AC 2010-1576: CURRICULUM-WIDE PROJECT BASED LEARNING BY REFINING CAPSTONE PROJECTS

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Curriculum-wide Project Based Learning by Refining Capstone Projects

Abstract

Our goal in this project is to address the twin objectives of: (1) systematically increasing project-based learning experiences throughout the Mechanical and Aerospace Engineering (MAE) curriculum at the University of Missouri; and (2) increasing the prospects for industry adoption and commercialization of industry-sponsored and student-generated MAE capstone design projects. We are upgrading the outcomes of recent MAE capstone design projects by having needed refinements to those designs serve as the basis for project-based learning activities throughout the MAE curriculum. Thus, students in pre-capstone courses will gain insight to, and experience with, many aspects of real-world engineering projects. Simultaneously, capstone design projects will be advanced further towards industry implementation and commercialization.

The refinement activities in the pre-capstone courses are being planned and managed by students enrolled in a new senior/graduate course in management of design, working under the direction of the pre-capstone course instructors. This approach makes it feasible to systematically integrate project-based learning into engineering education without requiring major curriculum reforms or new faculty resources.

In this paper, we first describe the process we went through to select the capstone design refinement opportunities, identifying the pre-capstone courses most suitable as venues for the refinement activities, and enlisting instructors of those pre-capstone courses to adopt these refinements as the basis for project-based learning experiences for their students. Next, we describe the design management course and the activities of those students in facilitating the refinement activities. We then turn to our plans for synthesizing the refinements into updated versions of the capstone designs. Finally, we discuss the formative assessment process currently underway, including interviews with, and surveys of, faculty and students.

Introduction

The project described in this paper addresses several recent calls for reforms to engineering education. Many "…have argued that engineering curricula should promote integrative, synthetic thought processes as well as reductive, analytical processes".[1] The National Academy of Engineering (NAE) adds to this call with its recommendation that "…the essence of engineering - the iterative process of designing, predicting performance, building, and testing-should be taught from the earliest stages of the curriculum, including the first year".[2] In addition, a workshop sponsored by the National Science Board concluded that "Since traditional curricula are so full, it is difficult to add traditional courses to the curriculum. Thus, it may be necessary instead to integrate experiences throughout the curriculum…. Experiential learning can …motivate student learning in the fundamentals(;) and can create opportunities to bring design and analysis together, rather than segregating design and analysis. There is also a need to create long-term experiences, such as projects that span years and make connections between different skills and applications. Students working on open-ended projects under expert mentoring will learn unanticipated things."[3] This project responds to these calls by testing an approach to incorporating real-world project-based learning (PBL) experiences throughout a typical engineering curriculum, without requiring either major curriculum reform or new faculty resources.

According to previous research, problem-based learning (using the same acronym PBL as project-based learning) can better prepare engineering students for the challenges they will face in the workplace. However, the "…the level of commitment to (PBL) is more than most programs or professors are willing to make. Even if such a commitment is made, PBL programs face the continuous challenge of populating their problem base with authentic problems that are informed by everyday practice"[4]. This project is testing an approach for providing such a steady stream of "authentic" problems and projects.

This project also addresses the fact that while analysis and design have traditionally been seen as two distinct aspects of engineering education, adoption of contemporary computer-based engineering tools has blurred this distinction in professional practice. The approach to PBL as described in this paper gives engineering students the opportunity to appreciate the relationships and interactions between analysis and design more readily.

The Capstone Design Project

The capstone design project is the foundation for the PBL experiences we propose to disperse throughout the engineering curriculum. According to the Accreditation Board for Engineering and Technology, "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and multiple realistic constraints".[5] This major design experience typically takes the form of a capstone design course whose duration varies from one academic quarter to an entire academic year, depending on the campus.[6] Many capstone design courses involve professional engineers as sources for project ideas, sponsors of projects, clients that interact with students, and evaluators of student performance.[6-11]. There are two major shortcomings to this traditional approach to capstone design.

First, traditionally many engineering schools have not introduced students to design thinking, skills, and processes prior to the capstone experience. That is, the "knowledge and skills acquired in earlier course work" have tended to be predominately analytical, rather than design, in nature. As a result, many students find the capstone course a "culture shock" and require a substantial period of adjustment before becoming comfortable with, and effective in carrying out, their design tasks.

Second, the capstone project does not usually lead to a successful closure to the design experience (of course, true closure is an oxymoron in the context of an open-ended design project). Incomplete documentation, inadequate analytical underpinnings, and the absence of prototypes, test data, and implementation plans are some of the missing ingredients in many of these projects.[12] Most students graduate as soon as they complete their capstone design project, so there is no opportunity for them to participate in follow-up design refinements or implementation efforts. Thus, although descriptions of the engineering design process universally stress the iterative nature of design and the importance of the complete design life-cycle, many capstone experiences are terminated before the students can experience either of these phenomena. Efforts to deal with these shortcomings have included expanding pre-capstone design experiences[13-20] and restructuring curricula to provide the students with a more integrated set of design experiences.[1, 21-23] However, most of these efforts have encountered many pedagogical and institutional difficulties.[4, 24] The fact that the most recent calls for reform in engineering education[2,3] continue to recommend these changes is evidence that the earlier efforts[13-23] have not been widely adopted.

General Approach

The approach described herein is a refinement and generalization of one first articulated by Hyman.[25] It addresses the twin objectives of: (1) systematically increasing project-based learning experiences throughout typical engineering curricula; and (2) increasing the prospects for industry adoption and commercialization of industry-sponsored and student-generated capstone design projects. The approach advances recently completed capstone projects through the remainder of their design life-cycle and simultaneously provides pre-capstone students a series of realistic PBL experiences in design and supporting analysis.

This is accomplished having needed refinements to capstone design projects be the basis for project-based learning activities throughout the Mechanical and Aerospace Engineering (MAE) curriculum at the University of Missouri. Thus, students in pre-capstone courses gain insight to, and experience with, many aspects of real-world engineering projects. Simultaneously, capstone design projects are advanced further towards industry implementation and commercialization.

The refinement activities are planned and managed by students enrolled in a Design Management course. We expect that his approach will make it feasible to systematically integrate project-based learning not only into the MAE curriculum, but potentially into many engineering curricula without requiring major curriculum reforms or new faculty resources. We now turn to describing the progress made in this project since its inception in January 2009.

Identifying Refinement Opportunities

Halfway through the Spring 2009 semester, a memo was circulated to all MAE faculty describing the proposed process and schedule for identifying capstone refinement opportunities and the pre-capstone courses that appeared to be suitable venues for carrying out the refinements. In addition to soliciting faculty feedback, the memo reminded faculty of the opportunity for summer support for those faculty adapting the refinement opportunities into problem-based-learning experiences in their pre-capstone courses.

We identified 24 refinement opportunities from six MAE capstone design projects completed during Fall 2008 and Spring 2009 semesters. We also identified 12 courses in the MAE curriculum as potential venues for carrying out the refinements. Statements of Need were prepared for each of these refinement opportunities and posted on the teaching/learning system *Blackboard* site along with the final reports and other files associated with these projects.

All departmental faculty were invited to review these materials and indicate their interest in incorporating the refinement opportunities in their courses. Seven faculty expressed interest in adopting 15 refinements in seven different courses. All five faculty members who expressed interest in summer support were provided with support.

Conducting Refinement Activities

In this section, we describe two new MAE courses established to facilitate the refinement efforts and realize the objectives of this project.

Design Management Course

During Fall 2009 semester, a new course in Design Management was taught with eight seniors and one graduate student enrolled. These students learned the concepts and techniques of managing design projects; and their term projects consisted of assisting the faculty and students in the pre-capstone courses to plan, coordinate, and manage the refinement activities.

As an example of refinements efforts, a Spring 2009 capstone design prototype failed. Three different types of refinements were conducted in Fall 2009: students in the junior introductory mechanical design course refined a screw mechanism, students in a senior-elective mechatronics class redesigned the motor controller, and another group of students refined the tolerance specifications and improved the quality of the detail drawings for several components. In each case, students in these three courses class were divided into teams, with each team managed by a student from the Design Management class.

Design Synthesis and Implementation Course

A new senior-level course, Design Synthesis and Implementation, is being offered during Spring 2010 semester. The five students in this course are synthesizing design refinements being carried out during Fall 2009 semester into a new version of one capstone design, as well as implementing comprehensive refinements to another capstone design from Spring 09. This course is a project-type course, with no lectures, homework, or exams. Student teams give three oral presentations and submit three written reports. Each individual student also maintains a design journal and accounts for the time they spend on various project activities.

Evaluation and Formative Assessment

The underlying educational purpose for this project is to develop the learning and teaching materials needed to support the systematic use of project-based learning experiences throughout our curriculum. With this purpose in mind, the assessment activities were designed primarily for formative purposes, but they also have important summative uses. The evaluation and assessment activities are being conducted by Dr. Borgford-Parnell, a co-author of this paper. The evaluation and assessment plan is intended to provide the necessary data and analysis to: (a) make improvements to and inform the effectiveness of the project-based curricular and assessment components in the participating courses, (b) develop and improve the new Design Management and Design Synthesis and Implementation courses and their integration activities,

(c) improve the processes by which participating instructors are supported, and (c) describe (summatively) the level of success of both the overall project and it's individual components in order to facilitate adoption and adaptation to curriculum in the broader engineering education field. The assessment plan for the Design Management course is composed of several key components, as shown in Table 1, and the remainder of this section describes the methodology and results of the Design Management assessment activities. The assessment plan for the Design Synthesis and Implementation course is still under development.

Table 1: Mapping Assessment Goals to Assessment Methods

		Goals			
		Improve Refinement Materials	Improve Design Mgt Course	Improve Support to Faculty	Measure Project Success
Methods	Pre-Course Faculty Surveys & Mid-Course Faculty Interviews	**X**	**X**	**X**	
	End of Course Faculty Surveys	**X**	**X**	**X**	**X**
	Mid-Course Student Focus Groups		**X**		**X**
	End of Course Student Surveys	**X**	**X**	**X**	**X**
	Design Mgt. Student Process Reports	**X**	**X**	**X**	**X**

Pre-Course Faculty Surveys & Mid-Course Interviews

Five MAE faculty members agreed to participate and to integrate a capstone refinement project (CRP) in their existing Fall 2009 courses. Each participating instructor was surveyed during the summer prior to implementation of their courses. These pre-course surveys were intended to determine whether the instructors needed any individual or group instructional support while they were preparing their courses. Each instructor was asked questions such as, the reason for choosing to incorporate a CRP in his/her course, whether the CRP replaced an existing course project, and how comfortable each instructor felt incorporating the CRP in the course and assessing the results. The main reason given for choosing to use a CRP in their courses was to provide their students with a "real-life" or "practical" design problem. On the whole, the instructors indicated feeling sufficiently comfortable integrating a CRP in their courses. One person (Professor A) however, was concerned whether students would have sufficient mathematical knowledge to complete the chosen project. This instructor envisioned the CRP as an individual homework assignment that followed a lecture presentation in which the project and related topics would be explained and discussed. These math concerns were resolved by incorporating the mathematical calculations in a lecture presentation.

At mid-semester, the participating instructors were interviewed individually and asked whether they had any new concerns, questions, or required any resources. At that point, they reported once again feeling comfortable with teaching and assessing the CRPs. Two of the instructors (Professor C and Profesor E) inquired about ways to proactively improve student project group participation. The instructional consultant discussed several techniques that could be used and provided each instructor with the resources they would need to implement a process for peer evaluation of group participation.

End of Course Faculty Surveys

Prior to the end of Fall 2009 semester, each of the participating instructors was given a survey questionaire that asked them to describe aspects of their experiences teaching and assessing the CRPs. The researchers were interested in issues and insights they may have developed during the implementation of the CRPs, such as whether they assigned the CRPs as individual or group projects; how well the CRPs helped their students achieve intended learning goals; and how they assessed their students' learning. Since the researchers' intent is to refine the process and firmly imbed it in the MAE curriculum, the researchers were also interested in whether these participating instructors would use CRPs again and suggestions they may have for improvement. To date, four of the five instructors who used CRPs in their couses have completed the end of course surveys. The fours instructors reported the following:

Professor A:

This instructor reported using a CRP as an individual assignment intending to help students learn how to test materials using mathematical modeling. Prof A reported that the CRP was an additional assignment and not a replacement. Prof A did not need or use students from the Design Management course. The main difficulty Prof A encountered in using a CRP was that students were unprepared to do all the necessary calculations. Prof A was able to overcome that problem and integrate the CRP activity into the course. Prof A chose the CRP because of it's relevance to the course, and wrote that it would be helpful if similar projects were available. Prof A reported that he would use a CRP again.

Professor B:

This instructor used a CRP as a group design project that replaced a previously planned group assignment. Prof B wrote that students had difficulty with the open-ended nature of the CRP, but that they eventually adjusted and successfully completed the assignment. Prof B wrote that the students had no prior experience with design projects. Prof B reported that the CRP did not match the course content well, but admitted that could have been resolved with better selection on his part. Prof B reported that the project management students were only partially helpful to his student groups and the main difficulty was in their lack of availability and responsiveness to student concerns and questions. Prof B suggested that better training with regard to being responsive coordinators would help. Professor B wrote that he would use a CRP again, but that he would check more closely to ensure a better match with course topics.

Professor C:

The CRPs in Prof C's course wered use as group design projects. They replaced previously planned projects. Prof C reported needing to develop additional constraints and clarification to allow students to focus on specific course topics. Professor C wrote that access to lab facilities and equipment would have been required to fully diagnose and refine the project. The open-ended nature of the CRP was the least helpful aspect of the project, and Prof C suggested "class projects should not focus too heavily on developing design requirements." Prof C reported that the project management students provided important help, but that more participation from them would have been helpful. Prof C would use a CRP again, but would refine the requirements so that students could get to the analysis and design work more quickly.

Professor D:

Prof D used three different CRPs with four student groups. This instructor reported that three additional lectures were developed in order to integrate the CRPs into the course. Prof D wrote that each teams' degree of success was based to some extent on student motivation. Team motivation varied across the four teams with only two of the teams earning maximum points on their project reports.

Mid-Course Student Focus Groups

At mid fall semester, students in the Design Management course were interviewed by the instructional consultant. The purpose of this in-class interview was to gather feedback from students on their experiences in the course. The interview was structured as a Small Group Instructional Diagnosis (SGID).[26] An SGID is a standard form of teaching and course assessment, often used by instructional consultants to diagnose the effectiveness of teaching and course activities. It is used for formative purposes (i.e. to help make improvements to the course). Results of the SGID were discussed with the course instructor and plans for future course refinements were made. At mid-term, the Design Management students were mainly concerned with whether or not they were sufficiently prepared to fulfill their duties as CRP managers in the participating engineering courses, none of which had begun the CRP assignments at that point.

End of Course Student Surveys

Hard-copy surveys, along with a stamped self-addressed envelope, were distributed to Design Management students in one of the final class sessions of the semester. The purpose of this survey was to gather feedback from students on their entire experiences in the course and as CRP managers in the participating engineering courses. Seven of the nine students in the course filled out the survey. The following is an overview of the survey results:

With the first four questions students were asked to indicate the extent to which they agreed with afirmative statements regarding the course. Their answers were marked on a lickert scale that ranged from, "*1. Strongly Disagree*" to *"5. Strongly Agree."*

1. The Design Management course was well designed to help me to achieve the course learning objectives. *(mean score = 4.0)*

2. This course built well on the knowledge I gained in prerequisite courses. *(mean score = 3.71)*
3. I was well prepared to coordinate/manage the capstone refinement project in the MAE course I was assigned to. *(mean score = 4.14)*
4. I was well supported by this course while I coordinated/managed the capstone refinement projects in the MAE course I was assigned to. *(mean = 4.14)*

The survey contained an additional ten open-ended questions that focused on three aspects of student experiences with this project: (a) how well the Design Management course prepared students to manage the CRPs; (b) managing the CRPs and interacting with the faculty in the other courses; and (c) success in refining the capstone projects. As indicated by the lickert scores above, the students reported feeling well prepared to manage the CRPs. Students suggested that the relevance of the homework assignments, the examples of management tools and scheduling and planning methods they were introduced to, the discussions with classmates, and the engaging lectures; were each important and helpful in their preparation. Students suggested that the component of the course that required the most improvement was in the actual project management of the CRPs.

The most prevelant suggestions provided by the students were to start the CRPs earlier in the semester, and to improve faculty commitment to the CRP process. Students suggested that with more commitment and an earlier start the biggest obstacle they encountered – communicating with the students in project groups – could have been more easily overcome. Students reported that “Getting in touch with the student groups,” and “Just making sure the team was all on the same page” were initial problems that they had to deal with. When asked if they were able to overcome the obstacles, each of the students reported some degree of success. For example they wrote, “In one case no. However, in others persistent and often face to face communication allowed me to overcome the obstacles,” “Yes, eventually communication would be established and everyone would be on the same page,” and “Yes, but it took a lot of time to get the project going.”

At the end of the semester, no student reported feeling unprepared for their project management duties. However, students did suggest that they would have had fewer problems and more time to deal with problems if there had been more communication between the Design Management instructor and the other participating instructors, if the participating instructors had started the projects sooner, and if they had stuck to their schedules more dilligently.

When asked if they thought that their teams had successfully refined the projects, each student reported that they had made improvements. The improvements they reported ranged from “the design is done,” to “produced near-professional quality drawings.”

Design Management Student Process Reports

Each of the students in the Design Management course was assigned to help with CRP management in one of the participating MAE courses. Since there were nine Design Management students and only five participating courses, several of those courses were assigned multiple students. By the end of the fall semester, each student was expected to provide an oral presentation, and both a written technical report and written process report on their CRP management experiences. These reports are used to assess Design Management student learning, to make formative determinations regarding how well the Design Management course prepared students for their CRP management, and to provide data for assessing the project overall.

Students earned an average score of 92.9/100 on their CRP written reports. Along with the technical details of the CRPs they also described the highlights of their project management processes. As in the surveys described earlier, students reported that they were prepared and able to manage their CRPs. As one student wrote, "I was able to actually act like a manager to these students. I think it made a difference being four years older than them. They looked up to me as someone in charge and respected me…I was able to help them become cohesive in a team and bond well together to work towards a common goal." However, students also reported that the logistics of communicating with their assigned instructors and with their project groups was the most difficult hurdle. One student summed up the communication challenges this way, "Some challenges showed up as the project progressed. Initially contacting Professor E was quite difficult. However, after the initial meeting with him, everything seemed to go according to plan. Communication with some of the students was also difficult, but was expected. This obviously made it difficult to help them and check their progress."

Triangulation of Data

At this point, data collection for the Design Management course is complete and data analysis is underway. Once the researchers have analyzed each data set individually then a process of data triangulation will begin. For example, student data from their process reports will be examined as to how well they allign with what the participating faculty members report in the surveys. Since engineering students and faculty both have a stake in the success of this project, it is critically important that both perspectives are taken into account in our analysis.
A preliminarily examination of the student and faculty data indicates that the project thus far has achieved a high degree of overall success, but that there are several areas in need of improvement. The results of the analysis, plus our subsequent assessment of the Design Synthesis and Implementation course, and our plan for improvement will be reported in a subsequent paper.

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