Is There a Difference in the Engineering Skills Fostered in Structured vs. Unstructured Capstone Courses?

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The structure of engineering capstone design courses vary both between institutions and within a institution from the perspective of faculty engagement, industry involvement, and course learning objectives. In this paper we present a summary of an ongoing study focused on assessing engineering skills pre- and post-capstone experience in two institutions where the course structures are different. These engineering skills are self-assessed by both students and industry sponsors involved with the mentorship of these projects in their organizations. The study we describe will assess the impact of pedagogical approaches and course structures on skill development and project success. The objective of our study is to identify high impact teaching practices by comparing the structured and unstructured capstone courses at two universities.

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Introduction

A capstone course provides students a culminating experiential learning environment and a valuable opportunity to solve large, unstructured problems in a classroom setting. Often times, these team-based projects reflect industrial settings which the majority of participants will find themselves in upon graduation. Throughout the capstone experience students find themselves faced with complexities not found in a traditional course, particularly when the projects are industry sponsored.

Capstone courses are prominent elements of engineering degree programs in many countries and are central to the development and assessment of student professional competencies for program accreditation [1]. Motivated by accreditation requirements and by industry concerns about workplace preparedness of engineering graduates [2,3], many degree programs across engineering disciplines have adopted industry-sponsored projects. In the United States, engineering program accreditation criteria established by the Accreditation Board for Engineering and Technology (ABET) specify requirements regarding the engineering capstone project in criterion 3 and 5[4]. These criteria require the integration and assessment of key performance skills within the context of a comprehensive design project.

At a time when student learning and assessment in capstone courses are increasingly important to program accreditation [1], capstone course instructors are being challenged by the need to plan and facilitate such a course.

Research Objectives and Program Goals

This paper aims to compare and contrast two methods through which the capstone project learning experience can be delivered; a centralized, structured format (CSF) versus decentralized, unstructured format (DUF). By CSF we mean that a design methodology is taught to the student teams in a formal classroom setting and instruction and evaluation are provided on a predetermined schedule. We define DUF delivery to be one in which the students are largely left on their own to accomplish the project without formal classroom instruction; however they do have some form of faculty mentoring. The faculty mentors are largely given freedom to work with their teams in a manner that they deem to be effective, i.e., it is not prescribed. The delivery format offered (DUF or CSF) can be a decision based upon the nature of faculty support, involvement of corporate sponsors, and departmental tradition.

The key question this study is designed to address is: *What are the perceived strengths/weaknesses of two different capstone course delivery methods?*

The purpose of this study is to inform the pedagogical development of such capstone design project courses as an increased number of engineering programs strive to integrate project-based curriculum. It is anticipated that this study will highlight exemplary course materials, assessment instruments, and other lessons that could be deployed to accelerate the adoption of effective practices and materials. This paper will serve to summarize the study that has been deployed in the Fall of 2013 at the Edward P. Fitts Department of Industrial and Systems Engineering at NCSU (ISE) and Worcester Polytechnic Institute (WPI)'s Operations and Industrial Engineering (OIE) program and will culminate in May of 2014.

A Comparison of Two Instructional Delivery Methods

We will first begin with a brief description of the similarities in the delivery of the capstone course at NCSU ISE and WPI OIE. Both universities rely on the expertise of an Industrial Engineering faculty member to lead or contribute to the conceptualization, development, and implementation of the program and course materials. At both institutions, a passing grade is required for degree matriculation and students typically enroll in the project during their senior year. Finally, both institutions follow [5] classification of *authentic involvement* which exposes the student to real situations with totally open-ended projects and use outside industry customers.

Beyond these similarities, however, were many differences among the two universities, providing a diverse set of methods, approaches and structures for the implementation of Industrial Engineering Capstone courses. Table 1 summarizes the course structures, problem area(s) addressed, and number of students impacted.

In order to answer our research question we will conduct an assessment of engineering skills learned by the students in each program. This assessment will include data from students and from the industry sponsors who are partnered with them during the capstone project. Data from this evaluation will highlight learning differences between the structured and unstructured delivery of guidance, learning challenges, and problem-solving skill development experienced during a typical capstone project experience.

After the completion of our study (in the summer of 2014) our aim is to discuss the findings from this assessment along with the similarities and differences of each program and provide an overall picture of the strengths and weaknesses of each delivery format.

Characteristic	**NCSU**	**WPI**
Faculty Responsibility	Single faculty instruction; project mentoring from other ISE faculty as needed	Single faculty instruction and advising by each OIE faculty.
Requirements for Project Completion	Final written report and one or more oral presentations	Final written report and one or more oral presentations
Team Formation	Formed using the CATME tool and student project rankings	Self formed
Average Team Size	2-4	2-4
Duration	1 semester (15 weeks)	3 terms (21 weeks)
Delivery Format	Structured class (lectures, guest speakers, and team time)	No formal class; instructional material (if any) defined by individual faculty; student arranged meetings with faculty
Role of Industry	Project definition and resources, sponsorship fee, mentoring, formal team/project evaluation	Project definition and resources, sponsorship fee, mentoring, project feedback

Table 1. Comparison of Capstone Course Structure at NCSU vs. WPI

Assessment Methods

Using an online-based survey tool, students from each institution and industry partners participated in a *pre* and *post* assessment evaluating levels of engineering skills. Students were asked to self-report their own skills at the start of the capstone course and then again at the conclusion of the course. For the students, the purpose of the pre- and post- assessments is to determine the differences in skills levels for the students attained prior to the capstone experience and a new assessment of skill level at the conclusion of the capstone experience.

Industry partners were asked to report expected levels of engineering skills from the students prior to the start of the capstone project, and then again asked to evaluate the skills of the students they worked with at the conclusion of the project. During the pre-assessment, industry partners assessed their expectations of general student's skills (i.e., not assessing a particular student), while during the post-assessment; the partners evaluated the team they worked with for the duration of the project.

The assessments focused on eight categories of engineering skills including, motivation, judgment and decision-making, innovation, client/quality focus, product development, professional/ethical practices, teamwork, and communication. All items were adapted from Davis et al.'s [1] list of attributes and performance factors for top quality engineers and measured using a 5-point Likert scale with 1 being poor and 5 being excellent. Our rationale for using the Davis et al. study to develop our survey items stems from a desire to include measures that can address the evaluation of engineering behavior and skills for engineers in training. The work done by Davis et al. presents a profile for a top engineer that includes ABET criteria, inputs from industry and guidance from engineering academics, making it an appropriate set of questions to measure the validity of capstone course delivery methods.

Data collection commenced in the Fall of 2013 and will conclude at the end of the Spring semester 2014 (i.e., 2013-2014 academic year). The sample consisted of four groups of subjects:

- Group 1 – WPI OIE students completing their MQP during 2013-2014 school year
- Group 2 – Industry sponsors interacting with the students in Group 1
- Group 3 – NCSU OIE students enrolled in ISE 498 – Senior Design Project course during Fall 2013 and Spring 2014.
- Group 4 – Industry sponsors interacting with the students in Group 3

Thus far, a total of 59 students and 13 industry partners representing both NCSU and WPI have completed the pre-assessment. With the different format of each university's capstone course, data collection is staggered based on project completion dates. Data collection will be completed by May 2014.

Preliminary Findings from Pre-test

A very early review of our data from NCSU students from Fall 2013 yields expected findings. A total of 9 NCSU students self-reported their level of skill for eight categories of engineering skills as proposed by Davis et al. Figure 1 shows the mean values for each of the skill categories as reported by the students for both pre and post measurement. There was an increase in skill level reported for all eight categories. Notably, the largest increase in reported level is for communication skills.

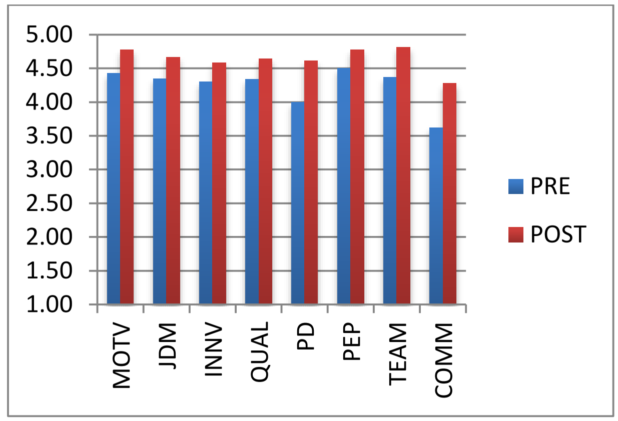

Figure 1. First Look: Pre vs. Post Engineering Skills Means for NCSU Students

Figure 2 shows the mean values reported by 5 industry partners. The sponsors were asked to assess their expected level of skills of the students for the eight engineering skill categories. The post evaluation, based on their interaction with the students during the capstone experience, yielded values higher than expected for five of the skill categories. Based on the findings from the industry partners, there appears to be a inconsistent assessment between how the students evaluate their professional/ethical practices and their ability to work in teams. Although these results are preliminary for both groups, we anticipate the trend of improved skills from the students and exceeding expectations from the industry partners to continue for the main study. A full analysis of student and industry partner data from both institutions will be conducted after the completion of data collection.

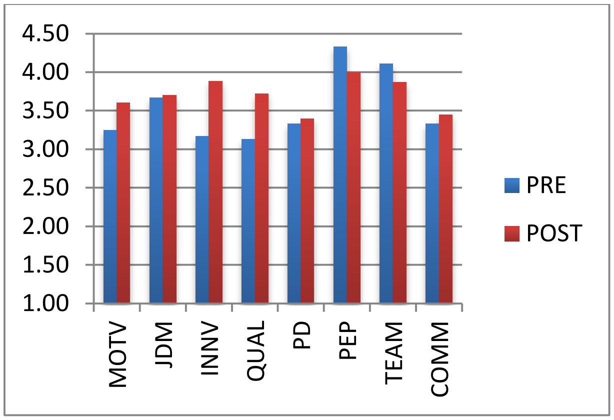

Figure 2. First Look: Pre vs. Post Engineering Skills Means for NCSU Industry Partners

Anticipated Findings and Potential Contribution

It is anticipated that this study will highlight exemplary course materials, assessment instruments, and other lessons that could be deployed to accelerate the adoption of effective practices and materials that contribute to engineering skill development and ultimately better alignment with industry needs. Likewise, the differences in delivery of the capstone experience by both institutions could be a factor in the consistency of the pre-assessment, self-reported skill levels of the students between institutions. Although we are not examining how the skills are developed prior to starting the capstone experience, we intend to include a discussion on pedagogical experience of the students during the years leading up to the senior capstone and how this can contribute to the findings from both the students and the industry partners. These findings will be linked to characteristics of CSF and DUF. The pre- and post-assessments from the students will provide insight on what methods seems to be effective and which seem to need improvements. The assessments from the industry partners will provide guidance on how well the students are able to compete in real-life problem-solving situations, ultimately leading to guidelines and practices to be incorporated into the capstone curriculum.

Conclusion

We expect findings from the present study to not only provide feedback on the current methods employed at WPI and NCSU for the respective faculty, staff, and administration, but to also provide an understanding of leads to better student outcomes and what needs more refinement for faculty and staff who are developing or redesigning capstone courses across Operations or Industrial Engineering and related disciplines.

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