

Adopting Best Corporate Practices for Capstone Courses: A Case Study at Ohio Northern University*

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The capstone process is meant to provide students with real-world design experiences, thereby developing skills that are transferrable to the corporate environment. To address the growing concerns of providing students with adequate preparation for the workplace, the Electrical & Computer Engineering and Computer Science Department at Ohio Northern University adopted both an industry-based project management standard and a corresponding project management documentation practice as an operational framework for their capstone design course sequence. Additionally, in order to provide capstone teams with appropriate technical expertise across the multidisciplinary topics that make up a typical design experience, a Project Review Board consisting of faculty selected specifically for their expertise relative to each project is assigned to each capstone team to both provide guidance and to conduct performance reviews. Both formative and summative assessments of the design process include the use of multiple communication formats to both internal and external audiences at specified decision points in the process. These two forms of assessment are evaluated using a standardized set of rubrics, providing benefits to students by explicitly stating performance expectations and to faculty by establishing a common definition of skill competencies. The quantitative and qualitative post-activity assessments indicated an improved student capstone experience. Recommendations are provided to assist other institutions in adopting the processes and protocols discussed in this paper.

Keywords: senior capstone projects; industry project management standards; rubrics

1. Introduction

In 2001, the Computer Science (CS) Department in the Ohio Northern University (ONU) College of Arts and Sciences was transferred into the College of Engineering and merged with the Electrical and Computer Engineering (ECE) Department to form the Electrical & Computer Engineering and Computer Science (ECCS) Department. While each existing department had a capstone format in place, they differed greatly in terms of length, focus, and content. This 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 ECE and CS faculty. The task before the faculty was to find a common senior design framework for all three majors.

Detailed in an earlier paper by the authors [1], the department settled on adopting a year-long model for capstones featuring student teams of approximately 3–4 students per project. Project ideas are obtained from a variety of sources, with about an equal split over the years between industry-sponsored and instructor-derived projects. Project proposals, consisting of a project statement of one to two paragraphs providing a general overview of both the problem and the desired solution, are provided to the students in the spring term of their

junior year. Because the department has more proposals than there are students to properly populate teams (over the last ten years, senior design cohorts within the department have ranged from 24 to 44 students), students are instructed to indicate their first, second, and third project preferences and submit this information to the department office. This process allows both a means for students to express their desires, thereby allowing for greater buy-in, and a way to effectively prune the less interesting projects from further consideration. Based on a combination of student interests and project needs, the faculty assigns students to project teams, with one team assigned per project. The teams are often cross-disciplinary (for instance, containing both electrical and computer engineering majors) and regularly involve teams formed across multiple departments, usually with Mechanical Engineering. Faculty are then assigned as project advisors; depending on cohort size and fulfillment of workload obligations, this results in each faculty member having either one or two teams to supervise. One or more preliminary meetings with student teams are held prior to the end of the spring term, with design work starting in earnest when the students arrive back on campus in the fall to begin their senior year. To insure that progress is being made, during the senior year students meet on a weekly basis with their faculty advisor.

In the ABET Criteria for Accrediting Engineer-

ing Programs, 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* (emphasis added) engineering standards and multiple realistic constraints” [2]. In some engineering disciplines, such as civil engineering, the use of appropriate engineering standards is relatively straightforward. In his 2008 paper, Kelly describes the need for students to understand standards as engineering tools, and provides various examples of such standards as they pertain to civil engineering [3]. However, he also points out that, if students are to be better aware of the use of standards as tools, then students require more access to standards than is currently the case. Some organizations such as ASTM have attempted to answer this call through developing such items as their “Standards on Campus” program [4]. However, the ECCS Department’s approach to senior design makes the use of such directed services, even with the reduced costs when compared to traditional methods of obtaining copies of standards, problematic. First, due to the highly diversified nature of the department’s projects, both within a particular year and across the years, the purchase of standards can be prohibitively expensive for a relatively small department. Second, no such requirement for incorporating standards exists under the ABET Criteria for accrediting computing programs, and the department’s computer science students and faculty are averse to having to do something for no other reason than to fulfill an engineering requirement. Additionally, many of the industry-sponsored projects did not have any standards associated with them; when this subject was discussed at one of the department’s Industrial Advisory Board meetings, several of the engineers present stated that their day-to-day design work in either electrical or computer engineering did not involve the application of formal standards—not even those from IEEE. Given the need, especially in a small program, to cultivate positive working relationships with industry, it would be foolhardy—perhaps insulting—to summarily dismiss an offered project from a willing sponsor simply due to the inherent lack of an IEEE-based or similar professional standard.

There are many definitions as to what a standard is; it can be simply stated as “a set of rules for insuring quality” [5] whereas the International Organization for Standardization (ISO) defines it as “a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose” [6]. Providing opportunities to work with standards as

part of the engineering design process is still a necessary component of the educational experience for all engineering students. However, this brings up two questions: what constitutes “appropriate”, and how does a program incorporate standards into the process such that all students experience it? One possible solution—the adoption of a common design project for all student teams—is a non-starter for the ECCS Department, given both the diversity of its students and the desire to engage a wide variety of industry partners. However, as noted in a paper by Kunst and Goldberg [7], there are three types of standards:

- *process standards*, which describe a general system or a way of doing things,
- *standard test methods*, which specify test protocols to be followed to evaluate the physical properties or performance levels of a product, and
- *performance standards*, which describe performance attributes, usually for a single device category.

While testing and verification are important parts of any design process, such methods are only germane to the product in question; for example, the ASTM F963–08 standard is suitable only for testing the safety of toy designs, and not for the design of other products [8]. Similarly, performance standards suffer from the need to be applied to a single device category, whereas in the ONU ECCS capstone there are usually as many device categories as there are projects. However, process standards can be adopted in such a way that they can be applied to all projects regardless of product or category. While there has been recent progress in the development of the new ISO 21500:2012 standards for good practice in product management, such standards do not readily connect with our students [9]. Students need to see a standard—any standard—in action, preferably personified by a practicing engineer to provide the “argument by industrial authority” credence that in a student’s mind validates a particular process because it might be something that they will use once they are employed in a corporate setting. While many capstone projects are, in and of themselves, free of what are typically thought of as standards, there are appropriate standards available at a higher conceptual level that can be applied equally to all projects; namely, internal project management standards developed by industry for use with their engineering projects. The remainder of this paper will discuss best practices adopted by the ONU ECCS Department for improving its senior capstone experience: application of a corporate project management standard, employment of project management doc-

umentation standards, objective performance evaluations through rubrics, and the utilization of design review boards.

2. MPMP: A project management standard

Ohio Northern University has had a working relationship with Marathon Petroleum Company for many years. An aspect of this relationship, unique at its inception in 2001, is the Engineer-in-Residence (EiR) program [10]. Formed at the time as a collaborative effort between Marathon Ashland Petroleum (MAP) and ONU to bring the professional workplace into an academic environment, the EiR program allowed a practicing professional employed by MAP to operate on campus. While the primary purpose of the program was to provide co-operative real-world work experiences to students without having to temporarily suspend one's studies, another aspect was to provide a mechanism whereby members of the engineering faculty could invite the EiR to participate in class activities [11]. Consequently, the instructor of the introductory senior design courses would invite that year's EiR to talk to the students about the subject of project management. In response, each of the EiR members would refer to their in-house project management tool known as the Marathon Project Management Process (MPMP) Framework. This information was well received by both students and faculty, so much so that in 2007 it was decided to adopt the MPMP Framework as a common industry-based standard for managing all senior design projects within the department, regardless of source or content.

The MPMP Framework consists of five phases to divide projects into smaller logical units to increase manageability. Between each phase are specific decision points that provide for external review, thereby improving the quality of the decision making process. At ONU, these five phases are used to organize the capstone design process over the period of three academic semesters, starting in the junior year spring term and concluding at graduation, and consist of the following activities:

Conceptual Phase: In the spring term of the junior year, faculty identifies possible capstone projects and seeks ideas from industry sponsors. A list of these projects is posed to the rising senior students who then vote for their top three project assignments. From this input the faculty designates the capstone teams.

Feasibility Phase: Now that the project concept has been identified, the group moves into a Feasibility Phase that lasts throughout the summer vacation months and into the beginning of the senior

year fall term. The project is researched, specifications are defined, and the team requests the formation of their Project Review Board (PRB), as described later in this paper.

Definition Phase: The remainder of September and most of October is devoted to the Definition Phase. The students form an implementation plan to solve the capstone problem, proposing a scope of work and corresponding schedule to which they will be held accountable. A project proposal is submitted to the PRB, which provides appropriate feedback to the team.

Implementation Phase: Beginning in November, the students focus their energies on following the project schedule to produce a working prototype as appropriate to their project. This phase concludes in mid-March with the demonstration of the prototype to the PRB.

Start-up/Close-out Phase: The remainder of the spring term wraps up the capstone project, in which students must complete both their project and their documentation deliverables.

Through the adoption of this phase-based structure, the Framework provides a timeline that guides both student teams and faculty advisors in the overall management of the design process.

3. Project management documentation

In order to design a product, a capstone team must first establish what capabilities the client desires to be present in the product. Capabilities are typically expressed at a high abstraction level, often expressing the functionality of the product purely in layman's terms and containing minimal technical detail regarding the operation of the device. In many ways the specification of capabilities is the most important part of the design process as this constitutes the interface through which the client and designer interact. Accordingly, substantial communicative effort on the part of the capstone team with the client in this area is critical in order to fully and accurately ascertain the client's wants, needs, and desires. As an example, assume that the design group is working with a client who desires a highly portable drone aircraft for tactical surveillance use. Among the capabilities could be the following:

CAP-01: The device is transportable by one person.

CAP-02: The device must provide a video signal to the operator via a secure connection.

Requirements specify particular behaviors and/or operations of the product that are both quantitative and testable. They are used to provide the technical guidelines necessary for the actual design of the product. Each requirement must be identified as

being associated with one or more product capabilities; accordingly, the requirements for a product are developed only after the capabilities have been established. These requirements are broken down into criteria, technical constraints, and realistic constraints. The criteria requirements express the desirable characteristics of the product, supplying specific performance functionality, as compared against a provided benchmark that the device is to achieve. Using the portable drone aircraft example, two of the criteria in support of CAP-01 could be as follows:

REQ-01: The device must weigh less than 30 kg.

REQ-02: The device must be capable of fitting within a large standard-issue (60 cm by 75 cm by 25 cm) backpack.

In contrast, the constraint requirements specify the limits to the product development due to either technical or realistic (i.e., real-world) influences. The technical constraints specify the limitations on the design due to STEM-based considerations; for example, while balsa wood is well-known as being a lightweight construction material, its lack of durability would make for a poor design choice. Accordingly, technical constraints are often used to eliminate poor choices up front, thereby enabling the design team to focus on the evolution of technically acceptable solutions. The realistic constraints are design limitations based upon such considerations as corporate economics, environmental impact, or operational safety. Examples of realistic constraints for the drone aircraft example would be the prohibition of using liquid fuels as a power source due to the possible combustion hazard or applying a specific manufacturing process to speed up delivery time. Both the capabilities and requirements specifications are recorded within a “Capabilities and Requirements” document and then updated as necessary as the capstone team progresses through the Feasibility Phase of the design [12].

Next, the students create a Demonstration Test Plan, which describes the tests and associated steps needed to demonstrate the capabilities of the device. This plan is used to provide “proof of concept” evidence to the client and to ensure that the designers have captured the general intent of what the client desires in the product. It does not, however, necessarily indicate the extent to which a particular task is accomplished. Each test specifies at a minimum the capability being tested, the materials and/or parts needed, and the steps needed to accomplish that test; all test plans are incorporated into the Capabilities and Requirements document. Following the conducting of the test, the results are also included in the document.

Demonstration tests do not require a functional overall system prototype; for example, the video system specified in capability CAP-02 can be demonstrated without the use of any sort of aircraft. Once the demonstration tests have been completed, the results are reviewed and revisions, as appropriate, are made to the specifications.

Similar to the capabilities being reviewed via the Demonstration Test Plan, the Acceptance Test Plan is used to verify whether or not the design meets the specified Requirements. The acceptance test plans should be written at the same time as the requirements in order to ensure that the specified requirements are, in fact, both quantitative and testable. Each test plan must verify at least one specific requirement, and all requirements must be addressed by at least one test. The test plan consists of specific tests, each containing detailed steps and indicating which requirement has been addressed.

The capstone experience is often the first (and perhaps only) time that students are let loose to work on a project; one of the benefits of this documentation approach is that it is an easy way to provide an appropriate, professional structure for students to both develop and document their project work. The “capabilities and requirements” design specification approach also ties in well with the MPMP Framework. The Test Plans are drawn up as part of the Definition phase, and are reported on throughout the Implementation phase. This has proven beneficial for organizing student work for both progress reviews by the project’s advisor and in anticipation of their formal review by the project’s PRB during the decision points of the Framework.

4. Assessment with rubrics

The assignment of grades to a capstone project can be a cumbersome experience. By its very nature, a culminating design experience such as that called for in ABET Criterion 5 draws from several areas; the evaluation of student performance in many of these areas can be very subjective and time-consuming. Accordingly, there is the temptation of utilizing a holistic approach to the grading of such design projects. The desire to assign a single grade to the overall project, or to an individual component of a project such as an oral presentation, makes such an approach compelling, especially for those instructors who profess to intrinsically know the difference between ‘A’-level and ‘B’-level work. However, what is gained in efficiency is more than offset by the lost opportunity for an understanding of student performance, or more to the point, deficiencies in student performance. When a professor holistically assigns a grade of ‘D’ for an oral presentation, how can one properly evaluate student performance

such that appropriate action can be taken as part of a continuous improvement process? It could be that the low grade was for glaring grammatical errors, or for a flawed design based on a poor understanding of certain engineering concepts. If it was determined that the curriculum was to blame, an action plan for correcting poor grammar would be radically different than an action plan for reinforcing the pertinent engineering concepts. Furthermore, as senior design projects usually involve multiple faculty members, there is a question of fairness, as grading standards will often differ between faculty members.

Thus, from a practical standpoint, the evaluation of capstone projects needs to objectively support both the assignment of grades and the assessment of student outcomes. This conclusion is documented by a national survey of engineering deans and capstone design instructors in [13]. In this paper, it is noted that 76% of the respondents indicate that the assessment must provide feedback to both the faculty and the students. The paper continues by noting that the surveyed faculty identified several ways they wanted to improve the quality of their capstone assessments. About one-half of the respondents felt the measures should be more objective and wanted to develop more detailed scoring guidelines/rubrics, and again about one-half desired clearer performance criteria. This requires an analytical approach to grading, where the assignment is broken down into its constituent parts, with each part being scored independently [14].

In [15], Gerlick, Davis, et al. presents a thorough literature review for the assessment of engineering design, with an emphasis on capstone courses. Their work notes the importance of assessing both engineering design knowledge, and the actual design products, including reports, presentations, and design reviews. As noted in the paper, rubrics are a popular evaluation instrument, particularly in areas where there is an inherent amount of subjectivity. A rubric is simply a scoring guide, consisting of a set of performance criteria against which a student is evaluated [16]. The criteria describe traits that constitute specified goals which are embodied within the assignment. To measure how well a criterion is being achieved, descriptive indicators are used that identify traits typical to a specified performance level.

The use of rubrics presents many benefits [17]. Instructors are forced to examine an assignment and determine ahead of time the grading criteria. The amount of time evaluating student work is lessened, as performance in each criterion can be categorized according to exhibited traits that correspond to the specified descriptive indicators. By distributing rubrics at the time the assignment is

made, clear expectation guidelines are provided. When used, criteria scores on an assignment provide information to the instructor as to what performance areas, if any, are in need of improvement. Also, when multiple faculty are involved, rubrics provide a common evaluation framework, minimizing the potential for inconsistent scoring. Finally, the use of rubrics constitutes a form of authentic assessment, where work can be measured according to real-life criteria; for example, written reports can be evaluated under the same criteria as those used for rating manuscripts submitted for journal publication.

ABET Criterion 5 states that students must participate in a culminating design experience that incorporates “appropriate engineering standards and multiple realistic constraints.” The senior capstone process as implemented in the ECCS Department breaks down the two-semester senior capstone sequence into three main components: proposal development, prototype design and verification, and final reporting. These components readily align with the industry phases of “Definition Phase”, “Implementation Phase”, and “Start-up/Close-out Phase”. Rubrics assist each phase of the capstone evaluation process, and examples of all of these rubrics can be found via the link provided in the Resource section at the end of this paper. This includes rubrics for oral presentations, written reports (for both style and content), the technical design evaluation, and the realistic constraints evaluation. A specialized rubric to support the work of the PRB via progress reports was also developed (See Fig. 1). Each rubric category is evaluated on a zero to three point scale, where descriptions are provided for every performance indicator level for all of the present criteria. Faculty can quickly record their evaluations of the students on the various categories by simply circling the appropriate box. The numerical scores can also be entered into spreadsheets to assist in streamlining the department’s assessment processes [18].

5. Project review boards and assessment

To assist with assessment, the department adopted the use of a Project Review Board (PRB) format beginning in the 2007–2008 academic year [19]. 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. Similar in concept to the design review boards used as part of a systems engineering process, the PRB collectively provides the necessary breadth of technical expertise and guidance that an individual faculty member would be hard-pressed to provide for interdisciplinary

	3 - Excellent	2 - Adequate	1 - Minimal	0 - Unsatisfactory
Project Overview	Provides a strong, clear problem statement.	Provides a problem statement that is generally clear.	Provides a problem statement that is somewhat developed.	Problem statement is unclear or absent.
Work Completed: Content	Content conveys all of the project detail; all key points are fully developed and supported.	Content conveys most of the project detail; all key points are developed and supported.	Content conveys some of the project detail; some but not all key points are developed and supported.	Content conveys little, if any, of the project detail; few if any key points are developed and supported.
Work Completed: Organization	The order in which ideas are presented is clear, logical and effective.	The order in which ideas are presented is reasonably clear and effective, but could be improved.	The order in which ideas are presented is occasionally confusing.	There is no apparent structure to the flow of ideas, causing confusion.
Demonstration Test Plan: Specifications	Plan includes specific tests, each with detailed test steps, needed to demonstrate that all capabilities have been met.	Plan includes tests and steps needed to demonstrate that all capabilities have been met, but is lacking some details.	Plan includes tests and steps needed to demonstrate that some, but not all, of the capabilities have been met.	Plan fails to include appropriate tests and/or steps needed to demonstrate the capabilities of the project.
Demonstration Test Plan: Verification	All elements of the test plan are verified as meeting or exceeding specifications.	All elements of the test plan are verified as implemented (either below, meeting or exceeding specifications).	Some elements of the test plan are not implemented; all implemented elements are verified as meeting or exceeding specifications.	A majority of elements of the test plan are not implemented or are implemented but below specifications.

Fig. 1. Example criteria from the PRB progress report rubric.

design experiences. At critical points of the design process (to be explained in detail later in this paper), each capstone team must submit a written report and make an oral presentation to their PRB; these presentations are evaluated using an oral presentation rubric that is shared with the students well prior to the presentation.

5.1 Project formative assessment

During the capstone experience, student teams meet weekly with their faculty advisor. The advisor's primary duty is to supervise, insuring that progress is being made. Additionally, during the Implementation Phase, teams are required to periodically submit formal Status Reports. In this Report, the team must provide a summary of the work completed since the previous Report, identify any issues requiring assistance, and present the updated schedule for the next work period. The Report is used to document progress (or lack thereof), to provide additional written communication practice, and it allows for oversight of all projects.

In the MPMP Framework, the Implementation Phase is where significant time expenditures are made and financial expenditures are incurred.

Accordingly, the design review conducted prior to this phase is of critical importance. The capstone team first develops a written proposal that summarizes project feasibility, presents an implementation plan, and establishes the scope of the work. This proposal is submitted ahead of a scheduled one-hour meeting with the members of the PRB. The design review starts with an oral presentation of approximately 15 minutes; the remainder of the time is spent discussing the merits of the proposal, with PRB members asking probing questions and providing suggestions to improve the quality of the design. Rubrics are employed by the PRB to score and assess performance concerning both design and communication skills. With this input, teams progress to the Implementation Phase, where they order components and construct a prototype.

The PRB also plays a formal role at the end of the Implementation Phase, where each capstone team is required to present the results of their Demonstration and Acceptance Test Plans; i.e., their proof of concept that their design is capable of performing the assigned task. Again, the capstone team submits a written report (that includes the relevant sections of the Capabilities and Requirements document)

and makes an oral presentation to the PRB. This is where the rubric shown in Fig. 1 would be applicable. The feedback from the PRB in this instance is used to assist the team in their achievement of the various requirements specified in the design.

5.2 Project summative assessment

At the end of the capstone experience, the teams report their results to a variety of audiences using multiple formats. Each group produces a final report that is evaluated via rubrics by the PRB. However, the final oral presentation is given to both the entire department faculty and one's peers. External audiences also play a role. Near the end of the spring term, the department holds an afternoon meeting with its Industrial Advisory Board (IAB). After the meeting, the IAB members are invited to dinner with both the senior students and members of the local IEEE Section. Following dinner, the seniors present their projects in a poster session, evaluated jointly by faculty, IAB members, and practicing IEEE professionals using a poster presentation rubric. Based on all of these evaluations, the team determined to have the best project is recognized by being invited to present before the College's Advisory Board and by having their names engraved on a plaque displayed prominently outside the office of the Dean of Engineering.

6. Results

The ECCS Department typically graduates approximately 32 students each year across the three programs. Senior design groups typically involve three to four students, and thus there is an average of 10 capstone projects in the department per year. At the end of the Implementation Phase in mid-March, just prior to Start-up and Close-Out, students are asked to complete a course evaluation that contains specific questions related to the project management process for the capstone experience.

This provides quantitative data of their impression of the process having just completed the bulk of the project. To obtain qualitative data regarding the new industry project management approach, an additional survey was distributed to members of the ECCS Department's alumni group on Facebook in Fall 2011, capturing feedback from alums who had graduated in the past 5 years. Specifically, alumni were asked to qualitatively answer three questions related to how prepared they felt they were for their employment. Both the qualitative and quantitative information confirms that this industry project management standard approach is a positive experience that alums can now utilize and relate to in their careers.

6.1 Quantitative results

Assessment data was collected through student course evaluation responses following the Implementation Phase for the last five cohorts, including the 2011 graduation class. Presented in Table 1 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 capstone format whereas the 2007–08 cohort data onwards represents the use of the MPMP Framework and Project Review Board. Additionally, the 2009–10 cohort data was the first cohort to use the formal capabilities and requirements specification process, and in 2010–11 the submission frequency of the Status Report was changed from a monthly to a biweekly basis upon the recommendation of the department's IAB, who also encouraged the adoption of a time-based budgeting process, complete with the recording of "billable" hours, that was incorporated into the Status Report.

Within Table 1, the second row indicates the # of responses received out of the cohort size for that given year. For each question summarized in the table, the cells in each row provide the mean

Table 1. Student Evaluation Responses by Cohort

The course helped me: # of responses / cohort size	2006–2007 15/20	2007–2008 25/35	2008–2009 20/27	2009–2010 32/40	2010–2011 26/40
Learn to apply design principles to real world problems.	4.4 0.50 100%	4.3 0.80 87%	4.3 0.62 90%	4.1 0.60 96%	4.5 0.63 92%
Develop confidence to engage in problem solving and design discussion.	4.7 0.44 100%	4.4 0.57 96%	4.1 0.62 85%	4.1 0.87 84%	4.6 0.57 96%
Develop an ability to work effectively in teams and respect team work.	4.1 1.15 73%	4.4 0.65 91%	4.1 0.67 80%	4.1 0.87 91%	4.5 0.50 100%
Develop project management skills.	3.6 1.30 53%	4.2 0.66 87%	4.2 0.60 90%	4.1 0.72 84%	4.5 0.50 100%

response, the standard deviation, and the percentage of agreement, respectively. (The percentage of agreement is calculated by adding all the responses who indicated Agree (4) or Strongly Agree (5) and dividing by the total number of cohort responses.)

The adoption of the MPMP Framework clearly had a positive effect on the development of project management skills, with a significant increase being reported; this is to be expected as an explicit, standardized methodology for project management is now being presented to the students. However, in the first year of the capabilities and requirements reporting format in 2009–10, there was no discernible difference in this area. Accordingly, modifications were made to the document and additional time was spent in class to better explain the process, resulting in another significant improvement. Placing greater stress on the systematic development of capabilities and requirements also resulted in a reported increase in the ability to apply design principles to real world problems back to prior levels. The ability to work effectively in teams had a bump in the first year of the MPMP approach but reverted to its prior level in the subsequent cohorts; the use of the Status Report and biweekly reporting of the time budget is the probable cause for the increase shown by the final cohort, as that held students accountable for their contributions by their peers. Of note is the decline shown regarding the development of confidence in the student's ability to engage in problem solving and design discussion until the last cohort. One explanation for this is that, under the current format, discussions are formally held 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. For the last cohort, the emphasis in clearly stating what the project's capabilities and requirements are probably helped to restore that confidence.

6.2 Qualitative results

To obtain evaluation data regarding the effectiveness of the new approach as perceived from the workplace environment, a survey was distributed in November 2011 to members of the ONU ECCS Department Alumni group on Facebook, which has been shown as a successful vehicle for interacting with the department's alumni [20]. Specifically, alumni were asked to comment regarding (1) in what ways the senior design course sequence prepared them for their career, (2) in what ways the

senior design course sequence did not prepare them for their career but should have, and (3) ways to use the senior design course sequence to improve a student's chances for success in the workplace.

Regarding how the senior design course prepared students for their career, comments germane to the class format included the following two examples:

"I learned most from the design proposal, email updates, weekly meetings, and formal presentations. I feel some of the required documentation needs to be tailored back to focus on the main written reports and presentations which are most useful."

"The senior design course gave experience in gathering requirements, defining the scope and deliverables, of a project, executing a plan, and reporting progress. No other lab courses brought together all of these design 'life-cycle' steps in one complete project like the senior design project."

Another aspect of how students benefited involves the managerial aspect of the sequence:

"I learned quite a bit about deadline crunches and trying several different approaches to a practical design problem under the guidance of a 'manager'. Working as part of a team for an extended period of time was also quite valuable because that is how the vast majority of engineering work is performed."

Placing an emphasis on specifications and constraints was also of value:

"In retrospect, the project helped me prepare for resource-constrained design (which is not the focus of many other textbook engineering classes). The project had a limited time, limited budget, and small set of core requirements. There were design tradeoffs between delivering a functional product and delivering a 'better' product. I think this lesson is incredibly useful in the real world since a lot of non-consumer engineering is focused on making a product that meets customer specifications but does not give away too many features for free."

Finally, an unexpected benefit was discovered when multiple alumni alluded to how the course sequence prepared them, in terms of relevant experience, for the interview process, such as:

"Having worked on this project really helped interview for my current position. It provided a topic of conversation during the interview that enabled me to show I had experience with teamwork; design, prototype, and test; customer interaction; verbal and written communication of results; as well as challenges faced and how I (or the group) chose to overcome those challenges."

While it is nice to read affirmations regarding what was "done right," improvements are more likely to occur via queries asking in what ways did the senior design course sequence not prepare students for their career but should have. The approach taken by the department has involved an amalgam of projects, where industry sponsored projects run alongside projects developed by

faculty. Accordingly, it is not surprising to encounter opinions such as that expressed in the following feedback regarding the lack of an external experience:

"I feel that the design project did not incorporate a large enough group of interested stakeholders, vendors, outside companies, etc. The design was completed mainly in-house with ordering parts over the internet and using established contacts with faculty. More projects should involve collaboration outside of ONU with Engineers, businesses, communities and so forth. I feel breaking out of the ONU bubble is an important skill I wish I had learned through the project."

As some students experienced design via a faculty-sponsored project, they also missed out on having a customer-based experience:

"There wasn't any 'customer' interaction. It would have been nice to discuss the project with a 'customer' and establish what requirements he or she wanted rather than leaving it up to the group members."

Additionally, even those students with a customer to work with felt that the process used in the course was somewhat lacking in terms of interaction:

"It did not accurately represent how an engineering team should interact with the customer. In many of my projects, the customer has been involved in bi-weekly (if not more frequent) status meetings, especially during the initial stages of understanding the problem and designing the solution."

The take-away from both these and other similar comments is that there is a clearly perceived advantage in having a client- or customer-based relationship with someone possessing a stake in the design as part of the process. While there is a limited industry presence in the immediate area of Ohio Northern University, with the advances in video conferencing software, faculty are striving to increase the customer-based projects. If alumni are contacted to serve as customers in the design process, it is an added bonus to both the institution and the students, as it maintains the alumni involvement.

The surveyed alumni also suggested ways to use the senior design course sequence to improve a student's chances for success in the workplace. Multiple responses addressed the unrealistic aspects of typical senior design projects. For example:

"I think that in the senior design course or in other courses, it would be helpful to start with an existing project and be required to fix problems or add features (like most projects in the workplace), rather than writing a program from scratch."

Another alumnus noted the following observation regarding the approach used at the institution where he attended graduate school:

"One thing I've seen ... is that some of their senior design projects are multi-year long running projects involving all levels (freshman through seniors and sometimes even

grad students). Each year a group of seniors then peels off a piece of the project to address/present as their senior design project. This allows the teams and students to gain experience in recruiting new team members, joining an existing team, sustaining work done by previous teams, and adding new work within established constraints. All valuable 'real world' experiences."

Another aspect that was mentioned was with the frequency of interaction between group and supervisor, both in terms of keeping track of day-to-day progress:

"I would recommend having more frequent meetings (perhaps twice weekly) with the 'program manager' (project advisor) in order to clarify points of design that are in dispute or where specifications are imprecise. This also provides an incentive for the design to show consistent progress and for any roadblocks to be addressed as soon as possible."

as well as overall contributions:

"I think there should have been more performance reviews to keep everyone in the group focused and accountable for his or her share of the work."

Finally, one alumnus suggested the following regarding managing the paperwork that is inherent with project development:

"Collaborating electronically between all of the members in the senior design group through hundreds of revisions of documents sent through email or dumped on a shared network folder was unrealistic. Real companies use source control systems and it would have been immensely valuable (not to mention a huge time saver) to have used these during the senior design project."

7. Conclusion and recommendations

A capstone design course is certainly not a new concept for use in an ABET accredited curriculum; neither is the incorporation of constraints and requirements in design. Similarly, employer surveys often request graduates to possess solid technical skills, while also stressing the basic need for strong communication, organization, and management skills. However, with the capstone curriculum reported here, the inclusion of a corporate design standard provides the framework for the project's organization and management, allowing students to gain practice with requirements documentation and the development of test plans. The usage of the PRB committee increases students' written and oral communication skills while supporting students in multidisciplinary projects. Closing the assessment loop with the assistance of rubrics provides individual student performance data along with the necessary program evaluation information. The overall result is an improvement in students' project management skills, confidence, and real-world design experience. Finally, reflections on the part of alumni indicate that the approach was of value to them in prepara-

tion for their careers; however, it could be further improved by using multi-year projects, systematically incorporating customer-based relationships and external stakeholders, and increasing the frequency of performing progress reviews.

This case study from Ohio Northern University's ECCS Department can readily be adopted at other institutions. Institutions that want to adopt this standard should approach their Industrial Advisory Board members to promote partnerships with industry that result in meaningful and potentially open-ended senior design projects. ONU has found these projects to be ideal for interdisciplinary teams; the mixture of majors benefits the students as it mimics what they will experience in industry. Also, while ONU adopted the specific standard of Marathon Petroleum Company, institutions should contact local engineering firms or companies with engineering divisions to work with them to promote their project management standards to the students. With regards to performance reviews, care should be taken to ensure adequate assessment for both the student's benefit and for the program's curriculum development. The usage of well-defined rubrics provides faculty with that necessary framework; other institutions are encouraged to adopt and build upon the various rubrics mentioned in the Resources section of this paper. In addition to this summative assessment, the adoption of the Project Review Board structure provides the necessary formative assessment to mentor the students and guide them to improve the design. With these underpinnings of corporate project management and assessment protocols, departments can strengthen their capstone design courses and thereby improve their ability to address ABET Criteria 5.

8. Resources

Copies of all materials referred to in this paper, including rubrics for assessing oral presentations, posters, realistic constraints, and technical design, along with forms for progress reports, written reports, bi-weekly reports, capabilities and requirements reports, design proposal reports, final reports, peer evaluation, and project progress reports are available at the following web site: <http://www2.onu.edu/~j-estell/seniordesign>

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