INDUSTRY-ACADEMIC PARTNERSHIPS FOR SUCCESSFUL CAPSTONE PROJECTS

Jeffrey L. Ray[1]

Abstract *- Current engineering curriculums have evolved over the past several years to address multiple concerns raised by industry. Their concerns include interdisciplinary engineering teams, teambuilding, project management, and others directly related to successful engineering careers. In order to better prepare future engineers, universities have implemented a variety of capstone courses to address industry concerns, as well as ABET EC2000 criteria. Capstone courses range in content from teams of students in the same discipline, working on the same or different projects, to industry-sponsored design projects primarily focused on producing paper designs. In very few instances schools require student teams to physically produce their designs. This paper discusses implementation and coordination of the projects, benefits of using industry-academic partnerships for capstone design courses, how the course effectively meets and exceeds industry and ABET concerns, additional benefits for the engineering school and the community. In addition, examples of several projects are presented.*

Index Terms – ABET EC2000, Capstone design, Industry/academic, Multidisciplinary teams

INTRODUCTION

The formats of capstone, or senior design, courses prior to ABET EC 2000 criteria implementation revolved around providing a sufficient design component in engineering curriculums. These courses were structured to develop student creativity, open-ended "real-world" problem solving skills, design methodologies, feasibility considerations, and detailed system descriptions. A survey was conducted by Todd, et. al. [1] on the state of capstone courses in North America. Results of the survey indicated that fewer than 30% of the programs participated in multidisciplinary engineering projects and only 59% solicited projects from industry. Additionally, 78% of the respondents only required an analysis report for completion of the project with no physical prototyping required.

In response to the revamped accreditation criteria, ABET EC 2000, more engineering programs implemented industry sponsored senior capstone design courses. These courses vary between universities and formats offered [2]. Additionally, the majority of these capstone courses are not multidisciplinary in nature, but are focused on providing real-world design projects for specific engineering majors, i.e. electrical/computer, mechanical disciplines only. Typical examples of these types of capstone courses include the University of Idaho's Electrical and Computer Engineering Department [3] and the Mechanical Engineering Department at the University of Arkansas [4]. These are only representative examples, but the literature is full of similar examples.

The Padnos School of Engineering (PSE) at Grand Valley State University (GVSU) offers accredited engineering programs in Computer, Electrical, Manufacturing, and Mechanical Engineering. All programs in the school require an alternating three-semester cooperative education experience after the first two years of coursework. All students are also required to take a multidisciplinary two-course capstone design sequence during their senior year. The two courses are structured to provide all students with a real-world understanding of the practice and principles of engineering and project management. The first course, EGR485 – Senior Engineering Project I, focuses on topics directly related to project management of industry projects including teambuilding, conflict resolution, leadership, resource availability, and design methodologies. In addition, students are assigned to teams and prepare a design proposal and presentation for the industry sponsor. During the second course, EGR 486 – Senior Engineering Project II, teams purchase all raw materials, build and implement their design, and write final documentation for the industry sponsors. One major factor in achieving the success of the capstone project program presented is the inclusion of the required co-op program.

The projects are entirely funded from external industrial sponsors. This ensures that students are exposed to real life design experiences involving multiple engineering disciplines. The inclusion of all interdisciplinary industrially sponsored projects makes the courses unique in engineering education. The spectrum of industry sponsors includes entrepreneurial startups, small companies, fewer than 100 employees, to Fortune 100 companies. The majority of sponsors are located within 75 miles of GVSU. This close proximity allows the student teams and sponsors the opportunity to meet face-to-face during the duration of the project. The course director acts as the overall project manager for all projects.

[1] Jeffrey L. Ray, Grand Valley State University, Padnos School of Engineering, 301 W. Fulton St, Ste. 718, Grand Rapids, MI 49504, rayj@gvsu.edu

The format and direction of the course allows PSE to achieve several EC2000 criteria [5] including:

- The ability to design a system, component, or process.
- Functioning on multidisciplinary teams.
- Identifying, formulating, and solving engineering problems.
- Communicate effectively.
- Use modern engineering tools and techniques.

In addition to the above criteria, the Padnos School of Engineering (PSE) at Grand Valley State University (GVSU) has developed several additional outcomes for its graduates. They include being able to:

- Create physical realizations of their designs in a team environment.
- Function in a manufacturing environment.

COURSE IMPLEMENTATION AND LOGISTICS

It is important to recognize the scope of the capstone program at GVSU is not appropriate for many universities. GVSU is a liberal arts, comprehensive regional university. The university's mission statement is to provide a liberal education for all students, service to the community and providing professional education. The university is located in a large manufacturing base with the top 20 industries serving 17 different industrial sectors. GVSU is also committed to providing excellence in undergraduate education and thus offers no degree higher than a masters in any discipline, including engineering. The highest degree offered by PSE is the Masters of Science in Engineering. The program outlined in this paper is dependents upon cooperation and open lines of communications between engineering departments.

The process of project selection and team assignments begins in the semester before students enroll in the course. Before any potential industry sponsors are contacted a group meeting of all students is held. During this meeting an application for senior project is distributed. The application includes questions regarding their major, technical electives taken or plan to take, co-op employer, specific co-op job assignments, top three technical strengths and weaknesses, and a skills survey. The skills survey component of the application lets students rank themselves from 1 to 5 on a variety of engineering skills. These include familiarity with hardware, software, codes and standards, build experience, design methodologies, and project planning. Students are required to submit this application back to the course director within two weeks. The purpose of the application is two-fold. First, the information provided allows the course director to understand the capabilities of each student before soliciting proposals from industry. Secondly, the information is very useful to the faculty in assigning students to their respective senior project. During this initial meeting students who have an interest in submitting a project proposal from their co-op employers are instructed on the procedure for proposal submission.

The course director begins soliciting projects during the fall semester prior to the course beginning in January. Due to the integrated co-op seniors take their final two semesters of coursework during the winter and spring/summer semester. Potential sponsors are contacted based on a variety of sources. These include: contacts made during the annual design conference, student's co-op supervisors, previous sponsors, and contacts from interested sponsors. A site visit is scheduled with each potential sponsor to explain the program in detail and discuss the sponsor's commitment and responsibilities, course timeline, as well as the project they have in mind. The sponsoring company must also designate a corporate mentor to act as the point person for the company. The majority of our projects are directed towards design of automated testing and production equipment. Other projects considered are the redesign an existing product or process. All sponsors are required to cover all material costs for the project. These costs include raw materials, special hardware and software, and specialty machining students are not capable of producing with our equipment. Project costs have ranged from $2500 to over $40,000, with the average costs of a project of approximately $5000. In addition, sponsoring companies must donate $500 to offset the indirect costs of operating the program. Sponsors must submit a brief proposal describing their proposed project based on the site visit discussion. A faculty committee, composed of a member from each discipline plus the course director, reviews these proposals and selects the projects that will be executed. Companies are then informed whether their project has been accepted or rejected. Proposals that are rejected are often modified and used for other course projects.

Student teams are assigned based on the faculty committee's understanding of the project design requirements, student application, and potential success of the team. Typical project teams range in size from four to six members based on the complexity and sophistication of the design project. During the first weeks of the course students are exposed to topics in problem definition, functional requirements, design methodologies, and design proposal writing. Projects are assigned to the students during the fourth week of the semester. Teams are then required to contact the corporate mentor and arrange a meeting to discuss the project in detail to gain a deeper understanding of the project.

The next phase of the course is for the team to prepare design proposals for presentation to the sponsor for approval at a design review held before the end of the semester. The proposal process takes 6 to 8 weeks to complete. The course director periodically reviews draft proposals for completeness and engineering design quality. Proposals must contain detailed descriptions of the project, including functional requirements and constraints, alternative designs, and selection of a chosen design. In addition the proposals

must contain a complete design analysis, including engineering drawings/schematics, program flowcharts, and other necessary documentation to defend their design. A detailed budget and bill of materials along with a project Gantt chart is also included. To assist the students in making sound engineering decisions, twenty hours of faculty consulting time is provided to each team. Teams are encouraged to use this time upfront during preparation of their proposal to reduce unforeseen difficulties that might arise in the implementation phase. They are also encouraged to meet weekly with their corporate mentor to discuss the project and its direction.

The last task to be completed before the end of the semester is a design review with the corporate sponsor. The purpose of this review is for the team to present their proposal for approval. Once approval has been granted, student teams work with the corporate mentor to write purchase orders for the required materials. All purchasing is handled by the sponsoring company and materials shipped to the students at the university.

Another task the team must complete during the first semester of the course is to maintain a web page. This facilitates better communication between the team, sponsor, and course. The company, due to confidentiality purposes, must approve material posted on the web page. Each team member is required to write a weekly progress report detailing major accomplishments, setbacks, and plans for tasks to be completed in the upcoming week. These reports are posted to the web page.

During the second semester of the course, which occurs in summer semester (12 week term) teams are actively implementing their design projects. Each team is assigned designated space in the design bay area for project implementation. This space is allotted based on space and equipment requested in the design proposal. One day per week (two lab periods) is scheduled for senior project. During this time each student team meets with the course director for a progress review meeting. These meetings are held in a conference room and are structured in an industry standard production meeting format. The purpose of the meeting is to discuss details of the project, review budgets, and evaluate the progress of the project using the Gantt chart. Meetings are scheduled at a specified time and last approximately thirty minutes. The remainder of the scheduled lab time is used by the teams for construction of their designs, debugging and preparing final documentation. During this semester teams must also complete the project and perform a live acceptance test with the industry sponsor. Final documentation typically takes the form of a users manual and troubleshooting guide based on an agreed upon format from the sponsoring company. This gives students the opportunity to experience the type of technical writing expected of them from industry, rather than the traditional academic design or lab report format.

At the end of the semester the PSE holds the annual Engineering Design Conference. The conference serves as culmination of the senior capstone courses. All projects are on display and team-prepared posters are presented. Invitees to the conference include the industry sponsors, co-op employers, industry advisory board, outstanding alumni, and benefactors of the engineering school. Participants are invited to an awards luncheon where the accomplishments of the seniors are recognized. Following the luncheon an official opening to the design conference is held. The public is also welcome to attend the conference. Immediately following the conference, family and friends are invited to an evening reception and the Order of the Engineer ceremony is held. Table 1 summarizes the timeline of events for the course.

TABLE 1
IMPLEMENTATION TIMELINE

Semester	Week(s)	Topic
1	1 – 4	Introduction, defining problem statements and functional requirements, and teambuilding
1	5	Project assignment, sponsor meetings, and draft proposal writing
1	6 – 9	Design methodologies, oral and written communications, project management, and conflict resolution. Writing of drafts and final design proposal.
1	10 – 12	Design review dress rehearsals
1	13 – 14	Corporate sponsor design reviews
1	15	Order materials
2	1 - 11	Manufacture of proposed design, project management tasks, and weekly progress meetings with course instructor
2	12	Presentation at the Engineering Design Conference

INDUSTRY/ACADEMIC BENEFITS

The west Michigan region is fortunate to be located in an area with a diverse manufacturing and engineering base. Of the top twenty manufacturers, seventeen are in different industries. Examples of some of the local manufacturers include:

- Goodrich Avionics Systems
- Steelcase
- DANA – Perfect Circle Division
- American Seating
- Siemens Dematic

In addition, a large number of small engineering and manufacturing firms are located in the area. The support for the capstone program and university has been extremely successful and allowed for much more mature capstone projects.

The benefits for industry, engineering school, and students are numerous. Students are the primary beneficiaries because they gain exposure to real-world engineering design projects. They have an opportunity to experience the true excitement of engineering by working on a project from initial concept to experiencing their design move from paper to a complete physical realization. Additionally, students are exposed to some of the inherent soft skill issues that arise in a significant number of engineering projects. Students must also become proficient in practicing teambuilding, meeting management, written and verbal communication, conflict resolution, and other skills not necessarily addressed by a course in an engineering curriculum. Additionally, students are exposed to a multidisciplinary engineering project, including interfacing with business and purchasing personnel. Another benefit to the students is the exposure to a variety of oral and written communication formats, including design proposals, equipment and operating manual documentation, and formal oral presentation standards. Students also benefit when they begin exploring the job market. The program prepares students for more immediate integration into their careers and the ability to assume more responsibility for their employers. Several students have gone to work for the sponsoring company, while others have learned that they did not want to work for a specific company. The program also provides students with increased exposure, beyond their co-op experience, to current industry practices.

For industrial sponsors of the design projects the payback in being involved with a capstone design team is significant. A major benefit to the project sponsors is the potential for a much lower cost solution to their design and manufacturing problems. This is a result of the sponsor only bearing the cost of materials and specialty machining, not salary and infrastructure costs typically associated with industry design projects. Most projects are not high priority ones for the sponsoring company, thus they are able to achieve more of their goals than they would otherwise with their available resources. The sponsors also have access to faculty expertise for their project provided free of charge within the extent of their project. Sponsors also benefit from discovering the range of capabilities of the engineering school and its graduates. Companies are also exposed to student's performance and engineering design knowledge over the course of the project. This provides valuable feedback for continual development of the engineering curriculum to meet future engineering employment needs of manufacturing.

Benefits for the university and engineering school, in particular, have been substantial. The most noteworthy of these benefits was realized in 2001 when the 30,000-ft^2 Keller Engineering Laboratories Building was opened. This represented a significant expansion of the engineering programs at GVSU and was funded entirely by private donations. A substantial portion of the building was funded by many of the companies involved in the senior capstone design course including monetary donations, equipment, and furniture. One of the major spaces in the building is the design bay for building the senior projects. The partnerships between the local manufacturing base and university are further strengthened beyond the cooperative education program. The collaboration with the project sponsors also provides real-world exposure that would otherwise not be available to the students due to budget constraints and normal classroom instruction. The high level of project quality is an added benefit for the student's academic experience. Additionally, sponsors provide valuable feedback to the faculty for further enhancement of the engineering curriculums. The partnerships with industry also benefit the university in meeting one of its goals in serving the local community. A final benefit for the engineering program is the achievement of meeting several of the EC2000 criteria and acting as one of the assessment tools for accreditation.

EXAMPLE PROJECTS

During the past six years local manufacturers have sponsored fifty-one projects. The direct cost of these projects for materials has exceeded $750,000. Several sponsors have been involved in the program for multiple years and the demand for senior design teams exceeds the number of students in our program. All projects must successfully be completed by fully implementing the design at the sponsor's site, having the sponsor sign-off on the project, and faculty approval. In addition, one project each year is selected as the outstanding senior project. The decision is based on voting performed by industrial guests and engineering faculty during the design conference, students and family members are not allowed to vote.

One of the very successful projects involved the design and fabrication of a vibration table to be used in Highly Accelerated Life Testing (HALT) of avionics system products. The sponsoring company had a need to install a vibration table inside an environmental chamber to add another parameter to their product testing. The constraints of the project included developing a system to operate in temperatures ranging from -50°C to 100°C with a maximum rate of temperature change of 50°C/min. The table was designed to withstand testing cycles ranging from 10 minutes to 16 hours and experience temperature cycles up to four times per hour. Additionally, the design was constrained to fit inside an environmental chamber measuring 24x24x24 (in). The desired vibration capability for the design was 40(Grms) of acceleration delivered to a Unit Under Test (UUT) of 10 pounds over a frequency range of 20 Hz to 2000 Hz. Electrical constraints required high level of computer control to monitor the spikes or dips due to resonance in the unit under test and, in real-time, decreasing the input signal amplitudes at the resonant frequency(s) so the energy dissipated remained within a

specified tolerance. The input signal to the table was white noise. The total budget was not to exceed $5000.

A team of four students (two mechanical, one electrical, and one electrical/computer engineering) was assigned to the project. Their design analysis include complete modal analysis using finite element modeling of the table, force and stress calculations to design a reliable table capable of producing the required vibration levels, software programming for control and feedback, and design of the power supplies and amplifiers cards. The team members performed all construction, testing, and installation of the design. The system has been in operation for the past five years and was the recipient of the Outstanding Senior Project award. A schematic of the student design is shown in Figure 1.

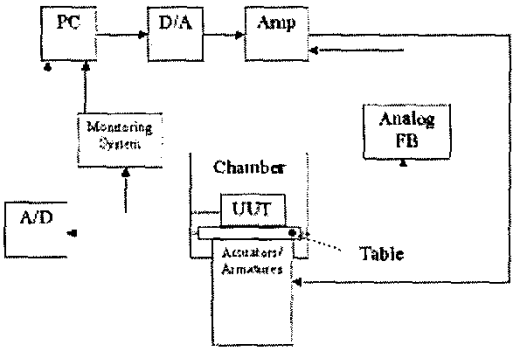

FIGURE 1
VIBRATION TABLE SCHEMATIC.

Another project involved the design and build of an automated adhesive spraying system for a local transit bus seating manufacturer to replace the existing manual operation. Minimization of adhesive over spray onto a cut fabric component was essential. The system was required to apply a 3M® adhesive to the fabric prior to being affixed to a fiberglass seating shell. The design constraints of the project included increased part capacity, maintain glue application consistency and minimize glue waste. Additional constraints were that the system should support a production rate of 500 pieces per eight-hour shift, compared to the manual rate of 325 pieces per eight-hour shift, the fabric loading and unloading process must be ergonomic, design should be adjustable to account for size variations of the fabric components up to 23 by 20 inches. Total budget for the project was $30,000.

Six students (two electrical, two mechanical, one manufacturing, and one mechanical/manufacturing) were assigned to the project due its complexity. The students performed a complete design analysis including velocity, acceleration, and torque calculations for the linear motion system, electrical power calculations for motors and other electrical components, economic analysis for cost savings to the sponsoring company, programmable logic controls and servomotor programming, and selection of an appropriate spray nozzle. The final prototype was successful and installed at the sponsoring manufacturing facility. The student design team was very impressed that the sponsoring company built a new enclosed work area for the machine to be located. The automated application system has been in operation for the past two years. A 3D solid model of the design is shown in Figure 2.

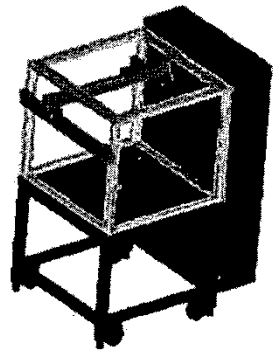

FIGURE 2.
SOLID MODEL OF THE AUTOMATED ADHESIVE SYSTEM

Additional projects have involved design and build of various electro-mechanical measurement systems for component testing, variable capacity storage devices for HVAC equipment, automated production equipment, and hardware/software design of circuit board and component test stations.

ASSESSMENT RESULTS

Sponsors and students are surveyed at the conclusion of each project. The overall response has been positive from both parties. Students are surveyed as part of the exit interview process prior to graduation. The response from students is typically positive with 64% of the students commenting on the senior project experience. Examples of responses include: "works on the technical skills while teaching a person the politics of getting a project done within a company", "Great program! I learned a lot about project management and what it actually took to see a project from design to completion", and "The senior project gave me the foundation needed to solve real life problems". The most common negative comment from students is that the course should include more project management material. Additional material has been included during the current course sequence.

All industry sponsors must complete a survey evaluating and ranking the student teams on several topical issues including, (1) communication and critical thinking skills; (2) ability to apply engineering theory to create physical realizations; and (3) ability to engage in a

successful engineering design project. Results of the surveys are shown in Table 2.

TABLE 2
INDUSTRY SPONSOR SURVEY RESULTS

Question Topic	Average Score
Effective communication and critical thinking skills	85%
Ability to apply engineering knowledge to create physical realizations of their theoretical concepts	78%
Demonstrate the abilities to engage in a successful engineering design project	85%

Overall the industry sponsors are quite positive of the student's abilities in solving real-world industry projects and their professionalism in dealing with vendors and industry sponsor employees.

CONCLUSIONS

The implementation of the current industry-sponsored senior design capstone course at GVSU has been a rewarding experience for all participants involved. This has not been realized without a significant time investment on the part of the industry sponsors and the faculty. However, the overall feeling from faculty and industry is that the benefits far outweigh the time commitment involved. To date only two projects have not been completed on time and under budget.

Continuous improvement in the course structure has allowed all participants to achieve successful implementation of multidisciplinary, high quality design projects. While our regional manufacturers, students and engineering faculty have embraced this program it should be noted that this type of program might not be suited for every engineering program. A major consideration for other engineering programs considering implementing a program of this type is the manufacturing base of the university's service region. It is very important to have the support of the regional manufacturing base in order to implement this type of capstone courses. The program has proven very valuable in our assessment of graduating students for ABET documentation.

ACKNOWLEDGMENT

The author and Padnos School of Engineering would like to thank all of the past and current capstone design project industry sponsors for their support.

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