

2007: SUCCESSFUL CAPSTONE COURSE MODEL FOR INDUSTRY- ACADEMIC PARTNERSHIPS

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Successful Capstone Course Model for Industry-Academic Partnerships

Abstract

Engineering education has evolved over the past years, due in large part to the ABET EC2000 criteria, to include a culminating experience for students. The number of engineering programs utilizing industry funded projects for capstone courses has been on the increase over the past ten years. Integrating industry partners into the capstone experience has proven to have many benefits for all constituents involved. The downside observed is the significant time commitment to establish and maintain industry partnerships for successful projects. However, the development of industry partners is one of the most critical phases in securing appropriate projects. Communicating the expectations of the program is essential to having dedicated industry partners and successful projects. Working together with industry partners allows several iterations in the project definition to occur prior to students being assigned to student teams. The capstone model implemented has resulted in over 80 projects being successfully completed for regional industries over the past ten years. The equipment and materials costs for these projects have exceeded \$1 million dollars in the same time.

This paper presents the model used to develop and maintain industry partnerships, securing appropriate industry projects, process of assigning projects to student teams, involvement of engineering faculty and industry mentors, and final deliverables. Also, a discussion of the benefits of the model implemented and feedback from industry partners and students over the past 10 years is included.

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 Howe and Wilbarger¹ on the state of capstone courses in North America. Results of the survey indicated that 35% of the programs participated in multidisciplinary engineering projects and 71% solicited projects from industry. Additionally, Todd, et. al² indicated that 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^{1, 2, 3}. 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 Department⁴ and the Mechanical Engineering Department at the University of Arkansas⁵. These are only representative examples, but the literature is full of similar examples.

The GVSU School of Engineering (SOE) offers ABET accredited engineering programs in Computer, Electrical, Mechanical, Product Design and Manufacturing Engineering. All programs in the school require an alternating three-semester cooperative education experience after the first two years of coursework. Students are also required to take a multidisciplinary two-course capstone design sequence during their senior year. The two courses are structured to provide students with a real-world understanding of the practice and principles of engineering, design, and project management. The first course focuses on topics directly related to design and project management of industry projects including design methodologies, teambuilding, conflict resolution, leadership, and resource availability. During the second course teams purchase all raw materials, build and implement their design, prepare final documentation, and deliver the project to the industry sponsor.

All costs are completely covered by the project sponsors. This ensures that students are exposed to real life design experiences involving multiple engineering disciplines. The spectrum of industry sponsors includes entrepreneurial startups, small companies with fewer than 100 employees, to Fortune 100 companies. The majority of the 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 format and direction of the course allows the SOE to achieve many of the ABET EC2000 criteria⁶. The School of Engineering has established six program outcomes. The following are the SOE program outcomes and the associated ABET EC2000 Criterion 3 (a) – (k) mapping.

- 1) The graduate must have the technical knowledge and capabilities expected of a practicing engineer. (3a,3b).
- 2) The graduate must be able to function effectively in an industrial environment. He or she must have the ability to communicate effectively, engage in critical thinking, and have highly developed skills in problem solving (in both individual and team situations). (3d, 3e,3g)
- 3) The graduate must have the ability to apply engineering knowledge and be able to create physical realizations of his or her theoretical concepts and models. (3k)
- 4) The graduate must have the demonstrated ability to engage in engineering design. (3c)
- 5) The graduate must have an awareness of the need for professional growth. (3i)
- 6) The graduate must have an awareness of, and sensitivity to, those areas in which engineering practice affects society, and the environment. Such awareness, extending beyond technical knowledge to include ethical and social responsibility, must frame continued professional and scholarly growth of the graduate. (3f, 3h,3 j)

The capstone course structure implemented addresses five of the six program outcomes. The outcomes assessed by the sponsoring company are 1, 2, 3, 4, and 6.

Capstone Model Implementation

It is important to recognize that the scope of the capstone program at GVSU may not be appropriate for many universities. 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 the SOE is the Masters of Science in Engineering. The program outlined in this paper is dependent upon cooperation and open lines of communications between engineering departments.

Development of industry sponsors is a critical component in the success of any capstone program. The capstone director begins soliciting projects during the fall semester prior to the course beginning in January. Due to the integrated co-op nature of the engineering program, seniors take their final two semesters of coursework during the winter and spring/summer semesters. Potential sponsors are identified based on a variety of sources. These include: contacts made during the annual design conference, student's co-op supervisors, previous sponsors, alumni, 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 the projects are focused on the design of automated testing and production equipment, involving PLC/Servo control and embedded system and/or computer control . Sponsors are required to cover all costs associated with 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 average project costs of approximately \$5000. In addition, sponsoring companies provide a donation of 10% of proposed materials costs to offset the indirect costs of operating the program. To have a project considered, sponsors submit a brief proposal describing their proposed project based on the site visit discussion. The proposal addresses the design topic, project purpose, functional requirements, special resources, design challenge, and deliverables. Industry proposals are submitted to the capstone director at the beginning of December.

A faculty project selection committee reviews the industry proposed projects for technical merit determining the appropriateness of the project, and educational value. The committee is composed of one member from each engineering discipline plus the course director. One week prior to the committee's decision meeting, the proposals are put out for faculty comment. This step is important since all faculty acts as consultants to the student design teams. Companies are informed by Christmas whether their project has been accepted or rejected by the SOE. Proposals that are rejected are often modified and used for other course projects, allowing real-world projects in lower level courses.

An important aspect of successful industry-sponsored capstone programs is maintaining a positive relationship between the sponsors and the capstone director, both during project execution and follow-up after the project is completed and delivered. Communication between the capstone director and the corporate mentor occurs every two weeks during the project duration. This allows for open lines of communication between all involved parties to avoid many potential project pitfalls. Common pitfalls include specification creep, change in project focus, and student performance.

The process of project team assignments begins in the semester before students enroll in the course. Before potential project sponsors are contacted a group meeting is held with all students

prior to the beginning of fall semester. During this meeting a brief overview of the capstone program and its implementation is presented to the students. Also, an application for senior project participation is distributed. The application includes questions regarding students technical electives taken or planned, co-op employer, specific co-op job assignments, top three technical strengths and weaknesses, and a skills survey. The skills survey allows students to rank themselves on a scale from 1 to 5 on a variety of engineering skills. Skills 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 capstone director by the beginning of October. 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 committee in assigning students to their respective senior project.

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. During the first four 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 fifth week of the semester. Teams are then required to contact the corporate mentor and arrange an initial meeting to discuss the project in greater detail. The meeting is used for the student teams to gain a deeper understanding of the project and its requirements.

The next phase of the course is for the team to prepare design proposals for presentation to the sponsor for approval at a critical design review (CDR). The CDR is held during the last two weeks of the first the semester. The design proposal process takes 6 weeks to complete. The capstone director and interested faculty periodically review 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 and 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. The student teams are provided with the research/consulting expertise of the engineering faculty. It is not mandatory for faculty to participate, but approximately 85% of the faculty volunteers their time. Teams are encouraged to use this time early during the proposal phase to reduce unforeseen difficulties that might arise in the implementation phase. Teams are also required to meet weekly with their corporate mentor to discuss the project and its current direction.

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

The second semester of the capstone course occurs during the spring/summer semester (12 week term). Design teams implement and deliver their design projects. Each team is assigned designated space for project implementation. One day per week (two lab periods) is dedicated for senior project work. During this time each student team meets with the capstone director for a progress review meeting to review and discuss details of the project, review budgets, and evaluate the progress of the project. Meetings are announced at the beginning of the lab periods 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. It should be noted that this is only a portion of the time students' work on their projects. A live acceptance test is conducted with the industry sponsor two weeks prior to the conclusion of the semester. Final documentation typically takes the form of a users manual based on an agreed upon format from the sponsoring company, allowing the students the opportunity to experience the type of technical writing expected of them in industry, rather than the traditional academic design or lab report format. Teams are also required to deliver their projects to the sponsoring company, setup and train operators on the equipment prior to grades being assigned.

At the end of the semester the School of Engineering holds an annual Engineering Design Conference. All projects are displayed and demonstrated in an exhibition format. 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 invitees are invited to the design conference exhibition. The public is also welcome to attend the conference. The conference also serves as the kickoff for the next season of design project recruitment.

Benefits of the Capstone Model Implemented

The benefits for industry, School of Engineering, and students are numerous. Students are the primary beneficiaries because they are exposed to real-world engineering design projects and the challenges associated with these types of design projects. Students must also become proficient in practicing teambuilding, meeting management, written and verbal communication, conflict resolution, and other skills not necessarily addressed by typical engineering or general education courses. Additionally, students are exposed to a multidisciplinary engineering project, including interfacing with personnel from many business areas including upper level management, purchasing, accounting, and vendor/suppliers. The program prepares students for more immediate integration into their careers and the ability to assume more responsibility earlier in their careers. The program also provides students with increased exposure, beyond their co-op experience, to current industry practices and standards.

For corporate 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. 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 at no additional fee, within the extent of their project. Companies are also exposed to student's performance and engineering design knowledge over

the course of the project. In many cases, students have been offered employment by their project sponsors.

Benefits for the university and School of Engineering, in particular, have been substantial. Two major fundraising efforts have been accomplished in the past seven years. The efforts have led to two new engineering facilities on campus totaling over 82,000 square feet with donations reaching \$12 million. The collaboration with the project sponsors also provides resources that would otherwise not be available for the students due to budget constraints and normal classroom instruction. 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 programs is the achievement of meeting several of the EC2000 criteria and acting as one of the assessment tools for accreditation.

Survey Results

Sponsors and students are surveyed at the conclusion of each project. Students are surveyed as part of the exit interview process prior to graduation. The response from students is typically positive with an average of 72% of the students commenting on the senior project experience. A typical response notes the integration of applying engineering and technical skills while teaching a person the politics of getting a project done within an organization. The most common negative comment from students is that the course should include more project management material.

All industry sponsors are required to complete a survey evaluating the student teams' performance. The survey is based on the SOE program outcomes associated with the capstone program. Results of the surveys are shown in Table 1.

TABLE 1
Project Sponsor Survey Results (1998 – 2006)

SOE Program Outcome	Topic	ABET Criterion 3	Average (1 to 5 scale)	Standard Deviation
1	Technical knowledge and capabilities expected of a practicing engineer	a, b	3.82	0.39
2	Able to function effectively in an industrial environment	d, e, g	4.17	0.29
3	Ability to apply engineering knowledge and be able to create physical realizations	k	4.10	0.53
4	Demonstrated ability to engage in engineering design	c	4.32	0.50
6	Awareness of, and sensitivity to, those areas in which engineering practice affects society, and the environment	f, h, j	3.83	0.29

Overall the industry sponsors are 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.

References

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