Acquiring a Consistent Source of Quality Capstone Projects

John P. Parmigiani, Javier Calvo-Amodio, and Tracy Ann Robinson
Oregon State University

Obtaining a list of suitable projects can be a challenge for a large capstone class, particularly for an instructor teaching the course for the first time. Linking capstone projects to faculty research can provide a significant source that provides quality projects to students and provides meaningful progress on research if properly staffed and structured. This paper describes an approach used at Oregon State University (OSU) to link capstone projects to multi-year research projects that involve graduate students. A key aspect of this approach is structuring the capstone course to cover all steps of the design process including prototype construction and testing. A second key aspect is placing the graduate student associated with the research project in the position of project advisor for the capstone project(s). The use of this approach at OSU has resulted in capstone projects providing significant contributions to research through device design and creation and through the education of the supervising graduate student in engineering project and personnel management. This work demonstrates the capability of capstone design to contribute to both the larger teaching and research missions of the university.

Corresponding Author: John P. Parmigiani, parmigjo@engr.orst.edu

Introduction

Capstone design courses are part of the curriculum of most engineering programs in the United States.[1,2] They provide key content for satisfying the design-experience requirements of the Accreditation Board for Engineering and Technology (ABET) for degree accreditation.[1,3,4] The overarching goal of these courses is to educate students in the use of the engineering design process. Course implementations typically consist of students working in teams to solve a design problem presented in the form of a project. Details such as team size, grading criteria, course length and content, writing and presentation requirements, and prototype construction expectations vary widely among programs. But the need for suitable student projects, sometimes in large numbers, is common to virtually all capstone courses.

Acquiring projects can be challenging, however, particularly for new instructors. Although capstone projects can also be created by an instructor solely for use in the course, this approach can be problematic. Such projects can appear contrived to students, can require internal funding (especially if prototype construction is required), and can lack the desirable real-world aspects of projects obtained from sources external to the course. For these reasons, it is common for capstone instructors to seek external project sources, including business and industry, university faculty, and community organizations. Ongoing securement of capstone projects from external sources depends either on cultivating strong philanthropic relationships with those sources or ensuring that the value of the project deliverables regularly exceeds the cost of project sponsorship (e.g., travel expenses to meet with students, costs associated with prototype construction and testing, etc.). In the authors' experience, capstone instructors tend to have much more influence over ensuring project value than over a sponsor's philanthropic inclinations. However, depending on a team of undergraduate students to provide a deliverable having a value that equals or exceeds the perhaps thousands of dollars provided by the sponsor can be quite risky.

The purpose of this paper is to describe an approach used in the capstone course in the School of Mechanical, Industrial, and Manufacturing Engineering (MIME) at Oregon State University (OSU) to consistently and reliably provide deliverables of value to the project sponsor and thus aid tremendously in obtaining subsequent projects from sponsors. Three key aspects of this approach are (i) structuring the course both to

include the complete engineering design process, from requirements definition to prototype testing, (ii) coupling capstone projects with larger research projects when possible, and (iii) using graduate students as capstone project advisors. The remainder of this paper will describe the OSU MIME capstone course in terms of these three aspects and provide case-study examples of how this approach is implemented.

Course Structure

The primary goal of the OSU MIME Capstone Design course is to give students an understanding and appreciation of the engineering design process from requirements definition through prototype testing and design revision. Specifically, the engineering design process is divided into seven steps: (i) design requirements definition, (ii) background research, (iii) translation of design requirements to technical specifications, (iv) consideration of design alternatives, (v) selection and specification of a complete design solution, (vi) prototype construction, and (vii) prototype testing and design revision. Capstone design in MIME consists of a course sequence involving two ten-week terms (i.e. these seven steps are completed over a twenty-week period of time).

During the first ten-week term, students complete the first five steps. Project assignment and team formation are completed by the second class meeting. Students immediately meet with the project sponsor to define design requirements. Simultaneously, students perform background research (literature reviews, sponsor conversations, internet searches, etc.) related to the project. Students then, as necessary, translate the design requirements, written using terminology meaningful to the sponsor, into quantifiable technical specifications. After having completed these first three steps, students have an understanding of what they are being asked to accomplish (in terms of technical specifications) and what related designs already exist. Given this knowledge, they proceed to the fourth step, generation of several design concepts. These are evaluated and one is selected. The selected design is then fully specified (components sized, bill-of-materials created, manufacturing plan created, etc.). The culmination of the first term is a report providing a complete justification and description of the team's design solution. Evaluation of the students' work in the first term consists primarily of grading a series of written reports.

During the second ten-week term, students complete the final two steps: prototype construction, and prototype testing and design revision. Students are allotted the first five weeks of the term to build a prototype. The second five weeks are devoted to prototype testing and design revision to meet requirements. Grading of student work consists of two "evaluations." Evaluation One is conducted after five weeks and measures the extent to which the construction of the prototype is completed. Evaluation Two is conducted at the end of the course and measures the extent to which the prototype meets design requirements.

A key aspect of this approach that contributes to consistently and reliably providing deliverables of value to the project sponsor is that a significant portion of the students' grade in the second term of MIME Capstone Design depends on their design satisfying the pre-established requirements. Student teams whose designs satisfy few or none of those requirements will likely fail the course. While this may seem overly harsh, the requirements and testing procedures used in the prototype evaluations in the second term are developed by the students during the first term, using a modified form of the House of Quality as described in Sherrett and Parmigiani.[5] Project sponsor and course instructor approval of the HoQ is required, but it is the students themselves who define the evaluation metrics listed within it. Through this process, students understand and accept that they will be held accountable for creating a prototype that meets the project requirements.

Capstone Projects Linked to Research

Many engineering programs have a large and active research component. Externally funded research projects can be a rich source of capstone projects, particularly if the faculty principal investigator has confidence in obtaining a useful deliverable. Routinely in the OSU MIME capstone program, capstone projects are used to add capabilities to existing research laboratory equipment and to create new equipment. For example, an OSU faculty researcher desired an

improved clamping mechanism for a scanning electron microscope stage. Given the structure of the MIME capstone course and the emphasis on providing a useful deliverable, he was confident in sponsoring a capstone project and received a useful stage in return for the funding and student advising he provided.

Graduate Assistants as Advisors

In the OSU MIME capstone course, the course instructor, an MIME advisor, and a sponsor mentor supervise each student team. The course instructor is the instructor of record for the course and is primarily concerned with guiding the students through the course deliverables and intervening in projects that do not proceed as expected. The MIME advisor is the primary technical consultant and provides topic-specific engineering guidance. The sponsor mentor provides project background information and details on project requirements and is the ultimate judge of project success.

Capstone projects that are part of a larger research project can reliably provide useful deliverables when the graduate student funded by the research is placed in the dual role of MIME advisor and sponsor mentor. Graduate students have been shown to generally be effective advisors and mentors, in terms of ensuring quality project results.[6] In most situations they can provide specific relevant technical guidance and help with details on project requirements. However, when projects are linked to the graduate student advisors' research, the quality of the results tends to increase even further, because of the additional motivation to support the design team in producing deliverables that will advance their own research.

An additional project staffing technique used is to create a "competition scenario" by assigning two undergraduate teams to the same project with identical requirements. The graduate student serves as advisor and mentor for both teams, and at the end of the capstone course chooses the "winning" project solution.

Case Studies

The following two case studies illustrate the effects of course structure, research-project linking, and graduate student involvement in providing quality deliverables from the MIME capstone course and thus assisting in providing a consistent supply of quality projects.

Case Study 1

An industrial sponsor funded a graduate student to perform research in knife-blade cutting mechanics. The focus of the research was to develop an analytical solution to model knife-blade cutting and use this model to optimize the shape of a rotary cutter. In order to validate the analytical model, related experimental data was needed. But at the beginning of the project, no equipment existed in the School of MIME to conduct the required tests.

The creation of the testing equipment was assigned as a capstone project. The associated graduate student was the project's MIME advisor. The structure of the MIME capstone course guaranteed that a prototype device would be created and that the students would be motivated to meet projects requirements since their course grades depended on it. The connection of the project to a graduate student's funded research assured that he would be a highly motivated and knowledgeable advisor. The association with the funded research project provided sufficient funding to construct the needed machine.

These factors led to a successful project. Over the two terms of the MIME course, the capstone students and the advising graduate student constructed a device that met all the requirements they were given. The machine did require some additional modifications by the graduate student after the capstone course ended, but the capstone students provided an almost-complete machine in only 20 weeks. This was much faster than what the graduate student could have done alone. The success of this project has led to subsequent research projects, with associated capstone projects, from the same sponsor.

Case Study 2

A doctoral student was working on a sophisticated control algorithm for a pendulum wave-energy generator and needed a device for testing. The device needed to consist of an adjustable pendulum mechanism contained in a seaworthy carbon-fiber enclosure. The creation of the device and the enclosure was accomplished through the MIME capstone course.

Due to the scope of the work to be accomplished, development of the device was split between two teams. One team was assigned creation of the internal mechanism; the other team was assigned creation of the carbon-fiber enclosure. The doctoral student acted as both MIME advisor and sponsor mentor. The doctoral student also had the additional responsibility of coordinating the efforts of the two teams. A significant aspect of this coordination was ensuring that the internal mechanism mounted properly in the enclosure. To increase the likelihood of a successful outcome, both teams were informed at the start that their project grades would be lowered significantly if proper mounting did not occur. Awareness of this requirement from the very beginning of the project prevented problems. The doctoral student's need for the device compelled him to be a very attentive and responsive advisor and mentor. His knowledge of his control algorithm enabled him to provide very detailed answers to student questions about requirements.

The project resulted in a fully functioning test device and a very positive capstone experience for all involved.

Conclusions

This paper describes a three-part approach used in the OSU MIME capstone course to ensure the delivery of quality results to project sponsors. The three elements include structuring the course to include all steps of the design process, including prototype construction and testing; linking capstone projects to larger research projects; and engaging graduate students to supervise capstone projects in their area of research. In supporting the development of deliverables whose value exceeds than the cost of project sponsorship, this approach has multiple related benefits. First, it leads to high sponsor satisfaction with MIME capstone project partnerships, which in turn helps generate "repeat customers," thus ensuring dependable sources of additional future projects for the course. Having consistent and reliable sources of high-quality projects also enhances the OSU MIME capstone course experience for students by enabling the course instructors to focus more fully on teaching rather than on project acquisition.

References

1. L. J. McKenzie, M. S. Trevisan, D. C. Davis and S. W. Beyerlein, "Capstone Design Courses and Assessment: A National Study," in *American Society of Engineering Education Annual Conference & Exposition*, 2004.
2. A. J. Dutson, R. H. Todd, S. P. Magleby and C. D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses," *Journal of Engineering Education,* vol. 76, no. 1, pp. 17-28, January 1997.
3. ABET Board of Directors, "Criteria for Accrediting Engineering Programs," ABET, 29 October 2011. [Online]. Available: http://www.abet.org/engineering-criteria-2012-2013/.
4. M. S. Tooley and K. D. Hall, "Using a Capstone Design Course to Facilitate ABET 2000 Program Outcomes," in *American Society of Engineering Educators Conference and Exposition*, Session 1625, 1999.
5. B. Sherrett and J. P. Parmigiani, "Implementation of the HoQ as a Tool to Assess Products of Design in Capstone Design Courses," *International Journal of Engineering Education*, vol. 27, no.6, pp 1324-1332, 2011.
6. I. Hyder, D. Arnold, J. Calvo-Amodio, and J. P. Parmigiani, "Using Graduate Assistants as Project Advisors for Externally-Sponsored Capstone Design Projects," *International Journal of Engineering Education*, vol. 30, no. 1, pp. 101-111, 2014