INDUSTRY BASED ASSESSMENTS IN AN ENGINEERING TECHNOLOGY CAPSTONE DESIGN COURSE

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ABSTRACT

One of the authors uses experience from his twenty-five year career in the aerospace industry to configure his school's Mechanical Engineering Technology Capstone Design Course utilizing assessments modeled from industry rather than traditional academic assessment concepts. Student design teams are required to take a design project from the initial concept phase through a Concept Readiness Review, a Preliminary Design Review, and a Critical Design Review, all of which are configured along the lines of those currently in use in industry. Risk management plans and integrated program schedules must be created and continually updated through the course of the semester. Teams are not scored on how well they stick to their original schedule. Instead, assessment is based on how well they modify their plans as the project evolves and requirements change. Additionally, guests from industry participate in the reviews and fill out Request for Action forms, or "chits," similar to those used in government contract reviews in industry. The student teams are not scored on how many chits their presentation generates. Rather, they are monitored on how well they address, and close, each of the action items that were raised, before the end of the semester. Additionally, intra-team peer reviews and participation reviews by the professor are utilized to judge the level of effort that various team members put into the group project. Only 10% of the course grade is based on traditional assessment approaches, the remaining 90% is based on industry based assessment styles. The paper will describe how the instructor has configured the assessments of his Capstone class to represent industry, giving students a taste of how the world will work after graduation. Additionally, how such an assessment approach correlates with ABET criteria will be discussed.

1. INTRODUCTION

In 2004, one of the authors made his move to academia after 25 years in the aerospace industry. In his capacity as Manager of Dynamics & Acoustics and later as Chief Design Engineer, he had the opportunity to work on a number of high profile commercial and military projects, including such Collier Award winning programs as the Global Hawk surveillance aircraft, the V-22 Osprey tiltrotor plane, the 578-DX Propfan, the record setting Citation X business jet, and the Joint Strike Fighter. He is, therefore, well acquainted with how successful engineering design projects are being conducted in industry.

Upon his career change, he assumed the duties of Assistant Professor of Mechanical Engineering Technology (MET) at Indiana University / Purdue University at Indianapolis (IUPUI). Due to his recent experience in the aforementioned design projects, the MET Department assigned him to teach their Capstone Design course, also known as the Senior Design Project.

The class format had always involved assigning students to teams and giving them a comprehensive design task to complete by the end of the semester. These teams function in much the same way that an Integrated Product Team (IPT) does in industry. Therefore, it seemed natural to the new instructor to revise the evaluations of these teams to more closely resemble the way that design teams are evaluated in the professional engineering world that he had just left. Thus began the transition of this particular Capstone Design class to industry based assessments.

2. PROJECT ORGANIZATION

The first topic covered in the lecture portion of the class is project scheduling. Many students who have not been in industry typically assume that the primary objective in a design project is to achieve the best possible design. The more cynical among them may assume that cost or profit is the main driver. Most will be surprised, however, when they are told that schedule is frequently the biggest driving force on today's major design projects. Their introduction to the topic includes examples of engineering contracts that included rather large financial penalties for missing major program milestones, or financial incentives for beating contracted deadlines. An example of the former was the Joint Strike fighter program, in which every one of the five major partner companies was subject to financial penalty if certain program deadlines were not met. This created huge pressures to make sure that designs were finished on time and hardware was delivered on schedule. An example of the second was a major highway design and construction project, known locally as the "I-65 Hyper-Fix," which tied up traffic throughout Indianapolis. The construction firm's contract contained both financial penalties and financial incentives if they missed or beat the contracted schedule. When they beat the schedule by over a month, they pocketed several million extra dollars. These types of situations make it paramount that today's engineering teams understand the time it will take them to design and complete a project. For this reason, project scheduling has become a major factor in planning design team efforts in industry.

With only one semester to complete their senior projects, and with graduation on the line, creating and maintaining a schedule is just as important to the Capstone Design students. Thus their assignment during the first week of the semester is to consider all the tasks that they must accomplish and plan them into a schedule which meets all the class milestones. This involves considering the time each task will absorb as well as considering what tasks can be attacked in parallel versus which ones must be done sequentially. Project scheduler software which provides the ability to link activities in various manners is not required, but proves to be extremely handy. The advantage to linked tasks is that a modification to any single task immediately shows the cascading effect on the entire design effort.

Just as an industry project team ought to be expected to show corporate management how well they are tracking with schedule on a weekly basis, the student teams are expected to update their project schedule each week and submit a copy to the professor. It must be recognized that the activities of a design project will almost never fall exactly on schedule. The key for students is not to always be perfectly on schedule, but rather to always know exactly where they are relative to plan. This allows the team to make adjustments, keeping continuously aware of the status of their team's schedule in the dynamic environment of the design project. Because of this, the portion of the course grade that is related to the schedule is not assigned for staying on schedule, but for always knowing where the team is on the schedule and for making schedule adjustments to keep abreast of the project's progress.

3. TECHNICAL RISK MANAGEMENT

The use of Technical Risk Management concepts has become more and more widespread throughout industry, especially in high-tech fields like aerospace. Many projects, both commercial and government, are now requiring that a risk management plan and process be in place from the earliest stages of a program. Typically this has been an area that has received little attention in the university classroom. In fact, a recent national survey of faculty involved in Capstone Design classes, as reported by James Conrad and Yesim Sireli, indicated that the least successful performance area for student teams was the "ability to foresee potential risks involving the project and create contingency plans. (Conrad, 2005)"

The IUPUI MET Capstone students get a thorough introduction to technical risk concepts. They are required to build a list, or register, of project risks and conduct an assessment, ranking the risks on the basis of probability of occurrence and severity of impact. These steps are all outlined in a previous paper presented by one of the authors at an ASEE conference in 2005 (Hylton, 2005). The next step in the process is to construct a risk mitigation plan for all of the higher level risks. Part of each team's ongoing project effort is to execute the mitigation plan. Additionally, teams are expected to continuously evaluate the evolving design for additional risks that may become apparent. These new items should be added to the risk register, assessed, planned for, and mitigated as the project moves forward.

In industry, design teams are frequently expected to present reviews of their risk plans and mitigation activities to management, the customer, and perhaps even the certifying agency on a regular basis. In the IUPUI Capstone class, once the risk register is completed, bi-weekly updates are expected to be submitted to the instructor, demonstrating that the teams are paying attention to their high risk items. Teams are graded on their effort to identify and evaluate initial risks, on their plan that will reduce the high risks, and on their execution of that plan. The team's ability to maintain their project's schedule and reduce their risks constitute a part of the team participation portion of the course grade.

4. TECHNICAL REVIEWS

The technical presentation or design review is one of the most pressure filled situations that today's design engineer must prepare for. Reviews may be conducted for groups as small as a handful of company managers. Or for major programs, they may include audiences of up to a hundred people with representatives from management, the customer, partner companies, and certifying agencies. Thus the ability to generate a comprehensive presentation of the design team's efforts is of paramount importance.

For the Capstone Design class in question, three review dates are set at the beginning of the semester. A Concept Readiness Review (CRR) is scheduled roughly one-third of the way into the course. A Preliminary Design Review (PDR) occurs two-thirds of the way along, and a Critical Design Review (CDR) is conducted on the last day of class. The objectives of the CRR, or first review, are as follows:

1. Give design objectives and requirements
2. Define secondary requirements derived by the design team
3. Present the concept that the design team has developed
4. Briefly cover any pertinent aspects of concepts considered but rejected
5. Display conceptual sketches or diagrams
6. Explain how the concept will meet the requirements from 1 and 2 above
7. Present preliminary cost data, risk management analysis, and project schedule

The teams are expected to prepare professional caliber presentations. They are directed to consider that the audience may have minimal background on the project. However, they should assume that the reviewer's assessments will determine whether or not the team receives authorization to proceed.

Once the team has received CRR approval, they must move forward with developing the preliminary design concepts. These will be presented at the PDR, or second review. This review must again cover objectives and requirements and must then proceed to present preliminary design details, including pertinent preliminary hand calculations, assembly drawings or diagrams, and a well developed description of how the design meets objectives and requirements. Naturally, updated cost, risk management, and schedule details are expected. For this Preliminary Design Review the instructor brings in outside reviewers, preferably from an industry related to the design tasks for the semester. The student teams are thus faced with audience members who know little or nothing about the project. This requires that the presentation be thoroughly developed so as to not lose or confuse the new reviewers. These industry experts are asked to fill out Request for Action (RFA) forms which the instructor modeled from his industry experience. These RFAs, often referred to in industry as "chits," will be discussed more in a subsequent section.

The final presentation, or Critical Design Review occurs at the end of the semester. For this review it is expected that teams will present a thoroughly developed design including solid element models and detailed component drawings. Additionally, pertinent stress, strain, dynamic, or heat transfer analyses are required using finite element models developed from the solid models. The design's ability to meet the project's objectives and requirements must be shown. A final status must be given on costs, risk, and schedule.

In addition to the in-class presentation, a final report must be submitted at the CDR. This report is intended to include adequate detail for either a project manager who missed the presentation or for an engineer who must pick up the design a year later without benefit of previous involvement or access to the original designers. The report and all presentations are expected to be team efforts, just as they would be if conducted by an IPT in industry.

As previously mentioned, the outside reviewers at the PDR fill out RFA forms or "chits." These are intended to be requests for additional research or analysis or consideration of additional work that may be required. They may also point out potential problems seen by the reviewers or suggestions that additions or alternatives be investigated. In each case, the design team must address the reviewer's RFA with a thorough discussion and supporting analysis. The response must be submitted to the professor for closure, and any pertinent changes or additions must be incorporated into the final presentation and report. This activity completes the remainder of each team's participation score.

5. INDEPENDENT VERSUS TEAM WORK

It will have become obvious by now that the class grades are predominantly based on team work. Team weekly participation (consisting of the schedule maintenance, risk management activities, and RFA activities) accounts for 20% of the course grade. The CRR presentation counts for 20%, the PDR presentation is 20%, and the CDR presentation and written report together are 30%. This is consistent with many industrial Integrated Product Teams where merit increases and bonuses are tied to the project results and thus dictated by whole team performance. However, individual effort is still recognized in industry and must be evaluated in the classroom. Therefore, in the Capstone Design class each of the team scores is multiplied by an individual participation factor which is derived from peer evaluations filled out by other members of the team, coupled with instructor observations on individual participation effort.

That comprises 90% of the individual student's course score. The remaining 10% comes from the IUPUI MET Department's Senior Assessment Examination (Rennels, 2003) which was created in conjunction with ABET program assessment initiatives. Graduating seniors are required to take this exam as part of the capstone course and their scores count for the final 10% of the course grade.

6. MEETING ABET OBJECTIVES

Since this class is among the last taken by MET students about to graduate, it makes sense to acquaint them with processes similar to what they will soon encounter in industry. For this reason, the department is pleased with the current concept of the course. As part of an ABET accredited program, this course utilizes multiple assessment tools for evaluating summative student performance against the ABET Program Outcomes a-k.

The matrix shown in Table 1 indicates how the authors believe the described course relates to the ABET outcomes, using a format suggested by Felder and Brent (Felder, 2005). The matrix maps the course into the following ABET Program Outcomes:

a. Demonstrate mastery of knowledge, techniques, skills and tools of the discipline
b. Apply current knowledge to emerging applications
c. Design and conduct experiments and analyze and interpret experimental data
d. Creatively design systems, components, and processes
e. Function effectively on teams
f. Identify, analyze, and solve technical problems
g. Communicate effectively
h. Recognize the need for and engage in life long learning
i. Understand professional and ethical responsibilities
j. Understand the impact of solutions in a professional, societal and global context
k. Exhibit commitment to quality, timeliness, and continuous improvement

TABLE 1 – Correlation of Course Outcomes with ABET Outcomes

Course Outcomes address the ABET Outcomes: 1= slightly, 2 = moderately, 3 = substantively

Assessable Course Learning Objectives	ABET Outcomes										
	a	b	c	d	e	f	g	h	i	j	k
1. Construct and maintain a project schedule											3
2. Create a concept meeting specific requirements		2		3							
3. Identify & evaluate risks to project completion	1	2				2			2	2	
4. Design risk mitigation plan using engr. skills		2	2	2		2					
5. Execute the mitigation plan using engr. tools	3	3	2	1							
6. Develop prelim. design meeting requirements	2	2		3		2					
7. Address RFAs from reviewers using analysis	3	2	2			3					
8. Create detailed design using engr. tools & skills	3	2		3							
9. Present CRR, PDR, CDR and final report							3				
10. Conduct all activities as part of a working team					3						
11. Senior Assessment	3					3					

As can be seen, there is a strong correlation between the ABET outcomes and the various outcomes of the Capstone course as taught at IUPUI in MET. A number of the evaluations shown are based on team activities. However, since the students are required to function as members of a design team, yet are individually evaluated on their level of input to the team's outcome, the final course grades for individual students are, in fact, based on both team and individual performance.

7. CONCLUSIONS

It is possible to give approaching graduates a taste of the real engineering world that they are about to enter, by introducing industry based assessments into the Capstone Design course. In addition to giving students an industry perspective, several aspects of this will also help them in the design and evaluation of their senior design projects. Finally, the course topics can be mapped effectively to the ABET outcomes criteria which are ultimately designed to reflect what industry (the primary constituent group) wants from our graduating students in order to meet our Program Educational Objectives.

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