CAPSTONE DESIGN PROJECTS WITH INDUSTRY: EMPHASIZING TEAMING AND MANAGEMENT TOOLS

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Abstract

The benefits of company sponsored capstone design projects, both to academia and to industry, have been well established. At Rose-Hulman the benefits to students include the broadening of their engineering skills, the required interaction with practicing engineers, the strengthening of teaming skills by working in design groups, the development of communication skills with required oral and written reports, and the experiences of project management. These projects are "owned and managed" by the student teams with company contacts providing appropriate data and information and with faculty serving as advisors only. The authors have developed and improved these student/industry interactions over the last few years with over 100 students working with 20 to 30 different companies each year. Recently, the authors have placed greater emphases on requiring that the projects use the tools of engineering management in the completion of the projects and in the formal written and oral presentations.

ABET 2000 requires that capstone design experiences build on knowledge gained from earlier courses. It is the purpose of this paper to discuss methods for the selection of appropriate projects from industry and then to show how students integrate teaming and project management skills from previous courses during completion of their capstone projects.

Introduction

Industrial/Academic partnerships are essential for technological development, regardless of the discipline. The purpose of this paper is to discuss the integration of teaming and project management skills into capstone design by integrating knowledge from prior courses.

The paper discusses student projects with industry which are performed as part of the course requirements for Engineering Design and Machine Design, the two 4-credit-hour senior courses that require these industrial projects at Rose-Hulman. In each course the design project represents 50% of the course grade and the enrollment is approximately 120. The students work in groups of 3 or 4 and are normally expected to spend approximately 4-6 hours per person per week on their projects. The teams are required to meet with their instructor weekly and submit

written status reports. Formalized design methodologies are required. (See for example Pahl and Beitz [1] or Dekker and Gibson [2].) In addition, oral presentations and final written reports are required of each design team, and some companies also invite the teams to their facility for an in-house oral briefing.

Screening

Over the past ten years, the authors have developed relationships with companies that are willing to provide projects for student teams. As industrial contacts suggest projects, the authors screen the projects by asking the following questions: (See Gibson and Brackin [3].)

1. Is the scope of appropriate length? For our purposes, projects must be essentially completed in twenty weeks.
2. Is the proposed project really a design project? At times companies are looking for a specific **analysis** of something or other (not a solution to a general problem) where they want to direct the students' process rather than letting the students manage their own process. These company proposals of specific analyses are almost always rejected.
3. Is there opportunity for student management of the project? It is a specific requirement that student teams must be allowed to manage themselves and thus maintain "project ownership." The industrial contact and the instructor both must restrain themselves from dictating the project direction even when they feel that it would be more efficient.
4. Does the project have the potential for benefiting the company? Students are quickly demoralized if they feel their project is "made-up." Projects are much more effective if they deal with real current company problems where fresh ideas or new approaches to a design problem are desired.
5. Is there a reasonable expectation of the project's successful completion? It is the responsibility of the instructors to select only topics that are matched to the students' professional level, that is, not trivial but also not overly ambitious.
6. Will the students' design education be enhanced by their interaction with a company's engineering staff? There is a significant education benefit from having a student team sit down with practicing engineers and discuss real problems faced by the company. Being given a glimpse of company policies and procedures is extremely beneficial to students.
7. Is a visit to the company facility reasonably convenient for the student design team? A tour of the company's facility is an added educational benefit which is almost always required. A four hour maximum drive is a typical condition for acceptance. The company also must agree in advance to reimburse students for nominal travel expenses. The companies also agree to fund any material or prototyping costs.
8. Will there be a company contact person that can be relied on to furnish needed data/information to the student team in a timely fashion? The students need to realize that their company contact has other important responsibilities, but also, the contacts need to keep in mind that the students are under an inflexible deadline.

Teaming and Project Management

ABET 2000 requires that senior capstone design experiences build on knowledge gained from earlier courses and this section shows how this is being accomplished at Rose-Hulman.

Mechanical engineering students are introduced to basic teaming and project management skills in their Freshmen Design course. Team training and project management training go hand in hand because students are required to manage "projects" that they must complete during the quarter. They are introduced to the concept of team roles, agendas, minutes, listening, decision making, peer evaluation, and scheduling. In their sophomore year, students are given training in peer evaluation that is reinforced in the junior year. In the junior year student laboratory groups are required to complete open ended laboratory projects. These groups are responsible for scheduling their work and performing peer evaluations. During the senior Systems Design course, students are given more in depth training on team motivation and interaction. They are introduced to scheduling concepts and are required to use Microsoft Project to complete "scheduling" assignments. By the time these students reach their senior capstone design project, they are prepared for more of a challenge in project management and teaming.

At the beginning of the first quarter of the two quarter senior design project, students are asked for their preference of both a project and their team members. They are allowed to request that up to two people may be excluded from their group. They also are allowed to give a preference of their top three choices from a list of potential companies which previously have been "screened" and approved by the instructors. The instructors make it clear that they do not know the exact details and scope of the problems suggested by the companies at this time. After receiving student preferences, the instructors assign teams and companies. After receiving their assignments the teams are responsible for making contact with their company and arranging for a visit. It is then each team's responsibility to generate appropriate questions and gather the necessary information to completely define the company's problem in its most general form.

At the beginning of the 20 week long project, students are asked to complete a project timeline using Microsoft Project. They are asked to look at typical tasks in a design project: weekly team meetings, meetings with the company, problem definition, research, development of customer requirements, development of product design specifications, generation of alternatives, concept development, concept selection, concept refinement, design calculations and drawings, economic analysis, etc. They are asked to estimate the time that they believe they will spend on various activities and to assign one group member the responsibility of keeping the team on schedule for each task. Finally, they are asked to use Microsoft Project to keep their schedule and to record the time that they spend on their project. The faculty advisor reviews the schedule quarterly, but it is the responsibility of the team to keep the schedule up to date and meaningful for their project.

The students are required to manage their own team. For example, typically one student is

designated as the company contact and this team member handles all communications with the contact person at the company. This practice is to insure that students do not interrupt the company contact with a string of questions spaced five minutes apart. After the designation of the company contact, students are free to administer their group in any way that they choose. Some groups appoint a group leader for the duration of the project. Other groups rotate a leader for each week. Some groups divide the work by task type and meet weekly to review their progress in each area.

Students are held accountable for their work in the group by peer evaluation.
At the end of each quarter students are asked to evaluate themselves and each other using a peer evaluation form used in a senior lab course. [4] The current form used asks questions in the following categories:

1) How do team members contribute to the team's work as a whole?
2) How do team members interact with each other?
3) How do team members work to keep the team on track?
4) What is the quality of work that the team members perform?
5) Do the team members have task related knowledge, skills and abilities?

Students have previously received experience in the proper use of this form in their senior lab course and are comfortable using it in the capstone design course.

Student teams are also required to meet each week with their faculty advisor. The teams present their "Weekly Status Report" in the form of a memo at this meeting, and send a copy of this memo to their company. The format of this memo is shown on the next page. Notice that students must always state the overall goal of their project in addition to reporting on specific work that was accomplished in the previous week. The weekly meeting with the faculty advisor is also an excellent time to review the project schedule and determine if adjustments need to be made.

In addition to these required, scheduled, 30 minute weekly meetings, the teams will typically "touch bases" with their advisors one or two additional times each week on an "as needed" basis. These formal and informal interactions between student teams and faculty advisor/mentors require between 7-10 hours per week per instructor or approximately 100 hours per quarter. This is based on two faculty members responsible for 30 project teams.

After visiting the company clients the student teams are typically in weekly communication with their company contact/mentors. It is estimated that company contacts spend approximately one hour each week responding to student questions/concerns.

It important to note that throughout the project activities the students are required to depend heavily on topics learned in other courses. For example, materials learned in courses such as Engineering Design, Machine Design, Thermodynamics, Fluids, etc, are inevitably integral "**analysis**" components in the success of these "**design**" projects. In addition, it is the

responsibility of each team to develop the appropriate Product Design Specifications in accordance with the methodology taught in Systems Design during the previous quarter. The time consuming, but essential development of these specifications guides and constrains the remainder of the design process.

Figure 1: Format for Weekly Status Report

Company Name Here

Memo

To: Your Team Advisor (either Brackin, Gibson, Chambers, or Sanders)

From: Team ____, Include full names of all team members here,

CC: Your contact person/s

Date: March 1, 2005

Re: Status report of (**company or client**) project as of week ending _____.

Problem Statement : Repeat here each week the GENERAL problem that your team is working to solve.
Tasks Accomplished This Week : List SPECIFIC, not general, accomplishments. Avoid vague statements like "we researched" this or that.
Tasks to be Accomplished Next Week : Again, you must be specific and detailed.
Problem Areas : Identify any problems (if any) that are beyond your control which are causing the progress of your project to be delayed. (Be careful not to point the finger of blame at individuals.)

After meeting with their faculty advisor, the student teams forward the weekly memo to their company contact. This is an excellent way to keep the company contact up-dated on the group progress. Weekly meetings last approximately 30 minutes and the role of the faculty advisor is to advise and counsel, but not direct the project. The degree of guidance requires considerable judgment on the part of the instructor but in order for students to gain this valuable design management experience they need to be allowed to develop their own design decisions. It should be obvious that this strategy is most successful when projects are on a "no-fee" basis. Both the instructors and the company contacts must understand that student teams need to be given the

"freedom to fail". This "student control" of the project is an invaluable educational experience.

Deliverables

Companies are informed that the student teams will give an oral presentation and will prepare a written report at the end of the 10 week Winter Quarter and again at the end of the 10 week Spring Quarter. After the interim report, students are asked to contact the company for input and suggestions. It is the responsibility of the student team to gather this input and respond to the company concerns. These company/team interactions prepare the students for professional interactions after graduation.

It is not unusual for a student team to produce a deliverable in the form of a prototype for a company. Depending on the requirements of the company, this might require the students to contact vendors, gather estimates, and follow their company's procedures for reimbursement. Some companies have lists of approved vendors that must be used and some require a minimum of three quotes before purchasing a component. Some also require a detailed description from the students that is sufficient for a purchasing department to prepare a purchase order. This insight into how companies conduct everyday business is a new facet of project management for students.

Outcomes

Students rank their senior design project as one of the highlights of their Rose-Hulman experience. These comments are generally written in the course evaluations. All senior design reports are evaluated by the ME design faculty each year to determine whether or not students are meeting the departmental design performance criterion. Table 1 below shows typical results from this analysis. The results are reviewed by the department as a whole and any necessary changes are made. It should be noted that the percentage for "Test and Refine" is lower because not all companies decide to implement the students' designs.

Table 1: Percentage of ME Students Demonstrating Design Performance Criteria

Performance Criteria	% Demonstrating
Develop a Product Design Specification	75
Generate Multiple Solutions	96
Evaluate Feasibility of Solutions	86
Choose an Appropriate Solution	93
Carry Out Detail Level Design using Appropriate Tools and Methodologies	82
Test and Refine	46
Document as appropriate for the Discipline	75
Present Documentation to the Client	100

In addition to departmental evaluation, the companies are asked to evaluate the students' performance. Each year, an evaluation form is sent out that asks the companies for feedback concerning communication, grasp of the problem, methodology, company benefit, and perceived student educational benefit. Results from 2004 are shown in Table 2. The company is asked to respond on a scale of 1 to 5, with 5 being excellent. (There were 18 respondents.) The response rate from the companies is over 50%, which is quite high, and the evaluation of the students' work is also quite good. The major area for improvement is communication. Improvement in this area is a continuing process.

Table 2: Summary of Company Responses

Questions	Average Rating
How well does the written report communicate the students' results and recommendations to your company?	4.7
How well did the students communicate with you during the project?	4.2
How good was the students' grasp of the general problem?	4.6
What was your opinion of the methodology the students used to approach and solve the problem?	4.6
Please estimate the benefit of this project to your company.	4.2
Please estimate the educational benefit to the student.	4.6

Conclusions

Capstone design projects with industry are recognized by engineering educators as being extremely beneficial activities. However, they are also acknowledged to be administratively challenging due to the additional tasks of soliciting, screening, arranging, scheduling, monitoring, evaluating, etc, and particularly challenging in requiring them for large numbers of students (over 100 per year).

One purpose of this paper has been to show how these tasks have been accomplished at Rose-Hulman and how, hopefully, other institutions can benefit from these techniques and expand the industrial design project activities in their programs.

The other primary purpose of this paper was to remind design educators of the ABET 2000

requirement of showing how capstone design experiences build on knowledge gained from earlier courses. Examples of how this is accomplished at Rose-Hulman were discussed in the Teaming and Project Management section above. Hopefully, these strategies for complying with ABET also will be of benefit to other departments.

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