Session 3125

Adapting the Studio Critique to Large Capstone Design Courses

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Abstract

In this paper we describe the successful adaptation and application of two techniques used primarily in teaching the visual arts, the studio and the critique, to a large capstone design environment. This new format for the class allowed us to successfully address four issues: to establish and achieve higher expectations for the teams, to improve each team's understanding of the fundamental engineering and science of its project, to encourage and increase the interactions between the teams, and to help the students to better "think through" the writing process which in turn helps them to better understand the organization of their project.

Introduction

The multidisciplinary capstone design course at the University of Houston, taken by the students in the Departments of Electrical and Computer Engineering (ECE), Industrial Engineering (IE) and Mechanical Engineering (ME), has been described previously [1]. This course is a one semester, three-hour credit course that has been taught every semester since the 1960s. Prior to 2002 the course was taken by only mechanical engineering and industrial engineering (starting in 1985) students. In 1999 the ECE Department added this course to its undergraduate degree requirements and the ECE seniors began taking the course in 2002. The normal enrollment for the course in the 1990s was approximately 30 to 35 (an annual graduation rate of about 65 BSME and BSIE students). The annual graduation rates for the BSEEs and BSCEs (Computer Engineering) has historically been in the 90s. Therefore it was clear that the teaching effort would need to be increased. Ross Kastor had been the sole instructor for the capstone course since 1991. The other two authors of this paper were assigned as additional instructors for the course. They assisted and observed the course for the first time in the spring of 2002 and became equal partners in the teaching of the course in the fall of 2002.

Challenges and Issues

The teaching team faced several significant challenges in implementing the course as it more than tripled in throughput. The specific issues and problems encountered and the changes, i.e., solutions, that have been implemented have been discussed in a previous paper[2]. That paper addressed not only the issues of size but also those issues associated with multidisciplinary capstone courses in general. This paper will focus on a particular change that was made in the course and how that change has addressed several of the issues/problems we had identified.

One of the major concerns that we had about the course was that, in most cases, the projects were not being brought to the level of completeness that we desired. Since essentially all the students were graduating seniors, a large number of unsatisfactory, failing, or "incomplete" grades was not the optimal solution. One of the contributing factors to this problem is the fact that this is a one semester (only) course. Conceiving and designing a solution and then obtaining materials and fabricating an artifact, all in about thirteen weeks while being able to devote only about ten hours a week to the project, is of course a challenge. In addition, since the four person teams are required to be multidisciplinary, most of the team members have little if any previous history together. The problem was perhaps compounded by our desire to place the burden of demonstrating "completeness" on the students – as part of the requirements of the project each team must present evidence of "validation" of its project results. In general, it is the team's responsibility to propose the validation method or process. It was clear to us that if we were expecting more, <u>we</u> would have to do more.

To the extent possible, the teams are composed of four students each. Informational and technical support for each team is provided by a client or "engineer-in-charge" (who proposed and financially supports the project) and a faculty consultant (a faculty member who volunteers to provide technical assistance, sometimes an instructor for the capstone course). The instructor's official role is that of a team facilitator. (The instructors also handle all the organizing, planning and grading for the class as well as serving in the role of the client and consultant as needed.) In the current course the instructor can expect to be "responsible" for about twelve teams each year working on ten or eleven different projects. For example, in 2003 (spring and fall semester combined), there were 131 students formed into 34 teams working on 24 different projects divided among the three instructors. The projects are listed in Table 1. Abstracts are also included for some of the projects. In the past we were disappointed in several areas with our results. The issues we felt we had to address are discussed in the next four paragraphs. (The change to the Studio/Critique format was implemented in fall 2003.)

The first issue has been expressed previously in this paper, i.e., we had expected more from the teams. The official interaction between a facilitator and his team was three 30-minute meetings during the semester. Of course, there were many other interactions, e.g.,

Table 1: Capstone Projects for 2003

Ten Projects Sponsored by Research Laboratories at the University of Houston

<u>Design of In-Vaccum Cold Sink</u>
A backside helium cooling system was designed to reduce stencil mask distortion due to overheating during x-ray lithography used for integrated circuit fabrication. Thermistors, placed on the membrane surface as carbon cement, were used to measure the temperature of the fragile membranes. The thermistors were calibrated with the aid of a digital hot-plate.

<u>Preparation of NASA Nanocomposites</u>
A mixing device was designed and fabricated to uniformly disperse carbon nanotubes within an epoxy in order to increase the tensile strength of the epoxy. The new mixer contained a variable speed motor capable of rotational speeds up to 10,000 RPM with a 10 blade, aluminum impeller. A new vacuum mixing vessel was fabricated with special sealing around the shaft. Tensile testing of both the old and new composites indicated that the new mixing device did improve the quality of NASA's nanocomposites.

<u>Manufacturing Research Data Base</u>
A user-interface to an existing database was developed using MS Access database software and ColdFusion web-application software to establish a more efficient method for tracking the data associated with the manufacturing films and masks from silicon wafers. The final product was a thoroughly tested, web-based system in which the user has the ability to scan a bar code and retrieve or input data associated with a wafer's manufacturing process. A comprehensive user's guide was provided.

<u>A "Feeling" Robotic Hand</u>
This was a haptic feedback, demonstration project, and represented the first step in the design and implementation of a "Feeling" Robotic Hand that could be used, along with other sensors, to practice medicine at the distance. A pressure sensor (acting as a "probing finger") was calibrated and used to produce a proportional current to drive a force actuator, a voice coil, that applied a calibrated force to the "sensing finger".

<u>Demonstration of a Magneto-Rheological Fluid</u>
Three interactive experiments/displays illustrating the properties and applications of a Magneto-Rheological (MR) Fluid were designed, fabricated and tested. An MR fluid is a fluid whose viscosity changes in the presence of a magnetic field. The three experiments are: a MR fluid disk brake, a vibrating platform with MR fluid dampers, and a crane that raises and lowers an electromagnet in and out of an MR fluid. All three experiments possess interactive controls and were mounted in a ventilated, acrylic display case.

<u>Demonstration of a Shape Memory Alloy</u>
Two electrically controlled, interactive Shape Memory Alloy (SMA) actuator demonstrations were designed, fabricated and tested. A SMA is a metal that demonstrates the ability to return to some previously defined shape or size when subjected to the appropriate heating or cooling. The first demonstration is a weight lifting mechanism that uses seven strands of 0.015 inch diameter Nitinol wire to lift twenty pounds when the wires are electrically heated. The other demonstration is a flexible limb mechanism composed of a strip of flexible metal that has 0.015 inch Nitinol wire actuators attached to both faces of the limb. The coordinated, alternating electrical heating of each wire allows controlled movement of the flexible limb. The Nitinol has a transformation

Table 1: (continued)

temperature of 90ºC, at which its crystal lattice structure changes from Martensite to Austenite that results in contraction of the wire. Both demonstrations are housed in a ventilated acrylic case currently on display in the lobby of the Department of Mechanical Engineering.

<u>Implementation of a Positional Feedback System for Metrology Tool</u>
The x-y stage of a metrology tool used to examine semiconductor wafers was upgraded by implementing a positional feedback system using a proportional-derivative control scheme and coded with LabView software that interacts with a charge-coupled- device camera to determine the coordinates of the stage. Testing of the system revealed that the system's precision was about 20 microns which was not acceptable. Part of the problem was traced to way the camera acquires images and to the positioning errors associated with the DC motors.

<u>Remote Sensing Hand Using the Internet for a Haptic Interface</u>
The "Feeling Hand" project from the previous spring was repeated. Different techniques were utilized for both the "probing" and the "sensing" finger, and an internet link was added between the probing and sensing functions. A unique "probing finger" sensor was designed fabricated, calibrated, and tested successfully. The internet link was established using LabView. An attempt was made to develop a novel "sensing finger" using a (variable viscosity) MR fluid (see above) as the working fluid in a cylinder-orifice system but it was not successful due to the clogging of the orifice.

<u>Smart Crutch Using an Electro-Magneto Fluid</u>
A Magneto-Rheological (MR) Fluid (see above) sponge damper controlled by an electromagnet was used in the design of an innovative crutch. A predetermined (and controllable by the user) electrical signal was generated with each crutch impact with the ground and then used to control the "damping" constant of the system (through the MR fluid) to reduce the impact shock of the crutch. The design was fabricated but met with only limited success because a damper system with a satisfactory orifice opening was not found. The iron particles present in the MR fluid tended to plug up the orifice.

<u>Active Guide Wire for Angioplasty</u>
A method was developed and implemented (in principle, not in patients) to overcome the lack of control in current procedures for directing the guide wire into position in the artery for an angioplasty procedure (displacement of plaque buildup in coronary arteries). Two Shape Memory Alloy (SMA, see above) actuators were micro-welded to opposite sides of the wire. By selectively heating and/or cooling the two opposed SMA actuators (by applying a pulse-width modulated current), the guide wire can be forced to turn to one side or the other as dictated while the progress of its tip is followed on a real time fluoroscopic x-ray screen.

Additional Projects (All projects required the design, fabrication and testing of a prototype):

<u>Seven projects for outside sponsors:</u>
An Active Defense Robot for Practicing Free Kicks (two projects)
A Dressing Station for Upper Bi-Lateral Amputees
A Multiple Station Extrusion Device
An Inventory/Distribution/Transportation Synchronization Decision-Making Tool
A Software Tool for Use as Part of NASA Shuttle Simulation Training
A Mechanized Fire Hose Lay-up Device

Table 1: (Continued)

Five projects sponsored by individual faculty:
An Interactive, Controllable, Demonstration of a Variable Speed Transmission
A Human Powered Electric Generator with Mechanical Energy Storage (two projects)
A User-Friendly, Computer Based System for Assisting Visitors in Finding People and Rooms in the College of Engineering (two projects)

Three product development projects that required market surveys, business plans, patent searches as well as prototype development and testing:
Commercialization of a Foot Activated Computer Interface
Commercialization of a Low Power Light Bulb
Commercialization of a Human Fatigue Sensor

Eight projects for regional student design competitions:
Seven Teams in the IEEE Robotic Competition (a 2nd and 4th place regionally)
One Team in the ASME National Design Contest (3rd place regional)

five formal oral presentations, five formal written reports, a prototype review, bi-weekly "planning reports", a final product review and many office visits (See reference 2 for details.), but we felt we could improve the effectiveness of these interactions. In particular, we felt the need to provide more guidance and an early sense of urgency for the teams. In other words, we wanted to replace the all too common scenario of very little team interest and/or progress for the first half of the allotted time, followed by a period of increasing urgency and activities concluding with the five days straight of no sleep just before the final presentation and product validation. What this concern boiled down to was that the teams could be more effective if we forced them to adopt better project planning procedures and required accountability throughout the semester.

The second issue was our dissatisfaction in some cases with the team's and/or an individual's level of knowledge of the underlying scientific or engineering principles as they applied to the project. For example, last year no one in a particular team was able to explain why a particular motor was selected or even provide a satisfactory explanation of how an electric motor works!

The third issue was the lack of interaction among teams, especially those working on similar projects. The IEEE robotics competition is an obvious example of similar projects, but there were others, e.g., the control systems for various projects had common elements and several projects had similar fabrication issues. But, in addition, it was felt that the teams would learn about the capstone issues (working in team, planning, communications, ABET criterion 4, etc.) by observing how other teams operated and if possible by having each team involved with several other teams. In short, we felt that all projects would benefit from the synergism of more interaction among teams.

The fourth issue has to do with communications and the related issue of organizing thoughts. Reference 3 describes our relationship and activities with the University of Houston Writing Center that has alleviated some of issues related to form, correctness and style of writing. However, we were still concerned with the students' ability to "think" through the writing process, for example, their inability to establish appropriate goals, to adequately describe context, and to clearly and concisely state problem statements and deliverables.

During one of our many discussions about these concerns, we began to consider the possibility of organizing the course around the studio/critique model commonly used in the visual arts. This visual arts model will be presented below before we discuss how it was modified and implemented for our class.

The Studio

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 student will devote a certain amount of time, e.g., twelve to eighteen hours a week, to completing the project. It just so happens that some of those hours, e.g., six per week, are in and during the regular meeting of the studio. The students come to the studio expecting to work on their projects, but they also seek advice from peers and teachers, offer advice to peers, and usually expect to take part in a "critique". 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. The critique is discussed briefly here but will be discussed in more detail in the next section. A critique may take place in every studio period or once a week or only every two weeks depending on the magnitude of the project. Two or three critiques may be 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 and in fact is, unfortunately, all too common in an undergraduate engineering laboratory section when most of the students come unprepared. However, what is new is the sharing of ideas, the unrequested advice, and the dreaded (for the engineering students) critique. For the visual art student these aspects of the studio are at the very heart of the studio concept. There is a strong sense that they all succeed together while for the engineering students individual success is usually paramount. The college-level visual art students have probably experienced the studio for ten years, and the studio is part of their culture. For engineering students any exposure to the studio environment is likely their first.

An important aspect of the studio culture is that the student and the instructor work as a team. During the studio period (normally three hours, twice a week) the students work on their projects while the instructor "circulates" informally reviewing and commenting on each project. The studio requires two resources which have equivalents in engineering education: the meeting space or studio (the laboratory for engineering) and the human resource (the instructor for both). Just like the laboratory in science and engineering, the studio is a dedicated space which is usually assigned to a faculty member or a small group of faculty in the same discipline, e.g., interior design, graphic design, etc. and reserved specifically for the teaching of studio courses by that faculty or the small group of faculty. To engineering faculty the teaching space resembles the "old" engineering "graphics" room with either a set of working tables with chairs or drafting tables with stools. The important elements are that classes are limited to about twenty students 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, on a space available basis, 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 the some engineering programs and in fact it is similar in appearance (except for the electronics and the hardware). Of course, 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 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 "sense" 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 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. But criticism, no matter how well received, is usually not without at least a little resentment. 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 truly "grin and bear 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".

The Critique

Critiques, lasting up to an hour or more, are held on a predetermined schedule during the time period assigned to a given project. Usually there are two or three critiques for a given project. The process begins with each student (or team) placing his/her current image or artifact on the table with all the other unfinished projects. The submission is anonymous, but many, including the instructor, can place the artist with his/her work. The instructor may group the submissions according to the point(s) to be made that day or the submissions may be discussed individually. In any event, the instructor will usually solicit initial input and comments from the class for each grouped or individual submission. The comments may be accepted, commented upon, discussed by the class, or rejected, all under the watchful eye of the instructor. Many times the discussion will lead to the inclusion of other submissions and expansion or reduction in the sizes of the groupings. When the class discussion on a given submission is over, the instructor will usually present a summary of the discussion and possibly an "edited" set of suggestions for the artist. But perhaps even more important than the opinion of the instructor is the discussion that the submission stimulated and the chance for the artist to hear his/her influence firsthand. This discussion is akin to "brainstorming" and even if the ideas put forth are not directly applicable and may have to be developed further; the seeds have been planted.

Adaptation of the Studio/Critique

The need for 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 have been 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. However, its use is usually limited to classes of about twenty students and in situations where the object of the design process is being created in the studio under the watchful eye of the instructor. None of these conditions is satisfied in our capstone design course. As many as 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 and 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 and critique process. This technique involves a "modulization" process so the technique can be contracted or expanded to accommodate (in theory) any number of students (assuming the appropriate number of instructors is involved). The following sections will provided a detailed 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 Cohorts

The project teams are grouped into cohorts. Each cohort is composed of teams facilitated by one of the instructors. In the fall 2003 there were three cohorts, one for each instructor. There were four teams (sixteen students) in two of the cohorts and three in the third. In the spring 2004 there were 88 students in the class so each instructor had two cohorts of three or four teams each. In the spring 2004 each cohort met for eight, 90-minute, studio/critiques usually with two of the three facilitators. Three cohorts met together on a rotating basis for the student oral presentations. Each team participated in four presentation sessions, giving its presentation and listening to ten or eleven other presentations. Students are also required to attend a minimum number of workshops (five of thirteen) conducted by the University of Houston Writing Center on technical communications. Additional information on the conduct of the class can be found in References 2 and 3. The remainder of this paper focuses on the Studio/Critique.

Rationale

The initial intents of the studio/critiques were:
- to improve the chances for 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 criterion 4 and communication topics.

Results

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

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 their 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." 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. (The course is organized through a website which provides a variety of communication options among class members and the instructors.) At the studio 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 a team) and options (from the other teams) about its 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 hopefully allows the students to think about these issues in a non-threatening situation. ("Participation" grades are determined for the studio meetings, but these grades represent nothing else unless a student becomes

"disruptive.") By working through the process together, e.g., to establish the project goals, the students will hopefully 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."

Demonstrated Progress

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 for their peers. Many times useful suggestions from the cohort (not thought of by the facilitators) have resulted in significant improvements in the project.

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 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.

From the Students' Point of View

At the end of the 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 2. 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 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) 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 lowest ranking statement (3.54/5.0), among those related to the cohort format, was modest agreement with the statement, "Our team received useful "help and information" by interacting with other teams." All the other statements related to the cohort format received a solid, "agree."

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 cohort format in the studio/critique approach contributed significantly to that success.

Table 2: Results of a Student Survey for the Capstone Design Course
Fall, 2003

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**

Discussion

We would like to able to state that by using this adaptive studio/critique approach that the project quality has risen X% this semester. However, as we know it would be very difficult to first quantitatively compare projects from semester to semester and second to separate out the cause and effect relationship since there are also other variables, e.g., class size (88 students last spring, 43 this fall.), (hopefully) the increase in facilitator effectiveness with experience (only the third time teaching the course in its current form), and the general increase in attention to the teams (with or without the studio).

Lacking this quantitative evident we can only say that the quality (and grades) of the reports and the quality of the project deliverables (several projects were run a second time after only limited success was achieved in the spring) are much improved this semester over last. It would be difficult to understand how the experience and the projects would not be better since the facilitators' access to the teams and the teams' interactions with each other increased substantially.

Conclusions

We feel that we were able to address our initial four issues:

- We have been able to keep the teams on schedules that assured the timely completion of most of the projects, except in cases in which vendors' deliveries were delayed.
- We are satisfied that the teams are more knowledgeable of their projects and are better able to explain the "physics" of their solutions.
- The interaction among the teams has greatly increased and there are many examples of the benefits of this increased interaction.
- The open discussions of draft writing samples (goals, abstracts, deliverable, etc.) in the studio/critique environment proved to be very effective and was well received by the students.

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Biographies

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Richard Bannerot is a professor in the Department of Mechanical Engineering at the University of Houston. His research interests are in the thermal sciences and in engineering design education. For the past thirteen years he has taught the required "Introduction to Design" course at the sophomore level and has recently become involved in teaching the capstone design course. He is a registered professional engineer in the state of Texas.

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Ross Kastor is a lecturer in the Department of Mechanical Engineering at the University of Houston. He has been teaching the capstone design course since 1991. He completed more than 40 years as a drilling engineer for Shell Oil Co., where he spent 16 years teaching drilling engineering in Shell's inside schools. He majored in machine design at The Ohio State University where he received the BSME and MSME degrees. He is a registered professional engineer in the States of Ohio and Texas.

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Paul Ruchhoeft joined the faculty of the Department of Electrical and Computer Engineering at the University of Houston in 2000 as a Research Assistant Professor after receiving his BSEE from the University of Texas at Austin and his MSEE and PhD from the University of Houston. He became a tenure track Assistant Professor in 2001. His research interests are in the areas of nanolithography and nanofabrication. He began teaching the multi-disciplinary, capstone course in 2001.