AC 2010-941: COLLABORATING WITH LOCAL PRACTITIONERS TO LEAD A CAPSTONE CIVIL ENGINEERING DESIGN COURSE

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Collaborating with Local Practitioners to Lead a Capstone Civil Engineering Design Course

Abstract

The paper describes a civil engineering capstone design course led by faculty and practitioners. The objectives, content, and organizational structure of the two-quarter capstone course are summarized. The primary student activity involves work on a multidisciplinary private sector development or public works project. During the first term, the students prepare a written Statement of Qualifications in response to a specific Request for Qualifications. During the second term, the students prepare a written Design Report with a full set of calculations and design drawings. Each term, the students present their ideas orally to a panel of faculty and practitioners. An instructional team of three to five faculty members and up to thirty senior-level practitioners leads each course offering. The practitioners play an essential role in the delivery of the course, acting as section instructors, guest speakers, interview panel members, and project advisors. Details regarding the responsibilities of the instructional team members are included in the paper. The paper also describes how local practitioners are prepared for their assignments. The new course represents a valuable program assessment tool since class activities permit direct measurement of program outcomes. Included in the paper are discussions of the course assessment processes and the procedures used to promote grading consistency among the faculty and practitioner evaluators. Improvements made to both the course and program are discussed.

Introduction

Our civil engineering capstone design sequence recently morphed from an individual study course into a directed study offering. A number of concerns motivated this change, including the desire to provide a realistic multidisciplinary capstone design experience and the desire to improve our degree program's assessment processes. Since the new course was introduced, over six hundred students working in over one hundred design teams have completed four different projects, all under the direction of four faculty members and a team of practicing professionals. To date, over forty local professionals have participated as members of the instructional team.

In this paper, we discuss the motivation for changing the format of the course. We also describe the structure of the new course and the activities that course participants are expected to complete. In developing and implementing the new course, we relied extensively on support provided by local civil engineering professionals. The local professionals were recruited to assist with the course so that (1) we could provide realistic design experiences for the students and (2) we could integrate professional practice issues directly into the course curriculum. In the paper, we describe the specific roles that local professionals play on the instructional team.

Both faculty members and local practitioners helped to assess course and program outcomes. We present course and program assessment data in the paper, along with a brief discussion of the results.

Background

Prior to 2006, the culminating design experience for civil engineering undergraduates at our institution was realized through a two-term course sequence entitled Senior Project. Individual students would work with a faculty member of their choosing to develop a proposal that defined their project objectives, scope of work, and timetable for completion. Most students selected their study topic from lists provided by the faculty members. However, sometimes a student would propose his or her own topic.

By fall 2004, the graduating senior class for the civil engineering program had grown significantly to nearly 150 students. Small issues that had always been associated with the Senior Project course had grown into full-fledged problems that required immediate attention:

- It had become increasingly difficult for the faculty and students to come up with novel projects.
- Projects often focused more on analysis than design.
- Projects often focused on only one of the four civil engineering emphasis areas taught within our curriculum (i.e. geotechnical, structural, transportation, and water resources engineering).
- The technical work undertaken often failed to account for the many non-technical issues that frequently control real-world designs.
- Project report and assessment standards varied considerably from one faculty member to another.
- Average grades in Senior Project were nearly a full grade point higher than those awarded in the program's other senior-level technical elective courses.
- Students frequently failed to complete their projects by the end of their final term in residence, which delayed graduation dates.
- Several faculty members were spending considerable time on senior project advising, which was keeping them out of the classroom and limiting their ability to pursue other professional development activities.

To address these growing problems and to provide a more realistic team-driven design experience for our students, the faculty members decided to switch to a structured course format for Senior Project. Other civil engineering programs had demonstrated prior success in developing structured capstone design courses for their students [1,2,3,4]. More recently, other authors have discussed their experiences with civil engineering capstone design courses [5,6].

In developing the focus of the new course, the faculty members decided to combine an integrated design exercise with elements of the program's existing course on "professional practice" in civil engineering. This course had been taught as a senior-level elective for the past ten years and had proven to be popular with the students. Over a third of our graduating seniors filled the course each year. Other civil engineering programs have developed similar courses[7]. In our course, local professionals presented lessons and exercises on various topics including ethics, professional licensure, leadership, communication, and project management. Course content focused on topics emphasized in two textbooks on project management [8,9].

In addition to participating in discussions with practitioners and completing supplemental assignments, the students in our professional practice course completed a Statement of Qualifications (SOQ) for a local engineering project. The students worked in teams of four to six students during the entire quarter to complete a written SOQ document. At the end of the term, the teams presented their findings to a three-person panel that included a faculty member, a public works official, and a private consulting engineer.

The faculty members felt it essential to incorporate a professional practice component into the new senior design course, given the past success and popularity of our professional practice course, the opportunity to further involve local practitioners in our capstone design offering, and the desire to more fully address some of the non-technical outcomes associated with the program's mission. The value of working with practicing civil engineering professionals in the classroom has been discussed by others [4,5,10,11,12]. Several authors have proposed means for incorporating non-technical outcomes into a capstone experience [13].

Course Outcomes and Activities

The new Senior Design capstone course sequence was designed to address the deficiencies and problems noted above. We selected course content to ensure that each senior had an opportunity to (1) participate as a member of a multidisciplinary team in an integrated culminating design experience, (2) acquire/practice many of the professional skills that are used on a daily basis by design engineers, and (3) demonstrate minimum technical proficiency in geotechnical, structural, transportation, and water resources engineering. We specified outcomes for the capstone course that corresponded with program outcomes and performance metrics developed by our constituents. These outcomes and performance metrics were based on the current ABET accreditation criteria and the Civil Engineering Program Criteria that were proposed for the 2008 evaluation cycle. We defined performance metrics as specific skills that we expected our students to have by the time of graduation. Table 1 lists performance metrics that were given particular emphasis in the new course offering.

Activities Outside the Classroom

The new course includes activities that are undertaken outside and inside the classroom. The primary outside-of-class activity involves work on a multidisciplinary private sector development or public works project that would benefit one of our local communities. The project is selected before the course begins with assistance from local consulting engineers and public works personnel. The project must include elements of geotechnical, structural, transportation, and water resources engineering, and an adequate set of field data must be available.

During the first term of the course, the students prepare a written Statement of Qualifications (SOQ) in response to a specific Request for Qualifications (RFQ). During the second term, the students prepare a written Design Report that includes a full set of calculations and design drawings. Each term, the students present their ideas orally during a formal 50-minute interview. Interview performance is assessed by a three-person panel consisting of a faculty member and two senior-level practitioners (all of whom are licensed Professional Engineers).

Table 1 - Program Outcomes and Performance Metrics Emphasized in the Development of the Capstone Course Curriculum

Outcome	Performance Metrics
Graduates have an ability to design a civil engineering system, component, or process to meet desired needs within realistic constraints	Demonstrate an ability to interpret current civil engineering standards and incorporate them into design Demonstrate an ability to design a civil engineering system, component, or process Demonstrate an ability to recognize and incorporate multiple design constraints Demonstrate an ability to produce civil engineering design drawings
Graduates have an ability to function on multidisciplinary civil engineering teams	Demonstrate an ability to describe the interpersonal and communication problems that hinder effective teamwork Demonstrate an ability to evaluate different personality types Demonstrate an ability to apply active listening techniques Demonstrate an ability to function effectively on a design team comprised of individuals representing two or more civil engineering emphasis areas
Graduates have an understanding of professional and ethical responsibility	Demonstrate knowledge of the American Society of Civil Engineers (ASCE) Code of Ethics Demonstrate an ability to apply ethical codes and evaluate ethics cases that may arise in civil engineering practice Demonstrate an ability to assess the impact of engineering designs and decisions on public safety and the environment Demonstrate an ability to identify and explain important aspects of project management, scheduling, contracts, risk management, and professional liability Demonstrate an ability to explain the reasons for seeking professional licensure after graduation
Graduates have an ability to communicate effectively	Demonstrate an ability to write effective essays and technical reports Demonstrate an ability to compose and deliver an effective oral presentation Demonstrate an ability to prepare a Statement of Qualifications (SOQ) for a civil engineering project
Graduates have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	Demonstrate an ability to develop community consensus building techniques for a civil engineering project Demonstrate knowledge of important environmental regulations relevant to civil engineering design
Graduates have an ability to use the techniques, skills, and modern engineering tools necessary for civil engineering practice	Demonstrate an ability to operate civil engineering drafting software

To date, we have offered the new capstone design course four times. The four projects involved: the design of a commercial office complex with associated parking and municipal roadway improvements; the design of a two-lane emergency access bridge over a protected creek; the design of a residential housing development with associated municipal drainage and roadway improvements; and the design of a high school football stadium, track, and parking lot with associated roundabout improvement. To illustrate the scope of work for a typical design project, we describe one of the projects in more detail below.

The 2008 project involved the design of a high-density, multi-family residential development for a local municipality in dire need of additional low- to medium-income housing. The design activities were complicated by aesthetic considerations (since this is an infill project, and any new development must have a minimal impact on existing vistas and be consistent with the City's vision, as laid out in its various planning documents) as well as environmental issues (since the 6.5 acre site includes steep slopes, protected vegetation, and a seasonal creek that drains into a major regional river). Each student team was required to create a specific design proposal that, at a minimum, addressed each of the issues enumerated below. In developing the project scope, we worked closely with local practitioners already involved with this project. We learned through multiple offerings of the course to spend considerable time developing the project scope so that the students had adequate time to complete their projects.

General:

- Site design including an improvement plan showing the location of all dwellings, retaining walls, roads, parking areas, open spaces, and key drainage features.

Geotechnical / Structural:

- Foundation design for dwellings.
- Lateral support system or retaining wall design (critical section only).
- Material and compaction specifications for all fill and pavement sections.
- Structural design for the vertical and lateral load resisting systems.

Transportation / Traffic:

- Geometric alignment of all intra-parcel roads.
- Pavement cross-section design for roads and parking areas.
- Striping plan and recommended signage.
- Recommendations for street improvements that are consistent with both the General Plan Circulation Element and the Traffic Impact Analysis performed for this development.

Utilities / Water Resources:

- Recommendations for preventing surface erosion.
- Recommendations for maintaining the quality of storm water discharge.
- Intra-parcel storm water management system design and detailing.
- Storm drain design to verify the adequacy of an existing culvert.

Other:

- Environmental compliance and permitting.
- Project advocacy in the context of community review.

Each student team was provided with an identical set of data, including architectural drawings, information on the local and regional geologic setting, a site-specific soils engineering report, traffic studies, rainfall intensity-duration-frequency curves, streamflow data, and AutoCAD files that define the site and regional topography and the location of all existing utilities. All design solutions were required to conform to all applicable local codes and standards.

Each student team was required to present their design recommendations in a comprehensive written report and a 20-minute presentation (which was followed by a 20-minute question and answer session and a 10-minute debriefing). The written report included a summary of the proposed design, which was supported by high quality engineering drawings and well-documented engineering calculations. The report also included a discussion of the team's overall approach to completing the work, recommendations for conducting the required public review, and suggestions for how best to obtain all necessary approvals and permits.

Activities Inside the Classroom

The new capstone course includes seminar-style presentations on such professional issues as assertiveness and interpersonal communication, advocacy and consensus building, negotiation, qualifications based selection, leadership and motivation, project management, delegation, contracts, professional liability insurance, risk management, avoiding litigation, environmental permitting, professional ethics, professional licensure, construction estimating, and miscellaneous contemporary issues. These topics were taken from the professional practice class described previously. Mostly local senior-level civil engineering professionals give the presentations. All students attend these presentations together in a lecture environment, and concepts are reinforced through in-class reflection exercises.

The course also provides formal instruction in four different civil engineering emphasis areas - geotechnics, structures, transportation, and water resources. Technical modules within these areas focus on quantitative considerations important for the design project and serve to reinforce some of the knowledge areas that typically appear in the breadth session of the National Council of Examiners for Engineering and Surveying (NCEES) Principles and Practice of Engineering Exam. These modules focus on such quantitative considerations as bearing capacity of shallow foundations, axial capacity of deep foundations, consolidation settlement, reinforced concrete spread footing design, reinforced concrete stem wall design, masonry design, timber design, seismic analysis and design, geometric highway design, pavement design, stormwater collection and management, culvert design, closed channel flow, and pumps. We worked closely with our Industrial Advisory Board and local practitioners to develop this list of topics. Faculty members and local practitioners give the modules. The students attend these modules in their design teams in a laboratory environment, and concepts are reinforced through in-class problem solving.

Course Format and Logistics

Course Delivery

Delivery occurs via a two meeting per week in a lecture-lab format that is valued at 3 quarter units per term (6 quarter units for the two-term sequence). Non-technical topics are discussed in a 110-minute Tuesday evening lecture session, and technical topics are presented in a 170-minute Thursday evening design laboratory. The first half of the lab session is devoted to a review of the evening's analysis/design packet, and the last half of the lab session is spent on team-based problem solving of a formal assignment.

The entire class (as many as 180 students) attends a common Tuesday evening lecture session. However, there are four separate Thursday evening lab sessions, which permit closer instructor-student contact during the associated analysis and design activities. On any given evening, one-quarter of the class will be dealing with geotechnics, one-quarter of the class will be focusing on structures, one-quarter of the class will be studying transportation design, and one-quarter of the class will be working with water resources. Each week, the instructors switch homerooms so that every student receives identical instruction by the end of a four-week rotation.

Team Formation

In the new course, essentially all student work (except for exams) is completed as a member of a multidisciplinary team. Therefore, considerable thought is given to selecting team rosters. The students complete a survey at the first class meeting that defines (1) their academic coursework, (2) their industrial experience, (3) their status with respect to Engineer-In-Training (EIT) certification, (4) their current grade point average, and (5) their experience with computer-aided design software. The course instructors use this information to subdivide the class into six-person teams, ensuring that each team has a comparable degree of technical breadth and depth, practical experience, professional preparation, and academic preparation. Each member of a given team is assigned a specific role (geotechnical specialist, structural specialist, etc.) that is in keeping with his/her elective coursework and industrial experience.

Student Assessment

A student's course grade is assigned based on his or her weighted course average (or SCORE). The current performance assessment equation is as follows

$$\mathbf{SCORE = (0.30 \cdot ICE) + (0.40 \cdot PRO \cdot PRS) + (0.30 \cdot EXM)}$$

where: ICE = performance on the in-class reflection and problem solving exercises; PRO = performance on the SOQ Project in Term 1 or the Design Project in Term 2; PRS = peer review score ($0 \leq PRS \leq 1$), as adapted from Martinazzi [14]; and EXM = performance on the final examination. Final exams are given at the end of each term. The exams are approximately two hours long and include non-technical and technical parts, which are based on content from the seminar-style presentations and the technical modules. This assessment equation has so far been quite effective at differentiating students on the basis of their personal effort and achievement, even though a considerable amount of each student's work is conducted as a member of a six-person team. The formula now used to establish a student's course grade (or SCORE, as defined above) is the product of earlier trials and errors. In a first iteration, the peer review score was a stand-alone category valued at 10 percent. The final exam was valued at 20 percent. In a second iteration, the peer review score was dropped altogether. Some highly motivated students felt that this removed much of the leverage they had over less-motivated teammates.

Faculty and Practitioner Instructional Team

An instructional team of three to five faculty members and up to thirty senior-level practitioners leads each offering of the senior design course. The practitioners play an essential role in the delivery of the course, acting as section instructors, guest speakers, interview panel members, and project advisors. All members of the instructional team are licensed Professional Engineers or appropriately certified non-engineering practitioners. Each team member has one or more of the following roles:

> **Course Coordinator** (1). The Course Coordinator is solely responsible for the content and administration of the course. The Course Coordinator is responsible for moderating the Tuesday evening seminars and ruling on all requests for special consideration with respect to any administrative matter (including absences from class, due dates of assignments, date and time of exams, grades, etc).
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> **Section Instructors** (4~6). The Section Instructors are responsible for leading the technical breakout sessions scheduled for the Thursday evening analysis/design labs. Sections have been team taught in the past. A particular Section Instructor will appear once in each section during each scheduled 4-week rotation. The Section Instructors are faculty members or practitioners with technical expertise in each of the following four emphasis areas: (1) geotechnical analysis and foundation design, (2) structural analysis and design, (3) traffic/transportation engineering and highway/pavement design, and (4) water resources and water supply/distribution.
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> **Guest Speakers** (12~16). Each Guest Speaker is responsible for preparing and delivering one of the Tuesday evening non-technical seminars. The speakers are senior-level practitioners who are well versed in the topic to be discussed and have personal experience with case histories that support the theoretical aspects of the seminar.
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> **Interview Panel Members** (12). The Interview Panel Members are responsible for reviewing the student-authored written SOQs and Design Reports and evaluating those same student teams during two 50-minute interviews (one each term). Interviews simultaneously take place in four separate venues, with each panel consisting of one faculty member, one senior-level consulting engineer, and one senior-level professional from a local public works agency. We require the Interview Panel Members to be registered Professional Engineers with relevant design experience.
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> **Project Advisors** (2). The Project Advisors hold senior-level positions within the consulting firm or public works department that is sponsoring the SOQ/Design Project. These individuals are extremely familiar with the nuances of the specific project being undertaken by the students and serve as the primary external contact point for project-related questions. We require the advisors to be registered Professional Engineers.

In 2009, the instructional team consisted of 2 tenured/tenure-track faculty members, 2 part-time lecturers, and 30 senior-level practitioners, making the capstone course offering a true faculty-industry collaboration. The course ran smoothly because of a well-defined organizational structure and universally enthusiastic team.

Experience and Outcomes

Completion Rate and Student Performance

As indicated in Table 2, the new lecture-lab format has corrected two nagging administrative issues associated with the old individual study format: project completion and project grade. The use of a structured delivery mode - with common activities, assignments, and assessment standards - has so far led to completion rates of 100 percent and has brought the average grade awarded in the capstone course back in line with the Civil Engineering Program average for senior-level electives.

Table 2 - Effect of Course Format on Student Performance

Metric	Old Format	New Course Format			
	Fall 2005	2006	2007	2008	2009
Number of Students Enrolled	62	138	146	173	160
On-Time Completion Rate	26%	100%	100%	100%	100%
Average Grade Awarded (4.0 Max) Capstone Design Course Only	3.9	2.8	2.7	2.7	2.9
Average Grade Awarded (4.0 Max) All Senior-Level Electives	3.0	3.0	3.0	2.9	3.0

The table illustrates that over 600 civil engineering students have completed the capstone design course under the new format. We have a rather unique situation at our institution, given the large number of students who pass through the civil engineering program each year. The large size of the program played a significant role in developing the curriculum and defining the format of the new capstone course.

SOQ and Design Project Assessments

Direct and indirect measures of student learning are taken on a regular basis as part of the Civil Engineering Program's continuous improvement efforts. The new Senior Design course incorporates many opportunities for assessing student learning at an especially critical point (just prior to graduation) using a consistent methodology. Indeed, the data collected in the new Senior Design course during the past four years have contributed significantly to the program's self-evaluation process. In the course, quantitative analysis/design assignments, qualitative reflection exercises, written project reports, oral project presentations, exam problems, and student/evaluator surveys are used to assess student learning relative to more than 40 program-specific outcomes and performance metrics. Scoring rubrics and multiple reviewers are used to assess student work whenever possible. Metric goals established by the faculty members help to define acceptable levels of student achievement. A unique and important aspect of the Senior Design course is that engineering professionals (from outside the program) now assess the abilities of all of our graduates relative to numerous technical and non-technical outcomes.

Consistency is always an issue when there are many individuals participating in a specific assessment. In order to promote assessment uniformity, custom scoring rubrics were developed for the written and oral components of the SOQ Project and the written and oral components of the Design Project. Each of the four rubrics is two or more pages long, so a full discussion of even a single example would be inappropriate. Hence, examples of assessment guidance are provided for only two categories. Guidance for a written evaluation category is reproduced in Table 3. Guidance for an oral interview category is reproduced in Table 4.

Table 3 - The "Design Summary - Engineering Drawings" Category of the Written Design Report Scoring Rubric

Area	Score	Qualifying Characteristics
Design Summary *Evaluate the team's engineering drawings and design details:*		
	100%	All of the engineering drawings are well laid out and of the highest quality. The team has seen engineering drawings before and has attempted to follow standards of practice in preparing their own.
	75%	Portions of the engineering drawings may lack important notes, dimensions, and/or details. The engineering drawings are basically solid, but they lack the clarity, completeness, detail, and/or aesthetic impact of a top-tier presentation.
	50%	Many of the engineering drawings are substandard. Certain required elements may be missing altogether. The work projects the image of a team that chose to take a minimalist approach to completing this particular task.

Table 4 -The "Audio-Visual Support" Category of the Oral Interview Scoring Rubric

Area	Score	Qualifying Characteristics
Audio-Visual Support *Evaluate the ability of the team to prepare effective presentation support materials:*		
	100%	The team is comfortable with the technology selected. The slides are extremely well constructed and easy to read. Each slide has an obvious purpose, and the total number of slides is appropriate for the allotted time. The presentation has been well proofed, and the glitz factor is just right.
	75%	The slides are pretty decent overall, but some may be difficult to read and/or contain grammatical errors. There may be too many slides for the time allotted. Some key issues and/or points may not be supported. Form may be getting close to obscuring and/or overwhelming content.
	50%	The slides or visual aids reflect a team that does not understand effective visual communication. The team spent very little time preparing the presentation support materials. There is evidence that the team does not fully understand the software and/or hardware that they are using.

Prior to assessment of the student projects, the Course Coordinator meets individually with each Interview Panel Member to discuss both the project and project grading. Each panel member is given a packet of information that includes the RFQ (Term 1) or RFD (Term 2), the scoring rubrics, an interview schedule, interview instructions, and review panel notes. The Course Coordinator and the panel member review this packet of information during their meeting. The review panel notes reiterate course objectives, provide hints on assessing the projects, and summarize important project design information and constraints. The notes are designed to assist the panel member in understanding the design project objectives and the expectations regarding project assessment.

A second 90-minute meeting involving the Course Coordinator, the Project Advisors, and all twelve Interview Panel Members is held each term just prior to the start of the oral interviews. During this norming session, the instructional team members have the opportunity exchange ideas and ask questions regarding the project. The forum helps to ensure that each reviewer understands the assessment standards set forth in the various scoring rubrics.

Shown in Table 5 are raw design project report and presentation scores for three different student design teams participating in the 2009 course offering. The table summarizes scores for four different reviewers for seven report categories (W1 to W7) and five presentation categories (P1 to P5). Scoring rubrics given to the Interview Panel Members provided guidance for scoring student performance in these categories. Recall that four panel members assessed each design report and three panel members assessed each oral presentation. We present the excerpted scores in Table 5 to illustrate the level of consistency observed in the scores assigned by the different panel members. These results are consistent with scoring results observed for all teams during all four offerings of the new course. Based on these results, we are satisfied that the scoring rubrics and norming sessions are helping to ensure consistency in the assessment of student work by faculty members and engineering practitioners.

As one would expect, our new capstone course is especially well suited for the assessment of student design skills. During each of the past four years, four separate reviewers (using detailed rubrics) graded each of the written Design Reports. Average scores for the past four years are shown in Table 6. Average scores in all categories exceeded our metric goal of 70 percent, indicating that the students had acceptable design skills at the time of graduation. However, the students' ability to prepare engineering drawings suggests that there is room for improvement in this area. Indeed, these relatively low scores were confirmed through individual post-course surveys completed by the reviewers, as well as through data collected in other courses. These results have caused the Civil Engineering Program to make curricular improvements in these particular subject areas, including a complete revamping of the sophomore-level CAD course sequence.

This is just one example of how faculty and industry professionals are working together in the new capstone course to assess and improve student learning. Valuable assessment results have also been collected with respect to our students' written and verbal communication skills, technical prowess in the different civil engineering emphasis areas, and problem solving abilities. For example, oral presentation assessment scores for Senior Design during the past four years are summarized in Table 7.

Table 5 - Excerpt from the 2009 Design Project Grading Sheet Showing Written Design Report and Presentation Scores for Three Teams and Four Reviewers

Team No.	Review Panel Member	Written Design Report Scoring Areas								Presentation Scoring Areas					
		W1 (5)	W2 (5)	W3 (5)	W4 (10)	W5 (5)	W6 (30)	W7 (10)	Total (70)	P1 (5)	P2 (2)	P3 (5)	P4 (10)	P5 (8)	Total (30)
22	1	4.5	4.5	5.0	9.5	4.0	27.0	9.0	65.0	3.5	2.0	4.0	7.0	7.0	23.5
	2	5.0	5.0	5.0	9.0	5.0	28.0	9.0	67.0	3.5	2.0	4.0	8.0	6.0	23.5
	3	5.0	5.0	4.0	9.0	4.0	27.0	9.0	64.0	3.0	2.0	4.0	9.0	7.0	25.0
	4	4.0	5.0	3.5	9.0	4.0	27.0	9.0	62.5						
Average:		4.6	4.9	4.4	9.1	4.3	27.3	9.0	64.6	3.3	2.0	4.0	8.0	6.7	24.0
23	1	4.0	3.0	4.0	8.5	4.5	24.0	8.0	58.0	4.5	2.0	4.0	9.0	7.0	26.5
	2	3.0	3.5	3.5	6.0	4.5	26.0	7.0	56.5	5.0	2.0	4.5	8.0	7.0	26.5
	3	4.0	3.0	3.0	8.0	3.0	24.0	9.0	56.0	5.0	2.0	3.0	7.0	6.0	23.0
	4	4.0	2.5	4.0	7.5	4.0	26.0	8.5	59.5						
Average:		3.8	3.0	3.6	7.5	4.0	25.0	8.1	57.5	4.8	2.0	3.8	8.0	6.7	25.3
24	1	3.5	3.5	3.5	7.0	3.0	23.0	7.0	51.5	3.5	2.0	3.5	7.0	5.0	21.0
	2	5.0	4.0	4.0	5.5	3.5	27.0	6.5	56.5	4.0	2.0	3.0	6.5	6.0	21.5
	3	4.0	3.0	3.0	6.0	4.0	27.0	7.0	55.0	5.0	2.0	3.0	7.0	4.0	21.0
	4	3.5	4.0	3.5	7.0	3.0	23.0	7.0	52.5						
Average:		4.0	3.6	3.5	6.4	3.4	25.0	6.9	53.9	4.2	2.0	3.2	6.8	5.0	21.2

Table 6 - Summary of Average Design Report Scores (out of 100) for Civil Engineering Senior Design Project Reports

Category Description	2006 Scores	2007 Scores	2008 Scores	2009 Scores
Project Understanding	73	76	80	79
Design Approach	78	76	77	79
Design Summary and Engineering Drawings	80	75	73	75
Design Calculations	82	85	82	85
Presentation and Overall Impact	75	77	74	78

Table 7 - Summary of Average Scores (out of 100) for the Oral Presentation Component of Senior Design Projects

Description of Scoring Component	2006 Scores		2007 Scores		2008 Scores		2009 Scores	
	SOQ	DES	SOQ	DES	SOQ	DES	SOQ	DES
Attire, Body, and Voice Control	79	86	80	81	86	86	83	84
Timing	80	89	84	88	84	72	88	81
Audio-Visual Support	83	80	80	84	77	81	80	83
Content and Overall Effectiveness	82	81	78	78	75	79	75	82
Response to Panel Questions	83	74	74	72	74	78	75	81
Note: SOQ = Statement of Qualifications (1st term); DES = Design Project (2nd term)								

Another benefit of the Senior Design course is that the course provides us with an ability to assess student learning of various professional skills embedded in the ABET criteria (general and program specific). These criteria state, among other things, that graduates understand professional and ethical responsibility; be able to explain concepts in management, business, public policy, and leadership; and be able to explain the importance of professional licensure. These topics are covered in some detail by the seminar-style presentations that are integral to the Senior Design course. Assignments, reflection exercises, and exam questions associated with these topics assist the faculty members in assessing student learning. For example, following the "Professional Ethics" seminar, students are asked to review ethics case histories presented by the National Institute for Engineering Ethics (NIEE). The Institute's web site presents real case histories and provides alternative solutions to the ethical issue being addressed. A take-home assignment in Senior Design requires the students to review two case histories and to develop written summaries supporting their chosen solutions. If appropriate, students are asked to cite specific "Fundamental Canons" or "Guidelines to Practice" from the American Society of Civil Engineers (ASCE) and/or National Society of Professional Engineers (NSPE) ethical codes. The assignment is graded on a scale of 0 to 10 using a rubric.

Practitioner Survey Evaluations

Near the end of the second term of the capstone course, immediately following the completion of the final design presentations and interviews, the Course Coordinator meets with the Interview Panel Members to discuss the design project results and the achievement of course objectives. These focus sessions have provided the course instructors with valuable suggestions for improving the capstone course and the Civil Engineering Program. For example, as a direct result of discussions during these meetings, scoring rubrics were modified to provide clearer assessment criteria, restrictions were placed on the scope of future design projects to help ensure that teams were given adequate time to complete their projects, and curricula for junior- and senior-level design courses were modified.

During this final meeting, each panel member is also asked to complete a four part survey designed to rate overall student performance for twenty-five different outcomes and performance metrics. The survey uses a 5-point rating scale where 1=Poor, 2=Fair, 3=Good, 4=Very Good, and 5=Excellent. We use a metric goal of 70 percent "good" or better when evaluating the results of the survey. Results for only Part I of this survey are summarized in Table 8 for the past three years. Note that we did not conduct the survey during the first offering of the course.

Table 8 - Example Results of Senior Design Panel Member Evaluations for the Past 3 Years (Part I of a four part survey)

Question	Percent "Good" or Better		
	2007	2008	2009
Part I - Assessment of Problem Solving and Design Skills: "Based on your evaluation of the design project reports and presentations, please rate the ability of the students to…"			
Recognize and incorporate the different design constraints of this project	86	91	100
Conduct research for this project using library and/or electronic resources	90	91	91
Identify and correctly interpret the relevant civil engineering codes and standards for this project	86	91	82
Interpret and assess data provided for the project (e.g. lab test results, field test results, topography, traffic data, as-built plans, etc)	100	100	91
Develop geotechnical engineering design solutions for the project	90	82	91
Develop structural engineering design solutions for the project	100	100	100
Develop transportation engineering design solutions for the project	76	82	100
Develop water resources engineering design solutions for the project	81	73	73
Evaluate the reasonableness of their design solutions relative to constructability, cost, regulatory environment, etc.	**57**	**45**	**55**
Assess the impact that their design solution will have on the local environment	71	**55**	**45**
Use computational software and/or spreadsheets to support their design calculations	100	100	82
Produce engineering design sketches and/or drawings	76	**64**	73

As noted in Table 8, the panel members rated three of the assessment categories below the metric goal. These results have led the civil engineering faculty members to develop and implement various program improvements. For example, and as noted previously, concerns related to our students' ability to produce engineering design drawings resulted in a revamping of our sophomore-level CAD course. We expect to see improvements in evaluation scores for the deficient areas noted in Table 8 as new undergraduate students navigate their way through the improved program curriculum.

Conclusions

The capstone design course sequence described in this paper has enabled the Civil Engineering Program at our university to meet a variety of short-term goals, including (1) ensuring that each senior has a similar culminating design experience, (2) ensuring that each senior completes his or her final design report prior to leaving campus, and (3) ensuring that each senior's work will be evaluated using a single assessment standard. The course also satisfies a number of program requirements by ensuring that each senior has an opportunity to (1) acquire a variety of non-technical skills that are used on a daily basis by design professionals, (2) participate, as a member of a multidisciplinary team, in a major culminating design experience, and (3) demonstrate minimum technical proficiency in geotechnical, structural, transportation, and water resources engineering. The course is a true faculty-industry collaboration. The local professional community has supported the course enthusiastically and without reservation. In fact, there is a long list of highly respected practitioners waiting for an opportunity to participate. In the eyes of many of the students enrolled, the involvement of so many design professionals as speakers and project reviewers is what validates the course and makes it such a great bridge between theory and practice.

Most of our recent graduates have not yet qualified (by virtue of insufficient post-baccalaureate design experience) to sit for the Professional Engineer licensing exam, so it's not yet possible to measure the effect this course has had on pass rate. However, surveys of our graduating senior class conducted during the past three years reveal that about 95 percent of our students earn their EIT/FE Certificate prior to graduation, even though such certification is not a degree requirement. At the very least, this course has led to an increased awareness of the importance of professional licensure and an increased desire to seek it. Indeed, a baseline survey conducted as part of the 2009 Senior Design course revealed that 90 percent of this year's graduating senior class (145 of 160 students) intended to earn a Professional Engineer license. All evidence indicates that the new course has fostered learning and enabled our graduates to be better prepared for the practice of Civil Engineering. On this basis, it may be concluded that the course has been an overwhelming success.

As part of the Civil Engineering Program's continuous improvement effort, direct and indirect measures of student learning are made on a regular basis. Having all seniors in a single class makes the job of data collection much easier. Many of the assignments, term projects, exam problems, and student surveys used in the Senior Design course were developed to assist in the evaluation of student learning relative to the specific outcomes and performance metrics defined for the Civil Engineering Program. A unique aspect of the course is that professionals (from outside the program) assess the abilities of all of our graduates relative to numerous outcomes.

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