Designing Outside the Capstone Box: An Innovative Capstone Course for Technology Students

Pete Hylton
Indiana University Purdue University Indianapolis

The Mechanical Engineering Technology (MET) program at Indiana University Purdue University Indianapolis (IUPUI) caters to a unique and diverse population of students. The students entering the program are divided between individuals fresh out of high school and preparing to pursue degrees full-time with an expectation of completion in four years and those who have already begun careers in industry and are seeking to improve their opportunities for advancement and whose expectation for graduation is further in the future. Thus, in catering to this diverse community of students, IUPUI's MET program has experimented with some innovative, and non-traditional, approaches to course design. One area where this innovation has proved noteworthy is in the design of the MET capstone course, where three different formats are employed in an effort to meet the needs of the student population. This paper discusses one of those options, aimed at enhancing program management skills, which stretches the boundaries of capstone pedagogy and tradition.

Corresponding Author: Pete Hylton, phylton@iupui.edu

Introduction

IUPUI is an urban campus, located in downtown Indianapolis, Indiana. Forty years ago, the university began with a small, predominantly commuter, undergraduate program meeting the needs of working individuals looking for ways to enhance their education and skills. It has grown to a campus of over 30,000 students and has become one of the leading urban research universities in the country. The IUPUI School of Engineering and Technology houses some of the most unique programs in the country (including engineering programs and technology programs in both biomedical and motorsports engineering), and the campus is now the selected destination of a significant number of traditional undergraduates, creating an interestingly mixed student demographic. Many of the older, non-traditional, students are unable to manage full-time class work while holding down a full time job, and thus may require six or eight years to complete all their credits for a BS degree in MET.

One curriculum area that has experienced innovation is in the design of the MET capstone course, where three different formats are employed in an effort to meet the needs of the student population. Two of these options follow a fairly traditional format for a capstone course in a technology program. They require students to envision, plan, organize, analyze, synthesize, design, and frequently construct, a physical design project. The primary difference between these two options is whether there is a rigid classroom and laboratory environment that facilitates the activity, or whether the activity is more self-directed by the students with the professor role being one of oversight rather than direct management and supervision. However, it is the third option that moves beyond the normal boundaries of capstone pedagogy and tradition by focusing more on the program management aspects of design.

A significant percentage of the IUPUI MET students already work in design or design support careers in industry while they attend the university. They often already have a significant amount of experience in conceptualizing, analyzing, and completing design projects by the time they reach the equivalent of their senior semester. They will also have encountered design projects of one form or another in several of their lower level courses, the inclusion of which, has been deemed by the faculty to be a key factor in the education of technology students. These soon-to-be graduates are more likely to advance within their existing careers if they can show their corporate management that they have the program management skills necessary to lead project teams in industry.

A Capstone Course Should Be What Students Need It To Be

Other schools have experimented with multiple paths for capstone involvement[1] and many have recognized that in addition to the ability to execute traditional design skills, there is a need for students to be able to balance a project's technical and non-technical requirements. This requires dealing with non-technical issues including time management, scheduling, costing, coordination, team dynamics, formal presentation, informal communication, and professional ethics.[2] A number of universities have recognized, like IUPUI, that "engineers are now faced with management responsibilities at their current positions, or promoted to higher positions" where "they need to have Program Management skills to manage various aspects of a project-driven technological organization."[3] Their roles combine managing engineering problems, human factors, time and resource constraints, and financial issues on a cross-functional team. A variety of schools have recognized the need for approaches that are flexible and innovative rather than concentrating all the development of both technical and non-technical skills into a single final year project class that provides insufficient time to fully develop either skill set.[4]

It is recognized that that there is a lack of consensus on what constitutes a quality capstone experience and the deliverables and documentation that should serve as evidence of a such an experience.[5] Having spent a number of years in industry, including quite a few years leading design teams as an engineering manager where he did very little design of actual parts, the author saw the need for a different approach for these students. He decided to move one option of the IUPUI MET capstone course outside the box of tradition, focusing more on the program management skills that this segment of his student population was more likely to need. The author considered what he had done as an engineering manager, and came to the realization that he had still been designing....by designing a design process.

Designing Outside The Capstone Box

Under encouragement from the university to investigate new scheduling formats to reduce campus classroom and parking lot crowding, and in response to the need of non-traditional students working full time jobs, the new course was constructed to utilize a lesser number of class meetings, but some very long and very intense classroom days. Further, the professor went out on a limb, rarely even considered in the engineering and technology teaching arena, and incorporated role-playing activities in the classroom. Lastly, believing that students gain most from experiential learning, he turned himself into a facilitator more than a teacher, forcing the students to self-learn, share experiences, develop innovative solutions, and occasionally fail, because some of life's greatest lessons come in recovering from failure. The new course was not only outside the box, it was so far away, that students quickly began to wonder, "Box?,… What box?,…. Has anybody even seen a box around here?"

At 8:00 am, on the first day of class, the professor walks in on the unsuspecting students and congratulates them on being selected by their employer, Fly By Night Aerospace, for the extremely important job of preparing a proposal for the new Anastazi Helicopter program. He introduces himself as the chief design engineer for the project and they are to be his engineering staff. They are then presented with a complete Request for Proposal document, and a stack of pseudo-realistic design and organizational data for the Fly By Night corporation. They have until the end of the day to prepare a complete proposal including design concept, design organization, schedule, budget, detailed technical risk management assessment, and much more, all of which would be expected in a real industry proposal. While the professor is constantly present throughout the day as a source of information, advice and occasional guidance, it is up to them to figure out how they, as a team, are going to complete this task. With occasional gentle nudging, the design, and the proposal take shape, until sometime after supper that night, an exhausted team usually presents a reasonably well thought-out proposal document.

The second day the team is congratulated on winning the contract. Then it is announced that Congress has cut the budget, the Pentagon has changed the schedule, and the company has announced a layoff. So just how are they going to produce this design now? Thus begins a day-long rollercoaster ride of changing customer requirements, budget cuts, resource allocations, schedule pressures, human resources dilemmas, ethics conundrums, team building exercises, and all sorts of other issues the students had never encountered, nor even dreamt of, before. Every piece of the program management experience is drawn from actual events that transpired during the professor's time as Chief Design Engineer for the Comanche helicopter engine program and as Integration Manager for the Joint Strike Fighter while working for Rolls-Royce Corporation.

Days three and four integrate the capstone with the other engineering technology courses as the students perform a detailed risk analysis defining hand calculations and computer analysis to be performed on their design. They do performance trade studies to optimize parameters and perform load analysis, failure analysis, stress calculations, and probabilistic design calculations to determine the reliability of parts. As the week-long class concludes, they also take the school's mandatory senior assessment examination, and they discuss ethical and human resources issues in an engineering context. After the last class meeting individual student papers are still due, each applying MET principles from the plan of study and concepts from the capstone course to real world problems.

Reaction To The Course

Student reactions vary throughout the course as they face all the challenges of managing a real engineering program. Most have never encountered a classroom environment anything even remotely close to this. As engineering students, they are not necessarily the most flexible and adaptable to new ideas and approaches. Nonetheless, the clear majority appreciate this unique learning opportunity. Actual student comments at the end of the course make this clear. One student expressed it like this, “Over my career as a student, I have taken many courses to prepare me for a job in engineering. So far, each class has taught me how to perform or deal with a specific task. However, none of my previous classes alone has prepared me to deal with the entire picture in the same way as MET414.” Another said, “MET414 has certainly been one of the classes that has given me a chance to grow and excel as an engineer and as a person. I can think of many situations where MET414 could have made a difference in a certain situation. Now I hope to take what I have learned and gained in MET 414 and use it in my profession because you never know what tomorrow has in store, and if this class is any indication, then ‘bring it on’.” The IUPUI end-of-semester student evaluation has seen the class average score as high as a perfect 5 out of 5, meaning that every single student in that particular group responded to the evaluation survey by giving the class a perfect score. In four semesters of offering this format, the average evaluations scores have been 4.3, 4.6, 4.7, and 5.0 (all out of 5). While the new course is popular, enrollment across the three different IUPUI MET capstone formats shows that students are still nearly evenly divided in the format that they choose.

Industry Advisory Board members supported the increase in program management experiences into the capstone. But some faculty thought it did not fit the traditional mold of a capstone design course. However, even the Accreditation Board for Engineering and Technology (ABET) is changing its expectation of exactly what a technology capstone experience is. The proposed wording for the update of criteria for technology programs reads “Capstone or other integrating experiences that draw together diverse elements of the curriculum and develop student competence in focusing both technical and non-technical skills in solving problems are required in baccalaureate programs.”[6] Interestingly, the words “design” and “project” do not even appear in that proposed wording. That leaves the field open for such innovative “capstone experiences” as the one described here. To verify appropriate course content, the professor who designed this new IUPUI course has generated a matrix of the well known ABET a-k outcomes[6] (see Table A) for technology compared against the university’s Principles of Undergraduate Learning, or PULs,[7] (see Table B) and defined a set of course outcomes, which make it clear that the course can meet both sets of criteria.

Table A: ABET Program Outcomes a-k[6]

a.	Mastery of knowledge, techniques, skills and tools
b.	Apply knowledge to emerging applications of math, science, engineering and technology
c.	Conduct, analyze, and interpret experiments and apply results to improve processes
d.	Apply creativity to the design of systems, components or processes appropriate to the program
e.	Function effectively on teams
f.	Identify, analyze and solve technical problems
g.	Communicate effectively
h.	Recognize the need for life-long learning
i.	Understand professional, ethical, and social responsibilities
j.	Respect diversity and understand global issues
k.	Commit to quality, timeliness, continuous improvement

Table B: Principles of Undergraduate Learning[7]

I.	Communication and Qualitative Skills	
	a.	Express Ideas Effectively
	b.	Comprehend, Interpret, and Analyze
	c.	Communicate Orally
	d.	Solve Qualitative Problems
II.	Critical Thinking	
	a.	Analyze Complex Issues
	b.	Synthesize Information
	c.	Evaluate Relevance of Data
	d.	Solve Challenging Problems
	e.	Generate and Explore New Questions
III.	Integration and Application of Knowledge	
	a.	Enhance Personal Lives
	b.	Meet Professional Standards
	c.	Further Societal Goals
IV.	Intellectual Depth Breadth and Adaptiveness	
	a.	Display Knowledge in at Least 1 Field
	b.	Compare Different Disciplines
	c.	Modify Approach based on Situations
V.	Understanding Culture and Society	
	a.	Compare and Contrast Diversity
	b.	Understand Global Concerns
	c.	Operate Civilly in Complex World
VI.	Values and Ethics	
	a.	Make Informed Choices
	b.	Appreciate Beauty and Art
	c.	Understand Ethical Principles

The specific course outcomes, all of which are met in the design of the course, are as follows:

1. Evaluate inter-related technical and non-technical aspects of an engineering program.
2. Integrate the various diverse elements of a technology program; determine the appropriate program requirements; and design an appropriate system or process for the program.
3. Understand the inter-relationships of different types of requirements derived from different aspects or disciplines within a program.

4. Evaluate and synthesize data of various types, and conduct parametric studies on that data to develop multiple possible solutions and evaluate those solutions to make informed decisions and arrive at reasoned conclusions regarding the best choices.
5. Use a variety of skills and knowledge to address challenging problems, of both a qualitative and a quantitative nature, related to program requirements, within the context of professional standards and competencies.
6. Modify responses, plans, and solution approaches to various problems based on changing requirements and situations.
7. Communicate effectively in both oral presentations and written presentations; in both one-on-one and group settings.
8. Function well in a team environment, with various members of the team serving in a variety of capacities both within and outside their formal discipline.
9. Operate professionally and with civility in complex and highly pressurized situations.
10. Make informed and appropriate decisions in situations involving human interaction and ethical complexities; evaluate the inter-connectedness of issues affecting local (i.e. job) versus the global (i.e. societal) viewpoints; and consider all consequences of those choices.

When these course outcomes were mapped to the a-k outcomes and the PULs, the resulting coverage of topics is shown in Figure 1, with the numbers correlating to the strongest course outcome connections.

There is inadequate space in this paper to extensively detail the assessments used to examine the course outcomes. However it should be noted that they have been based on industry style assessments[8] and students have responded positively and successfully.

Conclusions

With the changing engineering and technology environment that today's graduates face and in a setting where students exhibit a diverse demographic, it is to the advantage of both the university and the student to offer a variety of capstone experiences, affording the student an opportunity to pursue the one which is of most benefit to his career situation. This means that providing opportunities that are heavily program management oriented yet supported by appropriate design and analysis skills are as viable as courses providing culminating design experiences with the additional of supporting program management aspects. There is a place on some campuses for both, and there is definitely room to think outside the traditional capstone box when designing courses for the new generation of technology graduates.

Figure 1

Map of Course Outcomes to ABET a-k and PULs

ABET	a	b	c	d	e	f	g	h	I	j	k
PUL's											
1a							7				
1b											
1c					7,8		7				
1d											
2a		1,3		1,3		2,4					1
2b		1,3		1,3		2,4		10			4
2c		1,4		3,4		3,5					
2d		5,6		5,6		5,6					4,6
2e	4,6	4,6	4								4
3a											
3b	9			9					9,10	9,10	4,6
3c									9.10		
4a											
4b	4,5			3,6	5,8						
4c	6,2			3,6	8	3,6		2,10		6,10	6
5a										9,10	
5b								9,10	9	9,10	
5c					8,9		7,10		9,10		
6a									9	9,10	
6b											
6c									9	9	

References

1. Small, R., and Santacroce, R., "A Comparison of Capstone Design Course Choices for Undergraduate Industrial Engineering Students: Requirements and Advantages of the Integrated Product and Design Program Versus Senior Design Project," *Proceedings of the Engineering Capstone Design Course Conference*, June 2007.
2. Fuh, J., Lu, L., Quan, C., and Lim, S., "Product Design for Industry: The NUS Experience," *Proceedings of the Engineering Capstone Design Course Conference*, June 2007.
3. Conrad, J., and Sireli, Y., "Learning Project Management Skills in Senior Design Courses," *Proceedings of the ASEE/IEEE Frontiers in Education Conference*, October 2005.
4. McDermott, K., Nafalski, A, and Gol, O., "Project-based Teaching in Engineering Programs," *Proceedings of the ASEE/IEEE Frontiers in Education Conference*, October 2007.
5. Marchese, A, et al., "Toward a Common Standard Rubric for Evaluating Capstone design Projects," *Proceedings of the Engineering Capstone Design Course Conference*, June 2007.
6. ABET Technology Accreditation Commission, "Criteria for Accrediting Engineering Technology Programs," October 31, 2009.
7. IUPUI Institutional Portfolio, retrieved from: http://iport.iupui.edu/selfstudy/tl/puls/
8. Hylton, P., "Industry Based Assessments in an Engineering Technology Capstone Design Course," *Proceedings of the ASEE IL/IN & North Central Joint Section Conference*, March 2006.