Adopting Best Corporate Practices for Capstone Courses

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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 and Computer Engineering and Computer Science (ECCS) Department at Ohio Northern University (ONU) adopted both an industry-based project management standard and a corresponding corporate 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 (PRB) 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 at specified decision points in the process to both internal and external audiences. Both 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.

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MPMP: A Project Management Standard

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."[1] 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.

ONU has had a working relationship with Marathon Petroleum Company for many years. In 2007, the ECCS Department adopted Marathon's project management tool known as the Marathon Project Management Process (MPMP) Framework for use in capstone design. The MPMP Framework consists of 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 for external review, thereby improving the quality of the decision making process. At ONU, these five phases are executed 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: During the Conceptual Phase of the junior spring term, faculty identify possible capstone projects and seek 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 designate 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.

Project Documentation

In order to design a product, a capstone team must first establish what the client wants. Capabilities represent the functionality that the client desires to be present in the product. These are typically expressed at a high abstraction level, often expressed 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. These capabilities are identified and documented within a "Capabilities and Requirements" document[2] that is provided as a framework to the teams, and then updated as necessary as the capstone team progresses through the Feasibility Phase of the design. 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 specific 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, providing specific performance functionality as compared against a provided benchmark that the device is to achieve. Using the portable drone aircraft example, one of the criteria in support of CAP-01 could be as follows:

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

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 evaluation 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.

The Demonstration Test Plan 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 into the document. Demonstration tests do not require a functional 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.

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 with detailed test steps, and each noting which requirement has been addressed.

Rubrics in the Assessment Process

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. However, what is gained in efficiency is more than offset by the lost opportunity for identifying specific deficiencies in student performance. 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 requires an analytical approach to grading, where the assignment is broken down into its constituent parts, with each part being scored independently.[3]

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.[4] 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. 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 provides 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.

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 to both their advisor and the capstone supervisor. 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 work schedule for the next two weeks. The Report is used to document progress (or lack thereof), provide additional written communication practice, and allows for oversight of all projects by the capstone coordinator.

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 Test Plan; 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. 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.

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 has to produce a final report that is evaluated via rubrics by the PRB. However, the final oral presentation is given to both the entire 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 seniors 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.

Results

Assessment data was collected through examination of 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

Table 1. Student Evaluation Responses by Cohort.

The course helped me:	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
# of responses /cohort size	15/20	24/35	20/27	32/40	26/40
Learn to apply design principles to real world problems.	4.4	4.3	4.3	4.1	4.5
Develop confidence to engage in problem solving and design discussion.	4.7	4.4	4.1	4.1	4.6
Develop an ability to work effectively in teams and respect team work.	4.1	4.4	4.1	4.1	4.5
Develop project management skills.	3.6	4.2	4.2	4.1	4.5

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.

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. In the first year of the Capabilities and Requirements reporting format 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 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.

Conclusion

A capstone design course is certainly not new 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. 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. Finally, 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.

Resources

Copies of all materials referred to in this paper are available at the following web site:
http://www2.onu.edu/~j-estell/seniordesign/

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