EVALUATING THE CAPSTONE EXPERIENCE FROM THE PROFESSIONAL PRACTICE PERSPECTIVE

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Abstract

In the Department of Civil and Environmental Engineering at Northern Arizona University, we work closely with our Departmental Advisory Committee (DAC) to assure our curriculum is relevant to current engineering practice. The DAC consists of professional engineers primarily from the Arizona engineering community. In January 2005, the DAC set out to develop a capstone evaluation tool for their use in evaluating the final presentations of the year-long capstone design projects of our senior engineering students as a measure of learning outcomes. The tool, however, goes far beyond evaluating outcomes. It also serves to inform the faculty and students about what skills and attributes are important to our constituency as represented by the DAC, to enhance the overall performance of our seniors with their design project, and to further engage our DAC with the Department.

Introduction

The Department of Civil and Environmental Engineering (CENE) at Northern Arizona University (NAU) has the benefit of an active Departmental Advisory Council (DAC) which provides assistance to the department in a variety of capacities. Key roles of the DAC have included assisting in the continuous improvement processes associated with the Accreditation Board for Engineering and Technology (ABET) Criteria[1] 2, 3, 4 and 8 of our Bachelor of Science in Engineering programs in Civil Engineering and Environmental Engineering. As such, the DAC has recently helped in the development and use of a tool for evaluating our senior capstone design presentations. We discovered that in addition to the specific feedback on the capstone projects, the tool documents students' achievement of program learning outcomes and gives insights about the effectiveness of our design curriculum. It has focused the Department's discussions about curricula improvements; leading to refinements and enhancements of the junior and senior design courses.

The Design Curriculum at NAU

For engineering students at NAU, the capstone course is the culmination of a four-year sequence of five design courses known as *Design4Practice*, or D4P. These courses represent 13 of the 24 design credit hours in the Civil and Environmental Engineering programs at NAU. Implemented in 1994, D4P is intended to provide students with hands-on learning and the continuous practice of a broad set of professional skills in a cross disciplinary setting.

The D4P builds technical, managerial, and professional skills by increasing project intensity, technical difficulty, and process complexity one course at a time. EGR 186 and 286 are multi-disciplinary courses followed by the disciplinary CENE 386W, 476, and 486C. Each preceding D4P class serves as a prerequisite to the proceeding one and fosters the accumulation of skills and knowledge to

ensure a successful major design experience in the senior year. We summarize emphasis areas in the D4P curriculum in Table 1.

Table 1. Emphasis Areas in the Design4Practice Curriculum

- High-level design, creativity
- Detail design, analysis, tools, methods
- Prototyping, iterating, and building
- Documentation and communication skills
- Teaming and organizational theory
- Professionalism and ethics
- Economic analysis and budgets
- Planning, scheduling, risks, and change
- Customer and subcontractor interactions
- Project-driven technical, analytical and contextual knowledge

Senior design is a year-long experience for the CENE students and consists of CENE 476 in the Fall and CENE 486C in the Spring. CENE 476 Capstone Preparation is a one credit course that focuses students on finding a project, assembling a team, and creating a project proposal with scope, requirements, design concept, schedule, and budget. CENE 486C Senior Capstone Design is the follow-on course where detail design, analysis, iteration, documentation, presentation, and sometimes implementation take place. The programs of study are organized so all of the required technical courses are taken prior to CENE 486C; providing students with the opportunity to apply their skills and knowledge in a true culminating major design project.

The formats of the capstone courses are intended to resemble projects in engineering practice. Two professors, each possessing professional engineering licenses, co-teach the CENE 476 and 486C courses and act as project managers for teams of three or four students. At current enrollment levels, the instructors manage eight to ten teams per year. Each team has a separate project with an external client. Clients are typically representatives of city, county, or tribal governments, or private individuals or organizations. The course instructors and student teams work with the client to develop a scope of work, and the client understands that the resulting work products are not professional engineering documents. Students are also required to seek out the guidance of technical advisors who are typically departmental faculty and local practicing engineers.

The work products for capstone also resemble common deliverables in engineering practice. The CENE 476 students produce a design proposal in response to a request for proposals issued by the instructors. The students' CENE 486C deliverables include incremental 30, 60, 90 and 100 percent reports, a final plan set of design drawings, a poster and website for their project, and a 20-minute presentation of their project.

Final presentations are made in a professional conference setting near the end of the academic year. All of the engineering and science departments at NAU participate in the Celebration of Undergraduate Research and Design conference,

which we refer to informally as the capstone conference. Clients and instructors evaluate the students' work, while family and friends share in the student design experience.

The DAC and the Capstone Tool

The Department maintains a continuous improvement process that extends across all aspects of our two programs and attends not only to outcomes and objectives, but to students, faculty, professional issues, and the overall university environment. A goal of this process is to produce the type of engineering graduates valued by our constituency. Our constituency is represented by our 34-member DAC composed primarily of alumni, employers of our graduates, and representatives of graduate and professional schools. The goals of the DAC include reviewing and providing feedback on curricular offerings and providing advice on student recruitment, retention, career development and placement; faculty and academic programs; and capital and resource development activities.

A valuable contribution of the DAC to our continuous improvement efforts has been their evaluation of our student presentations. Traditionally the DAC has met on the day before our Capstone Conference and we have informally invited DAC members to observe student presentations. We recently formalized this process by developing an assessment tool with the initial intention of evaluating program outcomes. We soon realized that it also serves to inform the faculty and our students about what skills and attributes are important to our constituency as represented by the DAC, to correspondingly guide curriculum conversations, to bring additional focus to our senior-level capstone experience, to enhance the overall performance of our seniors with their culminating design project, and to further engage our DAC with us and our students.

Implementing the Tool

The DAC initiated the development of the capstone design evaluation tool at their January 2005 meeting through the work of a six member subgroup of DAC members and faculty. At this meeting, the sub-group decided on the tool's overarching principle: compare the capstone projects to industry standards of performance and then lay in ABET outcomes afterward. Following the meeting, two of the authors undertook the task of creating a tool from the meeting's discussions. The tool was drafted, critiqued and revised, and finalized for piloting at the Spring 2005 DAC meeting and for use at the capstone conference that same spring.

Capstone Conference 2005

In April of 2005, the DAC piloted the use of the capstone tool by trying it out with one example student team at the DAC meeting. This piloting exercise generated much discussion and a small number of revisions that were made over

night, so the revised tool could be used by the DAC evaluators at the capstone conference on the next day. Five DAC members stayed over for the 2005 conference and used the tool to assess the design projects of the civil and environmental engineering students.

The data from the Spring 2005 evaluations were collected and synthesized, and presented to the DAC in their Fall 2005 meeting. At this meeting, the DAC analyzed the results and the tool. In addition to making a few editorial changes and adding one additional metric, the DAC concluded that the tool did what was needed and it contained the right balance of technical, project management, and communication metrics. The DAC requested, however, that evaluator training be provided the day before 2006 capstone conference. This request was made to reduce the recognized variability of scores.

Capstone Conference 2006

The April 2006 DAC meeting incorporate the requested evaluator training whereby another example student team presented while the DAC members simultaneously used the revised evaluation tool to evaluate their project. Evaluation results were then compared and discussed. This discussion centered on two issues. The first was "What to do if a team did not address an item from the tool?" After much discussion, the DAC decided the following. Given that the students had been provided the evaluation criteria via their syllabus and by other means during their capstone courses, the DAC decided that missing items are given a score of "1." This score was in contrast to other possible options of a "3" or NA. The second issue affirmed and refined the evaluation tool's basic premise. The capstone teams and their respective projects should be evaluated within the context of a professional environment, but whereby the project represents the employee's first real project. Seven DAC members stayed over from the DAC meeting and attended the Spring 2006 capstone design conference and used the tool. Their results were analyzed at the Fall 2006 DAC meeting. Table 2 presents a summary of project score averages in the three skill areas plus the total score average.

Capstone Conference 2007

Based upon the DAC's Fall 2006 review of the Spring 2006 student capstone projects, a few additional revisions to the tool were suggested and were incorporated in time for the start of the spring semester. These included: rebalance the major category weighting to place more emphasis on the technical, revise scoring and questions so the form totals to 100, and encourage its distribution to the capstone students early in the spring semester combined with some use in assigning course grades. The current version of the tool is presented in Figure 1.

Table 2. Spring 2006 Capstone Evaluation Scores (Averages)

Project Name	Number of Evaluators	Technical Skills	Communication Skills	Management Skills	Project Total
Walnut Canyon Site Restoration	3	0.85	0.92	0.72	0.810
Flagstaff Reservoirs	4	0.86	0.81	0.66	0.764
Concrete Mix Design	2	0.94	0.87	0.91	0.910
Steel Bridge	3	0.83	0.81	0.87	0.844
Snowbowl Pedestrian Crossing	4	0.85	0.86	0.73	0.798
Concrete Canoe Hull Design	2	0.96	0.94	0.93	0.943
Residential Bridge Project	2	0.70	0.86	0.66	0.719
Arboretum Accessibility Design	2	0.86	0.96	0.80	0.857
Portable Water Treat. System	5	0.87	0.90	0.80	0.848
On-Site Waster Water Project	5	0.79	0.88	0.72	0.779
Class Average		0.85	0.88	0.78	0.827

As in previous years, the DAC invited a student team to make a presentation the day before the capstone conference to allow the DAC to practice using the tool and to compare their scoring. Each member tallied their scores and then discussed with their counterparts the tool and the project itself. A group-wide discussion followed focusing on the student project and on ways the DAC could help with enhancing the experience.

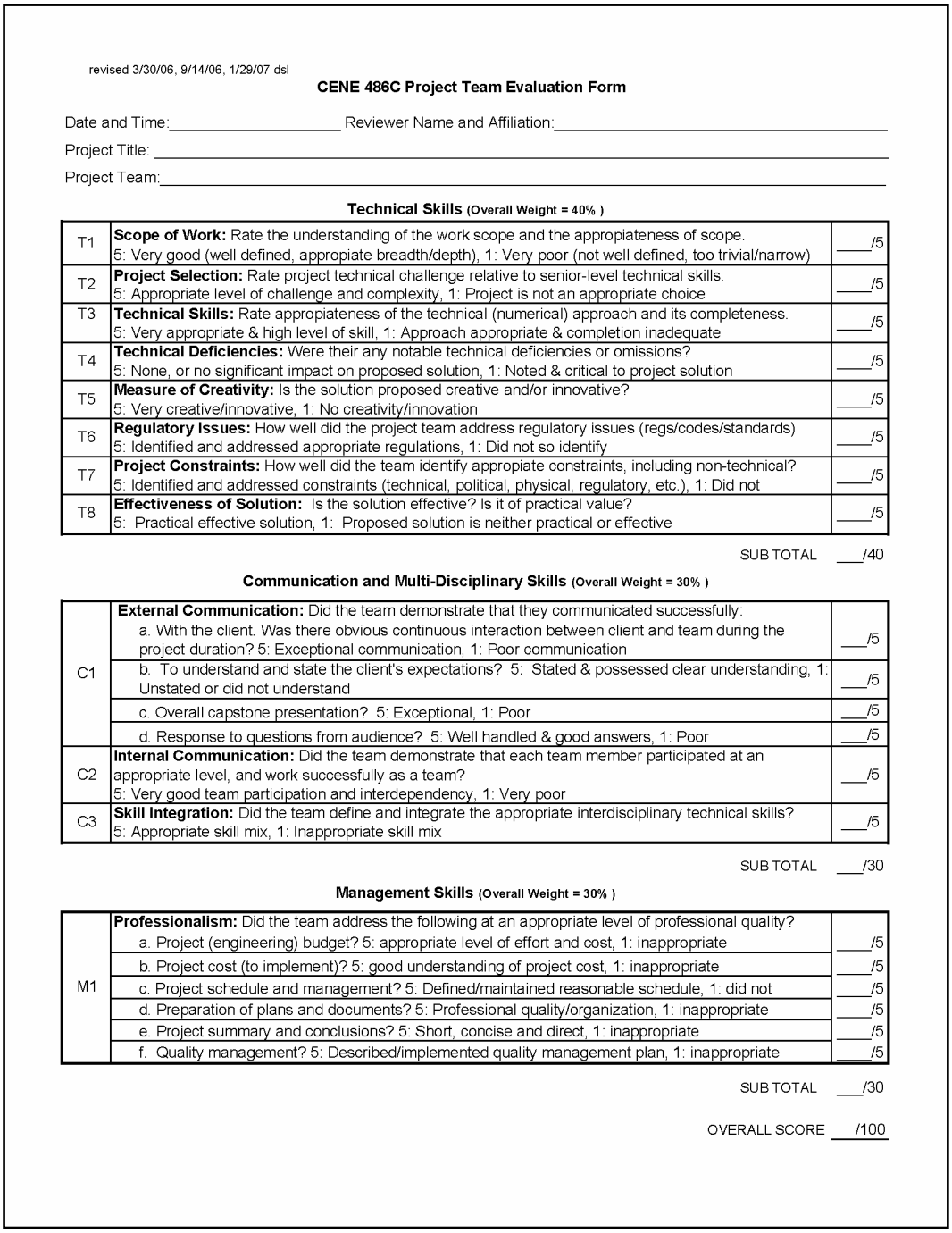
Similar to the conclusions of the DAC's Fall 2006 review of the previous capstone projects, this student team was not as successful with project management, as they were with the technical aspects of their project. Based upon this feedback and combined with the Department's review of outcome achievement, the CENE is refining its curriculum. The Spring 2008 offering of CENE 386W will be revised to further student skills in budget, scope, schedule, and overall project management. Additionally CENE 486C will be modified to include cost estimating and other management topics as follow-on to CENE 386W.

The additional assistance offered by the DAC included:

- Create a DAC Directory of Expertise upon which student teams could call when in need of technical advice.
- Establish a panel of DAC members to evaluate the student projects at mid-year to provide early and expert intervention.

Discussion

The use of our Departmental Advisory Council to assist in the evaluation of capstone teams takes advantage of some natural affinities and suffers from some inherent disadvantages. The strongest affinities relate to the linkages between our program for the continuous improvement of our curriculum, the assistance that our outside constituency can provide in maintaining a current and relevant



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CENE 486C Project Team Evaluation Form

Date and Time:_____ Reviewer Name and Affiliation:_____

Project Title: _____

Project Team:_____

Technical Skills (Overall Weight = 40%)

T1	**Scope of Work:** Rate the understanding of the work scope and the appropiateness of scope. 5: Very good (well defined, appropiate breadth/depth), 1: Very poor (not well defined, too trivial/narrow)	____/5
T2	**Project Selection:** Rate project technical challenge relative to senior-level technical skills. 5: Appropriate level of challenge and complexity, 1: Project is not an appropriate choice	____/5
T3	**Technical Skills:** Rate appropiateness of the technical (numerical) approach and its completeness. 5: Very appropriate & high level of skill, 1: Approach appropriate & completion inadequate	____/5
T4	**Technical Deficiencies:** Were their any notable technical deficiencies or omissions? 5: None, or no significant impact on proposed solution, 1: Noted & critical to project solution	____/5
T5	**Measure of Creativity:** Is the solution proposed creative and/or innovative? 5: Very creative/innovative, 1: No creativity/innovation	____/5
T6	**Regulatory Issues:** How well did the project team address regulatory issues (regs/codes/standards) 5: Identified and addressed appropriate regulations, 1: Did not so identify	____/5
T7	**Project Constraints:** How well did the team identify appropiate constraints, including non-technical? 5: Identified and addressed constraints (technical, political, physical, regulatory, etc.), 1: Did not	____/5
T8	**Effectiveness of Solution:** Is the solution effective? Is it of practical value? 5: Practical effective solution, 1: Proposed solution is neither practical or effective	____/5

SUB TOTAL ___/40

Communication and Multi-Disciplinary Skills (Overall Weight = 30%)

C1	**External Communication:** Did the team demonstrate that they communicated successfully: a. With the client. Was there obvious continuous interaction between client and team during the project duration? 5: Exceptional communication, 1: Poor communication	___/5
	b. To understand and state the client's expectations? 5: Stated & possessed clear understanding, 1: Unstated or did not understand	___/5
	c. Overall capstone presentation? 5: Exceptional, 1: Poor	___/5
	d. Response to questions from audience? 5: Well handled & good answers, 1: Poor	___/5
C2	**Internal Communication:** Did the team demonstrate that each team member participated at an appropriate level, and work successfully as a team? 5: Very good team participation and interdependency, 1: Very poor	___/5
C3	**Skill Integration:** Did the team define and integrate the appropriate interdisciplinary technical skills? 5: Appropriate skill mix, 1: Inappropriate skill mix	___/5

SUB TOTAL ___/30

Management Skills (Overall Weight = 30%)

M1	**Professionalism:** Did the team address the following at an appropriate level of professional quality? a. Project (engineering) budget? 5: appropriate level of effort and cost, 1: inappropriate	____/5
	b. Project cost (to implement)? 5: good understanding of project cost, 1: inappropriate	____/5
	c. Project schedule and management? 5: Defined/maintained reasonable schedule, 1: did not	____/5
	d. Preparation of plans and documents? 5: Professional quality/organization, 1: inappropriate	____/5
	e. Project summary and conclusions? 5: Short, concise and direct, 1: inappropriate	____/5
	f. Quality management? 5: Described/implemented quality management plan, 1: inappropriate	____/5

SUB TOTAL ___/30

OVERALL SCORE ___/100

Figure 1. Capstone assessment tool used by the Departmental Advisory Council.

curriculum, and our desire to conduct realistic capstone projects. We make it clear to students that their senior design experience reflects their transition to engineering practice, and as such they will be evaluated by practicing engineers. However an unrealistic aspect of the senior design teams is that they are in effect

composed entirely of entry-level engineers[2]. We recognized this, but have yet to fully reconcile this problem in our evaluations.

The tool is used to evaluate both student performance and the effectiveness of our curriculums. Indeed the initial intention was to use the tool to assess ABET Criterion 3 learning outcomes. In 2006 and 2007, student grades were based, in part, on their scores from the evaluation tool. Those elements that were not fully controlled by the students such as T2 Project Selection (Figure 1), were not incorporated into the course grading scheme. A related question arises when students scored poorly on the section relating to management skills. Consistently poor scores reflect curricula problems, rather than poor performance by the teams. As indicated by the consistently lower scores in Management, one of the strengths of the assessment tool is the feedback it provides to the instructors. Rarely have we had the opportunity to base course improvement on information beyond the evaluation forms filled out by students at the end of the term and by self-assessment. Improvements that have been made to the course based on DAC comments include providing additional instruction in graphics and presentation of engineering design concepts and attention to regulatory issues. Future improvements will include additional instruction in project management, better attention to project scoping, and providing additional technical expertise to student teams.

An aspect of the assessment tool that bears further study is the fact that it applies only to the students' final presentations. In its current implementation, DAC evaluators do not see any of the other work products of the students. In a sense this reflects the reality that there are certain "high stakes" presentations made in engineering practice, but we may be missing opportunities to take full advantage of the willingness of our DAC to provide input to our program by limiting their exposure of senior design projects to individual presentations. The additional involvement volunteered by the DAC during their 2007 Spring meeting may be worthwhile.

Students responded positively to the prospect of being evaluated by engineering practitioners. Informal discussions with students and comments on evaluation forms revealed that having to meet the expectations of professional engineers, rather than "just" their instructors provided an additional element of realism to the course and increased their perception of the level of performance to which they would be held.

The feedback we obtain from these annual DAC evaluations can extend well beyond improvements to the senior design courses. As indicated by the decision to increase the content of project management in the junior-level CENE 386W course, we have the flexibility to fine-tune course content down to the freshman level if necessary to provide students with the skill set to complete their senior design project.

Conclusions

In the Department of Civil and Environmental Engineering at Northern Arizona University, we have developed a mechanism for our Departmental Advisory Council to evaluate our senior design presentations. To date we have implemented this assessment tool for three successive years and through incremental minor revisions have refined our understanding of its capabilities in terms of assessing our program for ABET purposes, evaluating our student teams, and providing feedback to instructors for course improvement. Specific areas of course improvement include providing additional instruction in engineering graphics and project management and including technical review by the DAC earlier in the senior design process. The senior design courses are the culmination of a four-year set of design courses at NAU. As a result the feedback provided by the DAC has the potential to improve the content of courses throughout the design sequence.

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