INDUSTRY COLLABORATIVE CAPSTONE DESIGN PROJECTS

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Abstract: *Capstone design courses in engineering that provide students the opportunity to tackle open-ended real-world projects provide excellent learning experiences for the students. Reported here are experiments with several models that have students work in teams on industry sponsored projects requiring a tested prototype as the final deliverable. The first quarter deliverable is a written design proposal to the client with a poster presentation. The proposal is a complete specification of the design and a plan describing how it will brought to prototype stage in the next quarter. The proposal includes the design and economic analysis, drawings, schedule for completion and specification of the resource requirements in support of the proposal. The second quarter is devoted to detailed design, prototype construction and evaluation. A web-based system was employed to provide collaboration between students, clients, and the instructional staff as well as providing management structure and full documentation of project activities.*

Key Words: Collaborative design, capstone design, design management, and web-based design

INTRODUCTION

We need a change: The Accrediting Board of Engineering and Technology (ABET) in the United States requires a major design experience of our undergraduate students. This is accomplished through a Capstone design project lasting at least one semester (15 weeks) or two quarters (20 weeks). In the past we have a required only a one quarter (10 weeks) capstone design activity. These projects typically produced a 'paper design' with no prototype verification of concept and product performance.

A new approach: In 1995 the NSF sponsored Manufacturing Engineering Educational Partnership (MEEP) was started with the objective of changing the curriculum and teaching of design and manufacturing in response to the ABET mandate. The centerpiece of this activity was the Learning Factory [1, 9]. The Learning Factory is an industry-university partnership to produce world-class engineers by integrating design, manufacturing and business realities into the engineering curriculum. Industry sponsored capstone student design projects are a major part of the Learning Factory activities and our means to meet the ABET requirements. In the current design sequence in Mechanical Engineering at the University of Washington only one one-quarter course, ME 495 Capstone Design is required by all students and this is not enough time to bring a design project to a hardware prototype conclusion (see figure 1).

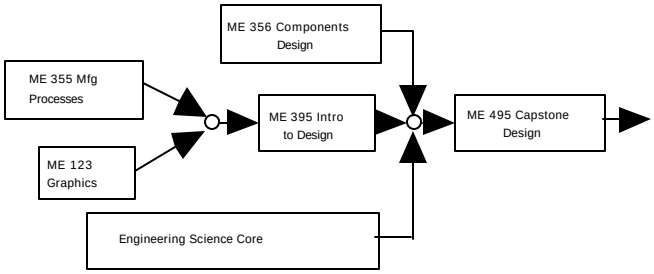

Figure 1
ME Curriculum leading to Capstone Design

During the 1999-00 and 2000-01 academic years we experimented extensively with a 'two-quarter' sequence involving industry sponsored design projects and full implementation of our web-based collaborative system. The two-quarter sequence involved project introduction in ME 395 Introduction to Design as the first quarters experience and immediately followed by ME 495 Capstone Design as the second quarter experience. In this paper we discuss our experiences and observations.

Model

Previous attempts at industry sponsored student projects were found 'mildly' successful in the 'one-quarter' time frame. In 10 weeks it is virtually impossible for the students to embrace a design problem, generate concepts, and carry one to a prototype stage. The typical outcome after 10 weeks was a 'paper study' on how to go about the design. For those teams that followed up on the projects with a second quarter we had very good success in reaching the prototype stage. Surveying our students and industry partners revealed that both wanted the projects to end in a prototype. A reasonable fraction (20%) of the students would like to see a 'three quarter' (one year long) project sequence.

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Course Requirements: The two-quarter project sequence is the first "experiential" design class for most undergraduate Mechanical Engineering students at the University of Washington. At the beginning of the first course, students are presented with the descriptions of several potential projects (via Requests for Proposal or RFP's). The project process is shown in figure 2.

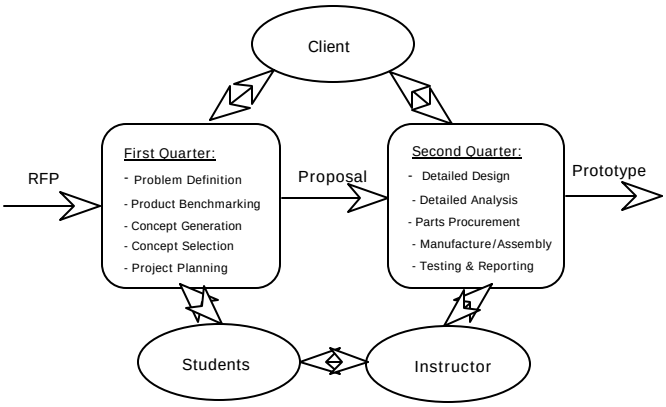

FIGURE 2
First and Second Quarter Design Process

The students meet the project sponsors at a "Design Kick-Off Fair", held on campus the first week of the quarter, and, having studied all the RFP's, select those projects on which they would most like to work. The instructional staff makes project team assignments and the teams spend about 9 weeks developing a comprehensive design proposal. The deliverable for the first quarter is the written comprehensive proposal, which describes the completed design work of the past quarter and proposes work to be completed in the follow-on quarter, ME 495, and result in a prototype to be tested for performance evaluation.

Client: The project RFPs are solicited from local and national industry prior to the first quarter. The client is the industry representative(s) that will be the major contact, be the project monitor, provide guidance for the students from the industry perspective, process information requests, and provide resources for prototype implementation and testing. Some clients are located in the Metropolitan Seattle area and readily available to the students but many are geographically sufficiently distant from our campus to pose restriction on face-to-face contact.

Instruction: The ideal structure would have the students complete ME 395 Introduction to Design before they enter the two-quarter Capstone design sequence. In ME 395 they will have been introduced to the product design cycle thought smaller exercises [2, 3] and can be considered as 'novice' designers. They would then be introduced to the Capstone design projects in ME 495, as the first quarter, followed by registration in ME 499 Independent Projects to complete the design as the second quarter experience.

In our experiments we had to operate within the framework of the required core course structure. Hence, we used the combination of ME 395 and 495 to provide the two-quarter sequence. We were faced with a 'just-in-time' teaching mode where we needed to expose the students to the material normally taught in ME 395. This was accomplished using the project design steps as the vehicle. The teaching process became self-based learning related to project needs but augmented with team and project management skills. Students are referred to the texts in previous courses [2,3], the library, patent, and vendor literature on an as-needed basis.

Implementation

The Capstone Design project activities and the associated schedule for a typical academic year is shown in Table I below

TABLE I:
Capstone Design Project Activities & Schedule

Autumn Quarter	Winter Quarter	Spring Quarter
Project Acquisition: • Contact Companies. • First Draft of Project RFP. • Agreement on scope and deliverables. • Project Acceptance. • Posting project description, the RFP, to the Web Board.	Project Design Proposal: • Design 'Kick-Off' Fair. • Student Team Formation and Project Selection. • Project Design Proposal Development. • Poster Presentation to students, client, teaching staff and visitors	Prototype Design: • Negotiate deliverables and schedule with client • Detailed design • Manufacturing and assembly • Performance testing • Design Report • Poster presentation at the Annual Design Fair

Project Acquisition: Projects are solicited from local and national industries through personal contacts and through web solicitations. Our Design Web site [4] both promotes our design activities and allows interested industrial clients to post project requests for proposals.

Project Screening and Promotion: We work with the client to help define the project objectives and the deliverables to best fit the educational, time, and resource constraints of the students and the university. Successful undergraduate student design projects should:

- challenge but not overwhelm the student teams
- avoid being on the client's critical path
- allow use of existing technology with reasonable extensions
- allow prototype implementation with mostly standard, off the shelf components

- instructors and client's envision specific solutions with reasonable high likelihood of success

Project and Team Selection: The projects are 'advertised', as a Request for Proposal (RFP), on our ME Design Web site [4] for the students to peruse and prepare themselves for the 'Design Kick-Off Fair' where they will meet the client face-to face for the first time. After the kick off fair they use a simple decision matrix to select their top three choices. Based on the student's selection input, the instructional staff makes up the team composition for each project. Our target team is four students. So far we have been able to provide the majority of the students with their first choice. It has been extremely rare for students to be assigned to a project team that was not in their top three choices

Design and Project Management: In a typical quarter we have from 12 to 16 four-person project teams. Project management relies on the help of team coaches, consultants, and the project client. One faculty member is assigned the roll of 'Project Manager', for the whole class, with the responsibility of scheduling the common meeting times for information exchange, deadlines, and supervise the web board activities. Team coaches, typically a faculty member or a graduate assistant (Ph D. level student) helps guide the team with organizational and technical issues. The client responsibility is to aid the students with technical and operational issues related to the requirements of the design. His or her availability is key to project success.

Project Management Structure: We reviewed design project management and documentation systems used by local companies and desired to introduce something similar for the student project teams. We recognized, however, that the students are novice design team members, their projects are brief in terms of both total and elapsed time, and furthermore they would probably only use our system one time before graduating. Additionally, any management and documentation system would need to work for the wide variety of projects that are undertaken in our educational setting. Therefore we sought to keep our system highly flexible and also minimize the students' investment in learning a "system."

We developed a set of 20 templates for documenting process and decision making throughout the 20-week project. The student teams use the templates as the basis for their meetings with instructors, coaches and clients and eventually as the source of information for their written proposals and final reports. The templates also assure those important and realistic constraints such as economic, environmental, sustainability, manufacturability, ethical, health and safety; social and political are considered in the students' efforts. Two templates, one for the comprehensive proposal required at the end of the first quarter and one for the final project report due at the end of the second quarter, attempt to assure quality and uniformity in the students' written documents [4].

The comprehensive design proposal consists of three sections, a formal problem definition that is based on stakeholder analysis (emphasizing customer expectations), an engineering rationale that establishes the team's approach to solving their problem, and a project management plan for the second ten-week portion of their project [4]. The project management plan includes task lists, personnel assignments, schedules and a budget. The proposal includes, as appendices, the templates related to:

- The team mission statement.
- Stakeholder (customer) expectations.
- Benchmarking.
- Functional requirement and constraint specification.
- Mapping stakeholder expectations onto functional requirements and constraints .
- Functional decompositions.
- Concept development.
- Concept Evaluation.
- Project schedule.

The project final report consists of four sections, the detailed product design and analysis, an overview of fabrication and analysis of the prototype, procedures for testing the prototype, and results and evaluation of the prototype [4]. The final report includes, as appendices, the templates related to:

- Project schedule (updated).
- Project task descriptions.
- Rationale and feasibility checklist.
- Product design.
- Product manufacture.
- Product assembly.
- Testing procedures
- Results and evaluation.
- Poster and final project report requirements.

Deadlines for templates and proposal/report sections are spread out over the 20 weeks so that coaches, clients and instructors have ample opportunity to assist the students in meeting the reporting requirements.

Web-based Collaborative Project Management: Four years ago we started experimentation with a web based design management and documentation system. The system has four basic components: A class portal web site, a class instructional and communications web board, web boards for each project and links to the Request for Proposals (RFP's) submitted by the clients, See Figure 3 below. The system is described in details in [5 and 6].

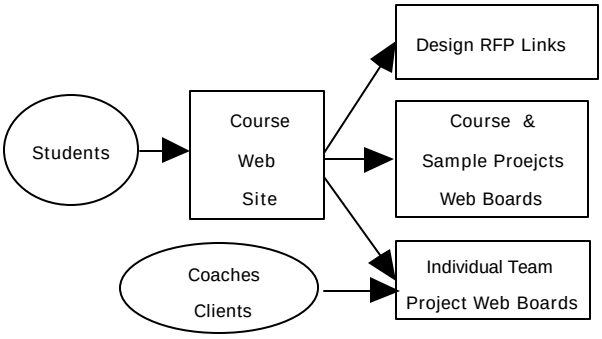

FIGURE 3
The Portal Web System

The Course Web Site is the launching point for the students throughout the duration of the two-quarter sequence. From this site, they easily access the Course WebBoard® [7], Sample Project WebBoard®, and their own Project WebBoard®s. Additionally, this Web Site is a home for archived Course and Project WebBoard®s, as well as archived RFPs. The students and instructional staff have frequently taken advantage of the information found in the WebBoard®s from previous quarters. The Portal Web Site is a key feature of the Design Project Management system [4. 5. 6].

The Class Instructional Web Board provides communication with all of the students. Course syllabus, handouts and past design experiences (reports) were posted to this board as well as announcements, schedules and deadlines. In addition, it provides a place for the posting of their assignments, reports and poster presentations.

Individual Project Web Boards provide the work in progress communication, discussion, management and documentation of the project. One of the features of the web board is that it can be partitioned so that certain parts can be made open to the general public while other parts are closed and only accessible by the students, client and the teaching staff. In this manner client specific proprietary information is protected if this is desired. Samples of the use of the class and project boards are given in [4, 8] and a typical project WebBoard is shown in figure 4 to illustrate the structure of the board. The board allows asynchronous communication between the students, the client, and the teaching staff. It allows students to post report drafts, analysis programs, and drawings such that all team members will have full access to all material generated by the team. This also allows comments and suggestions from both the client and teaching staff.

FIGURE 4
Sample of Individual Project WebBoard

Results

Overall Impressions: We have had a 100% success rate the past two academic years if success is measured by the quality of the design and the teamwork. If success is measured by the end result, the prototype, we had 80% completion ratio at the end of the 1999-2000 academic year and 100% completion ratio at the end of the 2000-2001 academic year. Compared to the previous 'one quarter projects' there were great improvements in the quality of the design solution, the confidence of the students as designers as well as the enthusiastic response from the clients. The process of implementation of the design into a working prototype provided a level of design maturity the students need and it also allowed them to develop a nice portfolio of their work so useful at job interviews.

The WebBoard System: This was a major innovation on our part and was well accepted by the students and clients as an excellent means of communication. In fact, most of the projects might not have been completed if face-to-face meetings had been the only means of interaction. Clearly, email and phone are other means; however, they are more cumbersome to use and do not provide the level of interaction and documentation of the WebBoard. Detailed statistics on the WebBoard use and student acceptance is found in [6] with a listing of the major findings below:

1) Over 75% of the students indicated that design courses would have been more difficult without the use of the WebBoard®, 89% indicated that it was more helpful than painful.
2) Nearly 90% of the students would recommend the WebBoard® and management program to a future design group.
3) The average time to "feel comfortable" using the WebBoard® was less than 10 days; 88% of the student respondents felt that they could teach the WebBoard® to a new user.

Most students agreed that the WebBoard® program was successful in providing a significant amount of geographic and temporal flexibility (5 out of a possible 7).

For the instructional staff, the WebBoard provided flexibility in the management of a large class, with typically 12 – 16 projects. Even with meetings of the class once a week, it is an arduous task to manage such a large number of projects. In the past, one instructor would manage 4 –5 design teams in a class. With the WebBoard it is possible, from any location, to peruse the team project boards, review the progress, and provide suggestions and encouragement to all the teams with the expenditure of 4 – 6 hours per week. The students were required to submit draft sections of their report (to the WebBoard) at regular intervals for the comments of both the client and team coach. This approach resulted in better reports and less 'last minute' hassle in the report preparation at the end of the quarter.

Increased Faculty Support: During the past 2000-2001 academic year, each team received guidance from the course instructors as well as a faculty coach who served as a technical advisor for the team. The faculty coaches focussed on providing technical support to their teams through the WebBoard as well as weekly face-to-face meetings. This allowed the instructors to shift their focus to guiding the design process and project management. We found this division of labor to be very effective, though it was admittedly more costly in terms of faculty hours. We attribute the increase from 80% prototype completion ratio in 1999-2000 to 100% completions in 2000-2001 to the increased faculty effort and division of labor.

Student Comments Spring 2000: We did a very cursory survey at the end of the Spring Quarter 2000. Most interesting were the comments on what worked well and where we needed improvements

What works well:

- Solving real life problems was a great experience.
- It was rewarding to apply engineering background to solve real problems – wish this were a full year project instead of one or two quarters.
- Experiments and analysis, testing and data evaluation contributed significantly to learning in the course.
- Appreciated little class time, the chance to work independently with client, team and advisor.
- Weekly meetings with advisor contributed to learning.
- Personal attention from instructor helped a lot

What needs improvement:

- Need to have the projects run for 3 quarters, too much time crunch
- Need better access to machine shop
- Need better access to vendors
- Need better tools like SolidWorks software
- Allow teams to come up with their own projects
- Client was not helpful in sharing necessary information

We were able to address the improvement issues this past academic year. Since out Spring Quarter ends June 10, 2001 we do not have survey information for the this quarter, However, a comprehensive survey instrument was constructed to provide feedback on teaching, learning, project selection and management. The students completed the survey at the end of the Winter Quarter 2001, their first quarter of Capstone Design. The survey was based on a scale from 1 to 7. A sore of (1) is poor and a score of (7) is excellent with the mean score of (4).

Student Survey Results Winter Quarter 2001:

Course organization	5.8
Material Coverage	5.2
Type of Design Projects	5.5
Management & Guidance	5.1
Client Effectiveness	5.1
Team Effectiveness	5.8
Team Coach Effectiveness	5.5
Template Usefulness	4.0
Assessment of Learning	6.0
WebBoard Usefulness	5.4

The level of improvement we achieved was gratifying. Most important was the introduction of coaches for each team as this help in the project management. Likewise, the attention the clients paid to student requests and their willingness to respond quickly is clearly evident. The use of the templates was viewed by a larger part of the students as distractions; however, the teams that did use them effectively did have better final reports in both content and organization. Further development of this tool is needed and the students suggested that sample use of the templates would have been helpful.

Conclusions

To complete a design project with a prototype deliverable a two-quarter (15 – 20 weeks) time frame is the minimum requirement for a successful completions. Based on our experience we will recommend that a new requirement for our students is a two-quarter Capstone Design project.

Involving industry in the project activity raises the interest and performance of the students. The 'real-life' experience they gain through the interaction with the industrial client is extremely valuable and provides a good 'look into' their future career path.

Diverse industry projects requires the university to reach out to a community not geographically collocated with the campus. The WebBoard system allowed this collaboration to take place efficiently, effectively, and with less of time burden on the client.

Our project management structure with the use of templates, additional teaching material, and the Web-based system for collaborative communication and documentation has not only been proven effective but allowed significant improvement in the performance of the design teams

ACKNOWLEDGMENT

Funding for this project was provided in part by NSF Award #DMI 9726178. The help of Ms. Dongmei Gui in setting up and maintaining the WebBoard® was appreciated. The WebBoard® server was provided by a gift/grant from the Hewlett Packard Corp. Funding for upgrading of our Student Machine shop came from the Boeing Company during 1999 -2001.

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