course.	15	17	6	2	1	**41**	**4.05**	**0.96**
3	I am proud of the “solution” which my team produced.	17	17	7			**41**	**4.24**	**0.73**
	The students' reaction to the cohort format								
1	I feel that the cohort environment was an effective compromise between team and class meetings for class discussion.	14	21	6			**41**	**4.20**	**0.67**
2	I feel that the interactions with the other teams during the cohort meetings were helpful.	11	19	9	1	1	**41**	**3.93**	**0.89**
3	The facilitator was helpful and interested in the project.	14	17	6	2	1	**40**	**4.03**	**0.96**
4	The faculty advisor was helpful and interested in the project.	14	11	12	2		**39**	**3.95**	**0.93**
5	I liked the fact that we were responsible for demonstrating that our solution “worked”.	13	19	8	1		**41**	**4.07**	**0.78**
6	I liked the fact that I was able to learn about all the other projects in the course.	12	21	6		1	**40**	**4.08**	**0.82**
7	Our team received useful "help and information" by interacting with other teams.	6	15	17	1	2	**41**	**3.54**	**0.94**
	The students' sense of the degree to which the course satisfied the various aspects of ABET Criteria 3								
	I improved in my ability:								
1	to analyze and solve open-ended engineering problems.	12	20	4		1	**37**	**4.14**	**0.81**
2	to manage a project and to complete it on time and within budget.	13	22	6			**41**	**4.17**	**0.66**
3	to communicate more effectively.	12	18	8	3		**41**	**3.95**	**0.88**
4	to design a system, component, or process to meet desired needs.	10	29	2			**41**	**4.20**	**0.50**
5	to function on a multi-disciplinary team.	9	23	7	1	1	**41**	**3.93**	**0.84**
6	to understand professional and ethical considerations.	8	18	11	4		**41**	**3.73**	**0.88**
7	to design and conduct experiments or tests, as well as, analyze and interpret data.	10	19	9	2	1	**41**	**3.85**	**0.93**
8	to identify, formulate and solve engineering problems	12	20	4	2	1	**39**	**4.03**	**0.92**
9	to use the techniques, skills, and modern engineering tools necessary for engineering practice.	10	20	5	4		**39**	**3.92**	**0.89**
10	I better recognize the need for, and an abilty to engage in, life-long learning.	12	21	7			**40**	**4.13**	**0.68**

TABLE 1
RESULTS OF A STUDENT SURVEY FOR THE CAPSTONE DESIGN COURSE, FALL 2003

Collaboration with the Writing in the Discipline Program

We have observed a definite improvement in the quality of the writing and the presentations in just one semester. Part of that improvement is probably due to that fact that we have done a better job telling the students what we want. Reference 2 discusses more of this collaboration and presents the results of a student survey that is summarized here in Table 2. Students 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%.

Implications of the JIT Model for Senior Design Faculty and the College of Engineering

The course instructors are pleased with the demonstrated improvements in the overall communication abilities of the students. Any single cause of these improvements is difficult to identify. WID Initiatives are multi-tiered, involving multiple elements such as writing workshops, tutorials with Writing Consultants, and instructional materials and evaluative tools developed jointly by WID Program staff and course instructors; it is difficult to isolate impact. In addition, the capstone course itself has undergone significant change to support communications skills: instructors have worked to convey the increased emphasis on communications skills through the course structure, assignments, and discussion in cohort meetings. Based on the fact and nature of the College of Engineering's commitment to communications, it appears that the *combination* of these efforts should be credited for student skill improvement.

However, writing and speaking abilities remain difficult skills to quantify. As is typical in WID Initiatives, writing or speaking is not the primary basis for any course-based evaluation. The WID Program staff and capstone faculty are working to develop indicators of discipline-specific literacy that may be expressed in writing, and integrating these indicators into evaluative rubrics as criteria for grading.

During the Spring 2004 semester, the College of Engineering has supported integrated interventions developed by the WID Program in both the capstone course and a sophomore design course in the Department of Mechanical Engineering. The College has also supported three sections of a new technical communications course that has become a required course in the BSEE and BSCE (computer engineering) curriculum. Three sections are also scheduled for Fall 2004.

SUMMARY AND CONCLUSIONS

This paper has presented a series of issues and their resolutions associated with the approximately tripling of the enrollment in a one semester capstone design course while transforming the class from one consisting largely of mechanical engineering students to one in which the number of electrical engineering students dominates. Additional issues associated with team-oriented design classes in general were also addressed. The significant changes that have been introduced into the course over the last year are: using cohorts to modularize a large number of students; using a "studio/critique" teaching/facilitating 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 (the staff of the UH Writing Center) in the teaching and evaluating of the oral and written reports; allowing the students to become involved in establishing the expectations for the products of their design process; and using a web site to enhance information transfer. These changes have had a positive effect on the course based on the instructors' evaluations of the designs and on the results from several student surveys.

Beginning of Semester

	5	4	3	2	1	N	mean	σ
Communication skills are important for engineers.	34	6	1		1	**42**	**4.71**	**0.73**
I am able to express my knowledge clearly through writing.	5	22	9	4	2	**42**	**3.57**	**0.98**
I am able to express my knowledge clearly through speaking.	8	16	12	5	1	**42**	**3.60**	**1.00**
Writing helps me organize my knowledge.	8	23	10		1	**42**	**3.88**	**0.79**
I can communicate complicated information to others.	8	19	10	3	2	**42**	**3.67**	**1.02**

End of the Semester

	5	4	3	2	1	N	mean	σ
Communication skills are important for engineers.	27	13	2			**42**	**4.60**	**0.58**
I am able to express my knowledge clearly through writing.	10	21	7	2		**40**	**3.98**	**0.79**
I am able to express my knowledge clearly through speaking.	12	20	7	1		**40**	**4.08**	**0.75**
Writing helps me organize my knowledge.	9	23	8			**40**	**4.03**	**0.65**
I can communicate complicated information to others.	7	19	13	1		**40**	**3.80**	**0.75**
My communication skills have improved by taking this course.	16	17	5	3	1	**42**	**4.05**	**1.00**
My technical writing skills have improved by taking this course.	14	17	7	3	1	**42**	**3.95**	**1.00**
I found the following workshops helpful:								
proposals	7	15	2	6	1	**31**	**3.68**	**1.12**
abstracts, introductions and conclusions	4	15	4	3	1	**27**	**3.67**	**0.98**
progress reports	4	13	10	5	2	**34**	**3.35**	**1.05**
technical reports	2	11	9	2	2	**26**	**3.35**	**1.00**
posters	7	16	4	3	2	**32**	**3.72**	**1.10**
extended abstracts	7	9	6			**22**	**4.05**	**0.77**

TABLE 2
RESULTS FROM TWO STUDENT SURVEYS FOR FALL 2003 IN THE CAPSTONE DESIGN COURSE

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