AC 2009-136: A COMMON STANDARD FOR ALL: USING A BUSINESS-ORIENTED APPROACH TO CAPSTONE DESIGN

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Introduction

ABET EAC Criterion 5 states that "[s]tudents 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 appropriate engineering standards and multiple realistic constraints." However, the definition of what constitutes an "appropriate engineering standard" has been subjected to various interpretations, both wide and narrow. Arguments have been made that all capstone design projects must include engineering standards from the appropriate professional society: IEEE Standards for electrical and computer engineers, ASME Standards for mechanical engineers, and so on. However, members of the educational community have objected to this approach based on the potentially exorbitant costs involved and that it serves as a constraint to project selection, especially when given the opportunity to work on industry-sponsored projects. Additional objections are raised over the narrow scope of such a position, as working engineers encounter a wide variety of standards beyond those set by professional societies.

There is a definite need for standards education, and for all engineering students to experience conforming to a standard as part of a design process – but it does not necessarily need to be a design standard. It is our contention that internal project management standards developed in the business community for use with engineering projects constitute "appropriate engineering standards." This paper presents the approach undertaken by the Electrical & Computer Engineering and Computer Science (ECCS) Department at Ohio Northern University that provides a common foundation to the application of standards in team-based capstone design.

Background

The College of Engineering at Ohio Northern University has had a working relationship with Marathon Petroleum Company for many years, with Marathon Petroleum often sponsoring a couple of projects in the ECCS Department each year. Part of this collaborative effort is manifested by the Engineer-in-Residence (EiR) Program[1] that was initiated in 2001. This program provides a co-op experience on campus through the establishment of a professional workspace located within the engineering building at Ohio Northern University, including an office for the EiR and four cubicles for use by engineering students that are employed as co-ops by Marathon Petroleum. The EiR serves as the on-site mentor and supervisor for these co-op students who typically work 15 hours per week in the EiR office. Having the co-op experience on campus allows the students in this program to remain full-time students, which allows them to graduate with their entering cohort. As part of the agreement between Marathon Petroleum and Ohio Northern, the EiR is available for use as a professional resource by the departments within the College of Engineering. This allows instructors the opportunity to have a practicing professional engineer discuss work-related issues and processes in the classroom.

The ECCS Department was created via the merger of two departments, containing a total of three degree programs, in 2001. One of the issues faced by the new department was the differences in the capstone requirements between the programs[2]. In the former Electrical and Computer Engineering Department, senior design consisted of a yearlong, three quarter sequence of courses. The first course focused on the characteristics of engineering design projects and the development of a project proposal, the second course focused on a comprehensive project, and the third course focused on the presentation of technical information from the project. In comparison, the former Computer Science Department had a two-quarter sequence for the senior project, where the first course examined the product life cycle as a vehicle for the production of a problem definition, which was then designed and implemented during the second course. Although both programs utilized team-based projects, this disparity posed a serious problem in and of itself, as having two unequal paths for the fulfillment of the senior design process could harm the esprit de corps of the ECCS student body and potentially affect the relationships between the engineering and computer science faculty. To address these and other observed shortcomings, several changes were effected in the senior design sequence: the curricular structure and operational requirements were made the same for all three programs, design concepts and team management skills received greater emphasis, and rigorous methods were developed to evaluate performance.

While these changes did have an overall positive effect, the new department's unified senior design sequence also allowed the introduction of a wide variety of projects across the programs, since students from different majors could readily work together as a team while all meeting their graduation requirements. Additionally, with this positive attribute came a new concern for the department to ensure that all students were properly exposed to design standards. The unified senior design approach was presenting project management standards at the beginning of the senior year, but not all groups were uniformly following its practice. The concept of utilizing a project management approach for capstone design is hardly new; however, one of the questions posed by Dym *et. al* in their seminal paper on engineering design[3] is with regards to how authentic should project-based learning experiences be compared to industry design experiences. In the ECCS Department, there was no formal relationship tying the senior design process to an industrial project management standard. Another area where authenticity was lacking was that students were not subject to any consequences incurred by failure to adhere to the process and its timeline. Additionally, as noted by Conrad and Sireli[4], "[w]hile many universities teach some [project management] concepts, guidelines for faculty to follow are sparse." It became apparent, from both assessment data and senior exit interviews, that better guidelines for the management of senior design projects were needed by both students and faculty, and that there would be greater perceived relevancy – and therefore greater buy-in – if an actual industrial design process was adopted for this purpose.

The Marathon Petroleum Framework: A Corporate Design Standard

The design experience in the ECCS Department at Ohio Northern University culminates in a year-long senior design sequence, which intends to provide a comprehensive experience involving exposure to professionals and clients, realistic constraints, team work, schedules and budgets, responsibility, and careful evaluation. A standard engineering design process developed at Marathon Petroleum Company is now used as the framework for all senior design projects. The Marathon Project Management Process (MPMP) Framework is a set of proven methods and tools for planning and executing projects; all engineering projects must adhere to this framework. It focuses on front-end loading, which is at the beginning of the project when a team has the greatest influence over the success of the project. Projects under the framework go through five phases to divide projects into smaller logical units to increase manageability: conceptual, feasibility, definition, implementation, and start-up / close-out. Between each phase are specific decision points that provide more focus on team effort and improve the quality of decision making. Figure 1 is a scan of a wallet-sized information card from Marathon Petroleum Company that is distributed to all seniors, and that provides an outline of the MPMP Framework. By using the MPMP Framework, we guarantee that all senior design groups deal with an appropriate engineering standard that is common to all groups, regardless of the nature of the individual project.

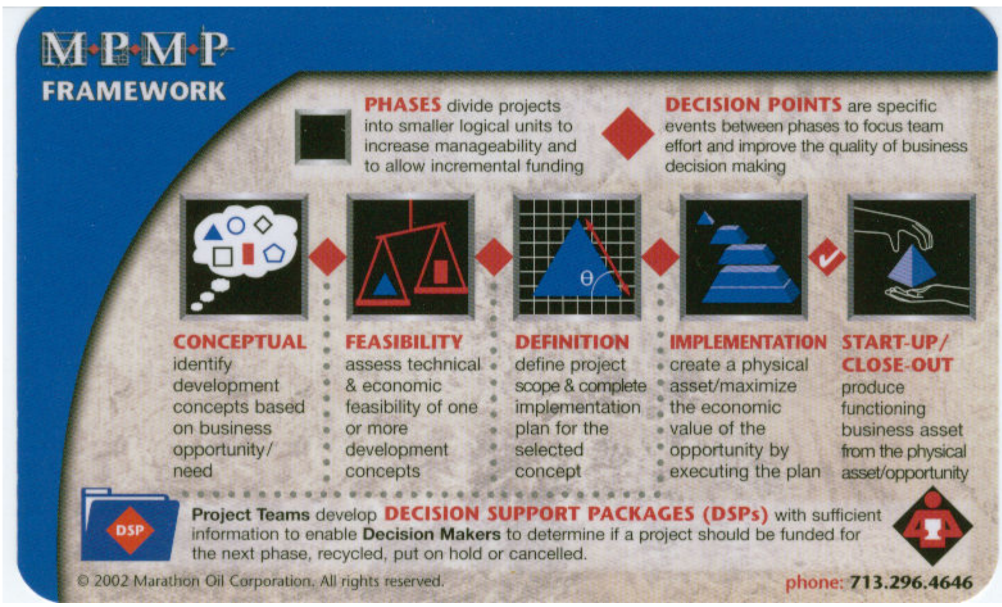

Figure 1. The MPMP Framework Reference Card.
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The MPMP Framework is integrated into the senior design sequence as follows. In the conceptual phase, the department solicits project proposals prior to mid-April of the junior year. A number of projects are sponsored and/or provided by external industrial clients, whereas other projects are proposed by faculty members of the department. Proposals are generally in the form of a one- or two-paragraph statement that identifies an opportunity or a need and puts forth a concept that can address that opportunity or need. At the first decision point of the process, represented in Figure 1 by the diamond between the conceptual and feasibility phases, all submitted project proposals are first reviewed in a department faculty meeting to ensure that they have an appropriate technical level of complexity. The approved project abstracts are then distributed to the junior students. Each student is asked to choose three project proposals and submit them in ranked order of preference. This feedback is reviewed by the faculty for their comments, after which the department chair and senior design coordinator assign students to appropriate project groups based on student capabilities, project needs, and placement preferences Each team is advised by a faculty member and students start interacting with their faculty project advisor prior to the end of the junior year.

The first course in the senior design sequence is the Senior Design Seminar (ECCS 404), which is offered in the fall quarter. The first portion of the course involves the feasibility phase of the Framework. Most of the students have previously attended the annual Engineering Futures presentation organized by our local Tau Beta Pi student chapter that focuses on Team Chartering. A Team Charter based upon the material from this presentation is constructed to specify the skill sets of, and specific roles for, each team member. Included with the Charter are a set of performance evaluation criteria and a mechanism for conflict resolution. Next, the Problem Identification Statement is developed. Included are specifications, designs, evaluations, and deliverables. During this period the students define the problem, identify the need, conduct a research survey, gather information, propose and evaluate design alternatives, and construct a time schedule for completion of the project. They also individually study the impact of realistic constraints such as economic, environmental, social, political, manufacturability, *etc*., on their design, and identify any relevant technical standards regarding the design topic.

The second decision point occurs midway through the 404 course. The faculty advisor reviews the team charter, problem identification statement, and realistic constraints with the team during one of their weekly meetings. With the faculty advisor's approval, the team progresses to the definition phase of the Framework. A written proposal that summarizes project feasibility, presents an implementation plan, and establishes the scope of the work to be accomplished is developed. The team members, in consultation with the faculty advisor and with the consent of the department chair, select members of the Project Review Board (PRB). One member of the PRB is the faculty advisor; the other PRB members are drawn normally from the department faculty and such that their expertise is relevant to that particular design topic. Based on advisor feedback, group members will merge their individual assessments of the realistic constraints into one position for incorporation into the written proposal. Once the preliminary design concept for the project is complete, teams provide written project proposals and present project proposals orally to their project advisory board, which constitutes the third decision point. The PRB members evaluate the project based on both the oral presentation and written report and provide suggestions to improve the quality of the design proposals. Students are then ready to progress to the implementation phase, where they order the components and start the design project.

The next course in the sequence is Senior Design (ECCS 405), which is offered in the winter quarter. Student teams continue in the implementation phase, working closely with their advisors on their design project while employing all steps in the engineering design process in the production of a working prototype. The end of the quarter constitutes the fourth decision point. Teams are required to submit a written progress report to the members of their PRB and give an oral presentation featuring a demonstration of the working prototype of the deliverable for the project. By requiring a demonstration of a working prototype at this point, the department insures that there is sufficient time in the process for revisions to be made, thereby supporting the iterative nature of real-world design. Appropriate incentive is provided to the students by requiring the successful demonstration of a working prototype in order to be eligible to receive an 'A' in the course.

Engineering Technical Communication (ECCS 406) is offered in the spring quarter. This final course in the sequence is used to handle the start-up / close-out phase of the project. During this time modifications and final touches are made to the projects; however, most of the work in this course is focused on the documentation deliverables. Students are given the opportunity to present their senior design in a variety of formats. Primary emphasis is placed on a professional quality written technical report, which includes detailed design documentation, and is graded by a team of senior design team faculty. Typically, the team of faculty consists of approximately half of the department's faculty, and includes representatives from all three majors. An oral presentation of their completed project to their peers and faculty is also a major course component. Teams also compete in two poster presentations, one judged jointly by the faculty, members of the local IEEE regional section and the department's Program Working Groups; and another by members of the College Advisory Board. Finally, each team develops a web site for their project that serves as a document repository that is hosted on the department web site.

To summarize, Ohio Northern's ECCS Department has taken its four-quarter approach to senior design and aligned it to the MPMP Framework to provide students with exposure to a industrial project management standard. Figure 2 provides a correlation between the project phases, the decision points, and the academic calendar. Marathon's Engineer-in-Residence presents the framework to the students at the beginning of this process, providing further credibility and practicality of the department's approach.

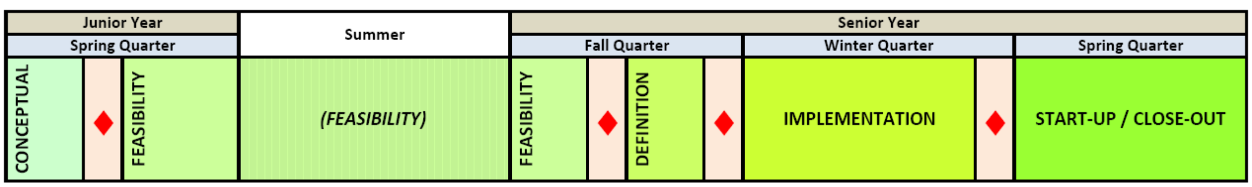

Figure 2. Correlation of MPMP Framework to academic calendar.

Results

The MPMP Framework approach was used for the first time during the 2007-2008 academic year. The most noticeable result was with regard to the status of the prototypes developed by each group. In previous years, there was little incentive to develop a working prototype by the end of the capstone, and so it was often the case that the prototype lacked full functionality, a result that was also observed by Conrad and Sireli at their institution[4]. Given that in an authentic workplace design experience a team suffers consequences for substandard performance, it was stipulated that a letter grade reduction would be incurred if a demonstration of a prototype could not be presented by the fourth decision point at the end of the second quarter course. This prototype does not need to be completely functional nor polished, but it should meet compliance with the majority of the design specifications listed in the fall quarter proposal. For the first time in recent history, all prototypes were successfully demonstrated. Part of the reason for this success is that the adoption of the Project Review Board allowed for greater interaction between faculty and the capstone teams. Under the previous format, several capstone teams each gave an oral presentation of 10-12 minutes in length to an audience of both students and faculty, followed by a three-minute question and answer period. The shortness of this time slice per group, plus the pressure to move on to the next presentation, effectively prevented a thorough discussion of the capstone project with the members of that team.

Under the PRB approach, a subset of the faculty convene to hear but one presentation, albeit of similar length as before, but now have the luxury of possessing adequate time to discuss and explore the project with its students. The students, having already dedicated a significant number of hours to the design sequence, appreciate the level of detail that the PRB review structure affords compared to the mass presentation structure of previous years. What starts as an intense questioning session often becomes a unique situation where the students and the faculty interact to improve the design, allowing the students to feel a level of professional respect that recognizes their preparation to soon enter the profession as a practicing engineer. Thus, the feedback received through such a process is valued by the students, as it provides a more thorough oral review of their project than previously possible. It also casts a streamlined management structure to the senior design courses' expectations, reducing confusion as to what is due and when, as all senior design groups are able to follow this management standard regardless of topic.

To obtain data regarding the new approach, a survey was distributed to members of the ECCS Department's alumni group on Facebook. The quantitative questions asked included the year of graduation, the overall level of satisfaction regarding the oral presentations, written reports, and poster presentations for each capstone team, the degree to which the prototype for the project was completed, and the estimated quality of the prototype on a 0 to 10 point scale. Table 1 presents the results from the questions dealing with the overall satisfaction, rated as a percentage, with the various forms of communication used to relay information concerning the capstone project. The number of respondents for each cohort is parenthetically presented next to the year; given that the overall response rate constitutes only 12% of our graduates during the six-year period represented in Table 1, only general observations can be made with this data.

Table 1. Satisfaction Results from Alumni Survey.

Graduation Year	Written Reports, %	Oral Presentations, %	Poster Presentations, %
2008 (n = 5)	88	94	84
2007 (n = 2)	70	80	70
2006 (n = 7)	79	86	77
2005 (n = 4)	77	87	85
2004 (n = 4)	92	82	72
2003 (n = 3)	93	90	57

It is worth noting that, while almost all of the data in Table 1 indicate a strong level of satisfaction, the numbers for the 2008 graduates indicate an improvement over previous years, including a very high level of satisfaction with their oral presentations, the majority of which were made to the group's PRB.

Two other quantitative questions were posed. The first asked for an indication of the level of completeness of the prototype on a 0 to 10 point scale. The second used a 5-point Likert scale, with 5 indicating strong agreement, for the question, "The senior design course sequence was of practical use in preparing me to work in a corporate design environment." Table 2 presents the survey results for these two questions.

Table 2. Results of Completeness and Practicality from Alumni Survey.

Graduation Year	Level of Completeness (0-10 point scale)	Course was of Practical Use (5-point Likert scale)
2008 (n = 5)	9.6	4.2
2007 (n = 2)	8.0	4.5
2006 (n = 7)	5.9	3.4
2005 (n = 4)	6.0	4.3
2004 (n = 4)	6.8	3.5
2003 (n = 3)	8.0	3.3

The 2008 data for the level of completeness is significantly higher than previous years; this is in large part due to the implementation of "consequences" that naturally go with a business-oriented approach. The practicality of the approach rated high, but it is noted that the data for the previous years, which used the previous course organizational format, is somewhat bimodal in that students either rated their answers with a strong positive or strong negative score. This was not the case for the 2008 cohort.

Additional data was collected through examination of student course evaluation responses in ECCS 405 for the last three cohorts, including the 2009 graduation class. Presented in Table 3 are results from four of the Likert scale questions (with 5 indicating strong agreement) asked on the course evaluation form; the 2006-07 cohort data represents the previous senior design format whereas the 2007-08 and 2008-09 cohort data represents the new format. The ability to apply design principles to real world problems stayed essentially the same, and the ability to work effectively in teams had a bump in the first year of the new approach but reverted to its prior level in the subsequent cohort. Of interest are the two remaining questions. There is a significant increase in the response for developing project management skills under the new format; this is to be expected as an explicit, standardized methodology for project management is now being presented to the students. Of considerable note, however, is the decline shown regarding the development of confidence in the student's ability to engage in problem solving and design discussion. One explanation for this is that, under the current format, discussions are formally held at the end of this course with the members of the Project Review Board whereas in the past it was just with the faculty advisor. As the students now have to give a presentation after which members of the PRB will critically analyze various elements of the project, it is natural for some students to perceive this process as more adversarial than having yet another sit-down with one's advisor, thereby causing the lowered level of confidence.

Table 3. ECCS 405 Student Course Evaluation Responses by Cohort

	2006-07	2007-08	2008-09
Number of responses / number in cohort	18/20	24/35	20/27
The course helped me learn to apply design principles to real world problems	4.4	4.3	4.3
The course helped me develop confidence in my ability to engage in problem solving and design discussion.	4.7	4.4	4.1
The course helped me develop an ability to work effectively in teams and respect team work.	4.1	4.4	4.1
The course helped me develop project management skills.	3.6	4.2	4.2

Conclusion

The ECCS Department at Ohio Northern University needed to ensure that all students were exposed to standards, as dictated in ABET's Criterion 5. There was also a need to streamline the project management details as the department's senior design topics grew in diversity and depth. Combining these two needs has resulted in the adoption of a local industry's project framework. This MPMP Framework has been found to provide all capstone teams with experience in dealing with a standardized business-oriented project management process that was developed by and for engineers. The students benefit from having gained corporate project management exposure while the faculty advisors have an organizational framework that fits all types of capstone projects and engineering disciplines. Working prototypes for the designs are more finished now because of the management process, and students report a satisfaction with the common standard utilized by all senior design projects in the ECCS Department.

Bibliography

1. B. Farbrother, M. Chow, M. Churpek, M. Woodruff, T. Schroeder, and T. Schroeder, "The EiR Program at Ohio Northern University: Paralleling the Workplace on the University Campus," Proceedings of the 2002 International Conference on Engineering Education, Manchester, U.K.
2. J. Hurtig and J. K. Estell, "Truly Interdisciplinary: The ONU ECCS Senior Design Experience", Proceedings of the 2005 American Society for Engineering Education Annual Conference, Portland, Oregon.
3. C. Dym, A. Agagino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering Design Thinking, Teaching, and Learning," Journal of Engineering Education, January 2005, pp. 103-120.
4. J. M. Conrad and Y. Sireli, "Learning Project Management Skills in Senior Design Courses," Proceedings of the 35th ASEE/IEEE Frontiers in Education Conference, Indianapolis, IN, October 2005.