AC 2012-3821: INTEGRATING PROJECT MANAGEMENT, LEAN-SIX SIGMA, AND ASSESSMENT IN AN INDUSTRIAL ENGINEERING CAPSTONE COURSE

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Integrating Project Management & Lean-Six Sigma Methodologies in an Industrial Engineering Capstone Course

Abstract

The ability to effectively manage large, complex projects is a skill required of most engineers in industry today. The skills required to be an effective project manager go far beyond technical engineering content taught in engineering curriculums. Industry sponsored capstone project experiences require students to communicate, deconstruct the large project into manageable pieces, and manage risk and uncertainty. This is a departure from traditional engineering problems which have a right answer and typically have a prescribed solution method. In this paper we discuss a pilot study that evaluates how a structured framework of project management, mimicking industry practices, affects the problem solving process throughout the project life cycle. Specifically we develop an approach that integrates project management methods and tools with Lean-Six Sigma methods. An additional objective of this research is to develop a better understanding of the unique aspects of the engineering problem solving process. We assessed the student's problem solving strategies, products, and design process reflections using Wolcott's "Steps for Better Thinking" rubric [1].

Introduction

Capstone courses give students the opportunity to solve large, unstructured problems in a classroom setting. These team-based projects mimic the industrial setting that most students will enter upon graduation. Throughout the capstone experience students find themselves faced with complexities not found in a traditional course, especially when the projects are industry sponsored. Student teams face challenges when defining objectives for an ambiguous project, controlling scope creep, achieving buy-in, and selling their results to the sponsor. These are skills that are not taught in most engineering curriculums prior to the capstone course(s). Our observations are consistent with the observations by other researchers who have studied the design process. Wilson et. al [2] highlighted how students in the capstone course setting struggle with setting milestones and soliciting feedback at the right times. Developing and effectively communicating the project plan and status are critical to the success of the project. As noted by Yildirim[3], there is a need for understanding the relationships between design activities, the evolution of the design process, and the solution or outcome. We share in this sentiment and feel that developing a framework that explicitly links the design process with design activities is beneficial for the students and the instructor. Given a design process framework, the students establish a sense of the key inputs and outputs needed to identify and solve their problem. The instructor now has a course structure they can exploit for assessments that can be timed at key intervals throughout the design process. Our solution was to leverage standard industry practices, specifically project management and Lean-Six Sigma, and overlay these methodologies on top of the capstone course. In the following section we describe the course content enhancements made in the Fall of 2011.

Course Enhancements: Using Project Management & Lean-Six Sigma Tools

In the Fall of 2011 changes were made in the capstone project course in the Industrial and Systems Engineering (ISE) department at North Carolina State University (NCSU) which were intended to both provide a framework for the design cycle and assess the problem solving process throughout each phase of the process. Our research interests are two-fold: (1) to describe an application of enhancing the capstone experience by aligning the content with industry project life cycle practices and (2) to assess the evolution of a student's problem solving skills through the course of the project. The capstone project course in the ISE department is a single semester course in which 100% of the projects are industry sponsored. In the Fall 2011 cohort there were 11 total students that were assigned in teams of 2 or 3 to four unique projects. The majority of class lecture time was spent introducing project management methods and Lean-Six Sigma (LSS) tools. From a project management perspective the course was framed as having four consecutive phases: Project Initiation, Planning, Implementation/Execution, and Closeout. Overlaid on top of the project management phases we introduced LSS methodologies (define, measure, analyzed and improve, control) and tools. Figure 1 shows the overlap in these project life cycle phases.

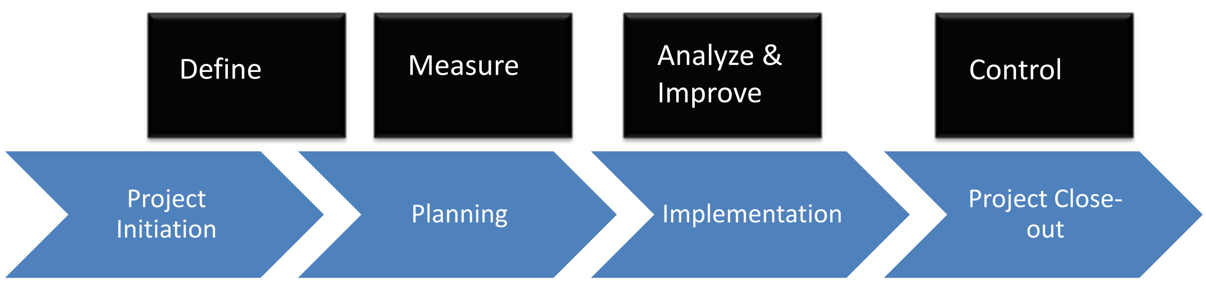

Figure 1: Relationship between Six Sigma phases and Project Life Cycle phases used in the ISE 498 Senior Design Project course

Various tools linked to project phases were discussed throughout the course prior to the estimated time in which the tool would be needed by the student team. Table 2 lists the tools that align with each phase. The tools with an asterisk were assignments that were graded while the others were optional. Since projects evolve at different rates, short, in-class cases were provided to the students to practice their design process skills. The students would work with their project teams during these sessions and then outcomes were discussed with the entire class. Providing in-class cases helped the instructor to informally assess the understanding of critical problem solving approaches.

Tools and methods alone do not result in successful projects. To further emulate industry practice, we incorporated two mechanisms to control the design process. First is the requirement that each team submit a Status Report every two weeks to the instructor and the industry sponsor. Figure 2 shows a sample status report. The intention of the report is to familiarize students with the process of representing project status in a single page with visual cues (red, yellow, green). We defined red as a milestone or deliverable that was missed, yellow indicated a concern that may jeopardize the success of the corresponding milestone, and green indicated that the item was on track or complete. The status report keeps the team and sponsor accountable for action items, milestones, and focuses the team on project risks and concerns. The report is a quick means of formal communication between the student team and the sponsor team that can be used as a basis for follow-up discussion.

Project Name:	Project X	Date:	9/15/2011
Overall Status:	R,Y, G	Project Sponsor:	Co. XYZ

PM Phase	SS Phase	Milestone	Owner	Plan	Status
Planning	Measure	Draft Schedule	Team	9/25/2011	G
Planning	Measure				
Planning	Measure				
Execution	Analyze				
Execution	Analyze				
Execution	Improve				

Major Issue/Concern	Owner	Target	Status

Risk	Mitigations Plan	Owner	Status

Figure 2: Sample Status Report

The second project control tool that we employed is the phase-gate process. Similar to industry practice, our phase-gate process was implemented by developing deliverables that are reviewed during each project lifecycle phase. In this context the syllabus contained deliverables at key points during the project so the instructor, students, and sponsor could monitor the project progress. These deliverables typically took the form of a document (e.g., project charter) or presentation (e.g., project proposal presentation) or a combination of the two. The following are a list of the major deliverables that occur throughout the semester in order of their occurrence:

- Project Charter (presentation and document)
- Project Failure Modes and Effects Analysis (FMEA)
- Project Proposal Report and Presentation
- Mid-phase Presentation
- Final Project Report and Presentation

While in industry these phase gates are used to make go/no-go decisions, in the context of the capstone course they were used by the instructor to give the student teams' feedback on project direction, approach, etc…

These structured project management and six-sigma methods provide a guide during the project lifecycle which can be an overwhelming and ambiguous experience. However, developing course content that enhances the student's exposure to these topics is not enough. We must assess not only the student's application of the concepts but also the potential impact these concepts have on their ability to solve problems. In order to do so we developed design reflection assignments at critical phases of the project (Planning Phase Exit, Mid-Implementation Review, and Project Closeout). Throughout these reflections we asked the students questions in order to discern how they were using information to solve their problem during that particular phase. Finally, we administered a skills survey pre- and post-capstone that measured self-assessment on a variety of measures. The same survey was sent to the sponsors who rated their expectation prior to the course and the reality post-project completion. We will describe this reflections assessment and rubric as well as the results of the pre/post skills survey in more detail in the following section.

Assessment Mechanisms

Now that we have set the context of the course content and structure, we will focus on the various modes of assessment. The assessments had two main objectives and the assessment timeline is shown according to the project lifecycle phase in Figure 3.

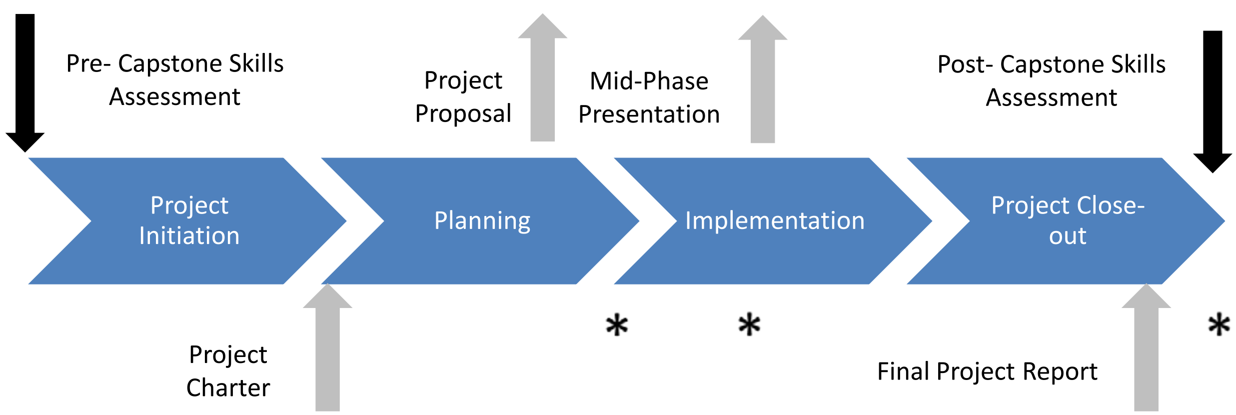

Figure 3: Assessment timeline where the asterisk denotes the design reflection time points in relationship to the project life cycle phase, the gray arrows indicate key deliverables, and the black arrows indicate pre/post surveys.

The first objective was to develop an understanding in the gap between industry expectations and student preparation on a number of measures (from technical to professional).

In conducting the comparable surveys before and after the course, we developed the following research questions:

1. How do companies' baseline expectations differ in regards to the following categories:
   - A student team's ability to communicate
   - A student teams' ability to solve problems
   - A student teams' ability to develop a design strategy throughout the project life cycle
   - A student teams' ability to communicate in various forms
   - A student teams' ability to function effectively as a team
   - A student teams' knowledge of project management methods
   - A student teams' knowledge of lean-six sigma methods
2. Are companies' expectations a representation of reality?
3. How do students' rate themselves on these same measures *before* and *after* their senior design experience?
   - Which measures appear to be impacted by the capstone experience?

Our second objective was to evaluate the evolution of the problem solving process using Wolcott's "Steps for Better Thinking" rubric (see Appendix 1). This rubric places students on a scale from less complex performance patters (e.g., confused fact finder) to more complex performance patterns (e.g., strategic re-visioner) during each of the 4 pre-defined problem solving steps. This rubric was used to assess student's problem solving capabilities using computational tools in engineering classes [4] and while these authors found the rubric to be a valuable assessment tool, they identified the need to revise the rubric to better align with engineering problem contexts and nomenclature. We set out to identify the limitations of the rubric and to revise it accordingly, so as to make it more relevant to the engineering problem solving and design context.

At three key points during the semester students were asked to write reflective accounts of their problem solving and design processes (see Figure 3). These reflective questions were based on the different stages in the Wolcott rubric. The two project researchers coded student reflective responses using the Wolcott rubric, and noted areas for improvement of the rubric as they proceeded with the coding. The focus of these improvements is on developing descriptions in each of the cells (see Appendix 1) that are more appropriate to the engineering problem solving design process.

Assessment Results

Assessment results are presented in the next sections.

Student's Skills Self-Assessment

To assess students' perceptions about gains made in the course, pre- and post-surveys were used and students were asked to rate themselves on common questions about skills. A five point scale was used with the following anchors:

1 - Novice = you are new to the concept/skill.

2 - Advanced beginner = you have some exposure to the concept/skill, but have not used it frequently and need to learn much more.

3 - Competent = you have had reasonable exposure to and use of the concept/skill, but can still develop further.

4 - Proficient = you have had a lot of exposure to and regularly use the concept/skill but there are a few areas for advancement.

5 - Expert = you have had significant exposure to and use the concept/skill routinely, and there is little or nothing to improve.

Due to the small sample size the Mann-Whitney *U*-test was used to establish significant response differences. Table 1 below shows all questions asked, with significantly different changes highlighted in gray using an alpha of 0.05.

Table 1: Student pre- and post-survey scores for surveys conducted at the beginning and end of semester.

Topic	**Pre-test Mean**	**Post-test Mean**	**Question**	
Problem Solving				*u*-value
Q1	3.73	3.73	Differentiating between useful and irrelevant information	.9
Q2	3.27	3.64	Identifying uncertainties and limitations	0.3
Q3	3.91	3.64	Considering different perspectives or viewpoints in solving a problem	0.56
Q4	3.64	3.45	Identifying strengths and weaknesses of different perspectives	0.9
Q5	4.00	3.73	Interpreting and organizing information	0.85
Q6	3.27	3.73	Generating different solutions to a problem	0.27
Q7	3.55	3.91	Deciding on the most appropriate solution	0.19
Q8	3.91	3.82	Generating a plan to solve the problem	0.95
Q9	3.36	3.50	Communicating decisions about the best solution	0.56
Q10	3.18	3.27	Dealing with uncertainties, limitations and tradeoffs	0.95
Q11	3.82	3.91	Looking for ways to improve solutions and processes	0.85
Section Mean	**3.60**	**3.67**		

Topic	Pre-test	Post-test	Question	
Design				*u*-test
Q12	3.64	3.40	Generating appropriate goals and objectives	0.71
Q13	3.55	3.80	Identifying key design issues	0.17
Q14	3.73	4.00	Identification of necessary tasks and actions	0.43
Q15	3.18	3.50	Identifying deliverables	0.51
Q16	3.27	3.50	Creating a project schedule	0.61
Q17	3.36	3.70	Identifying resources and constraints	0.25
Q18	3.55	3.90	Implementing the process	0.25
Q19	3.82	3.80	Organizing and managing tasks	.71
Q20	3.18	3.50	Monitoring and evaluating progress	0.51
Section Mean	**3.47**	**3.68**		
Communication				
Q21	3.09	3.64	Writing technical documents (proposals, reports, etc.)	0.24
Q22	3.27	3.55	Making oral presentations	0.61
Q23	3.64	4.09	Written professional communications (e.g. email, letters)	0.19
Q24	3.10	3.91	Professional oral communication (e.g. phone or other medium)	0.04
Section Mean	**3.30**	**3.80**		
Team work				
Q25	4.27	4.09	Attending meetings	0.95
Q26	4.00	4.00	Contributing to idea generation	.8
Q27	4.00	4.09	Contributing to decision making	0.52
Q28	4.18	4.18	Communicating with team members	.44
Q29	4.00	4.18	Taking on a fair share of tasks	0.33
Q30	4.09	4.18	Dependability and preparedness	0.61
Q31	4.73	4.36	Team spirit and respect for others	0.85
Q32	4.27	4.09	Negotiation and conflict management skills	0.9
Q33	4.09	4.00	Time management	1.0
Q34	4.09	4.36	Completion of work assumed/assigned	0.19
Section Mean	**4.17**	**4.20**		
Project Management				
Q35	3.64	3.82	Assuming the role of a project manager	0.52
Q36	3.09	3.55	Developing a design roadmap	0.15
Q37	2.55	3.27	Developing risk management plans	0.06
Q38	3.18	3.73	Managing a project through each project life cycle phase: (1) Planning Phase	0.08
Q39	3.00	4.00	Managing a project through each project life cycle phase: (2)Implementation Phase	0.004
Q40	3.27	3.64	Managing a project through each project life cycle phase: (3) Close-out Phase	0.17
Q41	2.18	3.91	Using the six sigma methodologies (DMAIC) to solve problems	0.000
Q42	2.27	4.00	Using the Lean methodologies to eliminate waste	0.000
Section Mean	**2.90**	**3.89**		

Problem solving and design skills generally stayed the same or improved throughout the capstone experience. There are some interesting results where the skill level is reported to have decreased, namely Q2-5 and Q12. Though our sample size is limited we believe there is an explanation for this regression in skill level. Questions 2-4 focus on working with others and integrating different perspectives in the problem solving process. Students may have overestimated their ability based on a lack of experience working with people from different backgrounds. The result in Question 5 regarding interpreting and organizing information leads to an inherent challenge in a capstone course that incorporates real-world problems. Since data and information are not provided to the students in a formal classroom-like setting the instructor believes that the students may have encountered a significant challenge that they had not anticipated. Many students in the course expressed the difficulty of defining project goals (Question 12) and most groups anticipated that the sponsors would define the objectives. These sentiments were discussed during the Lessons Learned lecture at the end of the course.

Given the structure of the course it was not surprising to find that the skills defined in the communication and project management increased significantly throughout the course of the semester. We can observe that all skills in that category increased and almost all were significant. As discussed in the Course Enhancements section, the instructor delivered content and assigned deliverables specific to project management. The students had the opportunity to communicate using many modes: email, phone, and formal presentations (3-5 per team). The spring 2012 senior design course will further emphasize these topics. Given the small class size in fall 2011, the researchers will extend the same pilot survey to approximately 30 students in order to validate the results and observations from this study.

Industry Expectations

In order to assess the performance of students and appropriateness of course content it is critical to understand industry expectations. The pre-capstone skills assessment's objective was to set the baseline expectations on the measures discussed in the previous section before the sponsor interacts with the student team. The instructor also completed a parallel survey assessing the same constructs as those assessed in the student survey.

For the industry ratings, no constructs resulted in statistically significant difference pre/post capstone. However, there were several constructs that were significant at the alpha = 0.06 to 0.1 range and we will discuss a few instances that fall into this category. For example, the companies lowered their score on Q2 noting that students did not deal with uncertainty as well as they expected (alpha = 0.06). Q14 (identification of necessary tasks and actions) had an alpha of .1 and highlighted a weakness in the students' ability to define tasks and actions. We believe this may be related to a weakness in planning and solving problems under uncertainty, thus combining the trend seen in both Q2 and Q14. Finally, the industry representatives had higher expectations related to the students' ability to assume the role of the project manager (Q35). This result further emphasizes the need for instruction in project management at the undergraduate level.

Another interesting result of this analysis was the variation in expectations between companies. For example, Figure 4 shows the industry assessment on the problem solving skills question set (Q1-Q11). In the post-capstone, survey "Company 3" had three employees who participated in the survey. All other company representatives stayed the same and completed both questionnaires. As previously mentioned, there were no significant differences in the industry assessment pre/post capstone. However, we hypothesize they may be due to the averaging of the scores and small sample size. Many of the scores pre and post-capstone varied by as much as two to three points on the likert scale between companies. In general, companies did not have high expectations (i.e., most Skill Level ratings $\leq$ 3) pre-capstone. Regardless of the expectation level entered during the pre-capstone survey, the sponsors' expectations seem to be met (i.e., a similar post-capstone score was recorded). We hypothesize that there could be a correlation between the expectation level of the company and student performance. This may be due to the level of support and pressure to succeed and is an area that we are interested in exploring in the future.

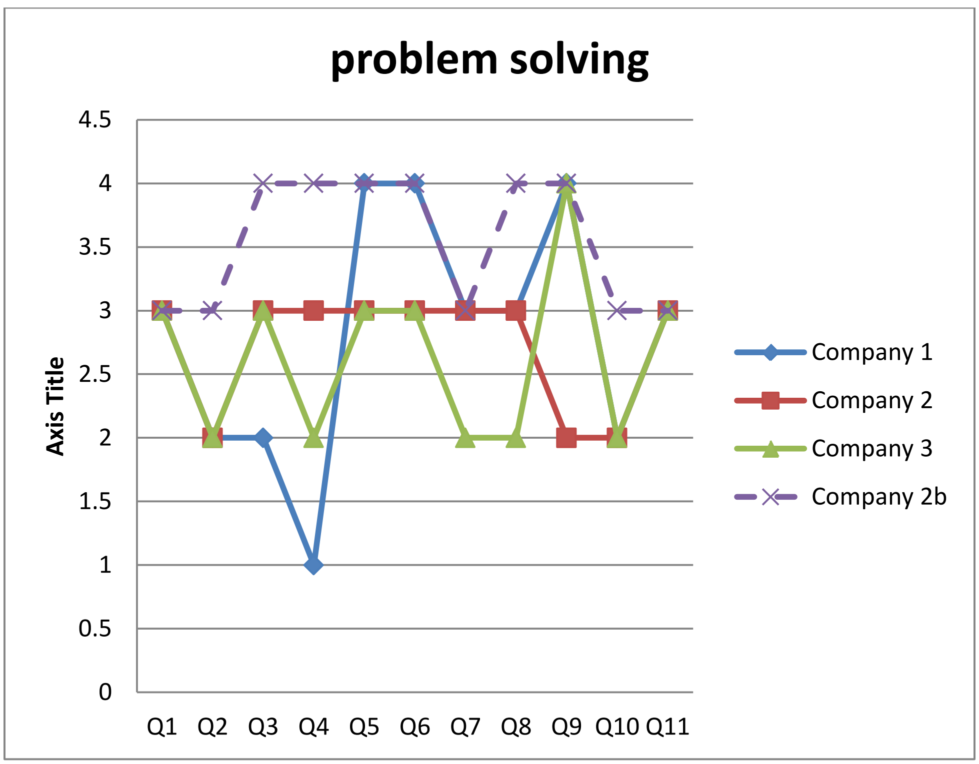

Figure 4: Industry pre-capstone scores on questions 1 through 11, which reflected problem solving skills.

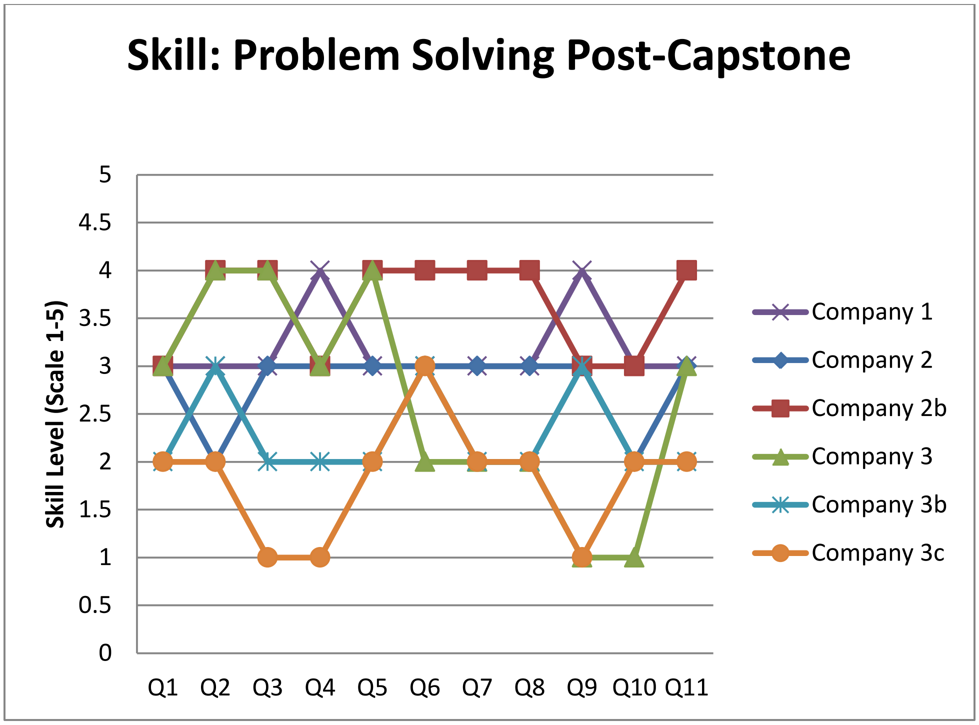

Figure 5: Industry post-capstone scores on questions 1 through 11, which reflected problem solving skills.

In addition we compared the post-capstone responses between industry and student respondents. The significant differences are summarized as follows:

- Written professional communications
- Team spirit
- Completion of work assumed
- Managing projects through implementation and close out phase

Since there were three companies (and four respondents) in fall 2011 we will again be validating these results in the Spring 2012 semester with a larger sample size. In the spring of 2012, there will be nine distinct companies involved and all new companies will take the pre-survey. At the completion of the semester all companies will respond to the post-capstone survey. With this larger sample size we will reanalyze the data in order to draw stronger conclusions and validate the findings from the pilot study. In addition any themes that emerge will be investigated for further course enhancements.

Scoring of Student's Design Reflections

As previously discussed the students submitted three design reflections at key milestones (Refer to Figure 3). We constructed the survey such that the questions mapped to a specific design phase in Wolcott's rubric in order to assess the individual student's performance. For example, the following questions represent a subset of the questions posed in the planning phase exit survey which occurs immediately following the project proposal submission:

- What was the most useful information used to identify project objectives? What information was not useful?
- What assumptions did you make? Why are these assumptions necessary?
- Is there one correct way to solve the problem you are working on? Explain your answer.

These questions corresponded to the Identify step in Wolcott's rubric. Both researchers worked together to score the student design reflections at these milestones, by discussing and reaching consensus on the score for each reflection. For each step and sub category (e.g., Step: Identify, sub-category: A) the performance pattern was scored from 0 (Confused Fact Finder) to 4 (Strategic Revisioner). Student reflections showed a transition from lower levels in the rubric at the start of the semester, to higher levels over time (see Figure 5 below). The responses to the reflection questions were useful to the instructor in developing interventions and additional course content. For example, there were individuals within one team that had not identified any project assumptions. The instructor called a meeting with the team and it was discovered that they had not established a good understanding of the project objectives set by the project sponsor. This finding led to two changes implemented in the Spring 2012 capstone course. First, the project charter is developed in two phases allowing time for feedback from both the instructor and the sponsor. Second, content has been added to the corresponding lecture to discuss the difficulties that past teams have exhibited in developing project objectives, assumptions, and constraints. The reflections enable the instructor to intervene in the design process at critical points and provide targeted direction and advice.

Steps for Better Thinking SKILLS	←Less Complex Performance Patterns			More Complex Performance Patterns→	
	"Confused Fact Finder" Performance Pattern 0—How performance might appear when Step 1, 2, 3, and 4 skills are weak	"Biased Jumper" Performance Pattern 1—-How performance might appear when Step 1 skills are adequate, but Step 2, 3, and 4 skills are weak	"Perpetual Analyzer" Performance Pattern 2—-How performance might appear when Step 1 and 2 skills are adequate, but Step 3 and 4 skills are weak	"Pragmatic Performer" Performance Pattern 3—-How performance might appear when Step 1, 2, and 3 skills are adequate, but Step 4 skills are weak	"Strategic Re-Visioner" Performance Pattern 4—-How performance might appear when one has strong Step 1, 2, 3, and 4 skills
Step 1: IDENTIFY A—Identify and use relevant information B—Articulate uncertainties	Overall, FIRST reflections located in these cells	Overall, FIRST reflections located in these cells	Overall, SECOND reflections located in these cells		
Step 2: EXPLORE C—Integrate multiple perspectives and clarify assumptions D—Qualitatively interpret information and create a meaningful organization		Overall, FIRST reflections located in these cells Overall, SECOND reflections located in these cells	Overall, SECOND reflections located in these cells		
Step 3: PRIORITIZE E—Use guidelines or principles to judge objectively across the various options F—Implement and communicate conclusions for the setting and audience			Overall, THIRD reflections located in these cells	Overall, THIRD reflections located in these cells	
Step 4: ENVISION G—Acknowledge and monitor solution limitations through next steps H—Overall approach to the problem		Overall, THIRD reflections located in these cells	Overall, THIRD reflections located in these cells	Overall, THIRD reflections located in these cells	

Figure 6: Overall classification of students on the Wolcott rubric at each of the three phases in the design process.

However, the application of the Steps for Better Thinking rubric does not map exactly for an engineering context. The researchers identified a need to revise the rubric to contain terminology for an engineering problem solving context. Further, we observed the need to revisit steps in Walcott's rubric. For example, students (and engineers) revisit problem solving phases throughout the project life cycle. As objectives are being defined and understood, it may be necessary to revisit the activities undertaken in the Identify step. A revised rubric which reflects this iterative nature would be of significant value to instructors and researchers who are interested in the progression of problem solving throughout the design process. We are currently working to extend Wolcott's rubric to address some of the limitations that we identified in this pilot study.

Conclusions

The study presented in this paper is a first step towards developing a deeper understanding of the design process using a combination of structured approaches: project management and Lean Six-Sigma and assessment methods. Project management and Lean Six-Sigma tools provided a structure to an otherwise overwhelming project environment. We are continuing to refine these tools and develop new deliverables that will help the students overcome the challenges we have observed in the Fall of 2011.

This analysis has revealed the need for an assessment rubric that shows the iterative design process along a spectrum of project performance. While we were able to capture the general trajectory of students thinking throughout the design process using Wolcott's rubric, it was difficult to translate some of the terminology in an engineering context. A correlation study between the outcomes from the rubric, the pre/post surveys (industry and student), and the individual's (team's) performance on the final project will be conducted with the additional data that is being gathered in the Spring of 2012.

References:

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