AC 2007-1513: ENHANCING THE CAPSTONE DESIGN EXPERIENCE IN CIVIL ENGINEERING

Shashi Nambisan, Iowa State University

Shashi Nambisan, PhD, PE: Director of the Center for Transportation Research and Education and Professor of Civil Engineering at Iowa State University (ISU), Ames, Iowa. Prior to coming to ISU, Shashi was at the University of Nevada, Las Vegas (UNLV) from July 1989 to January 2007. He enjoys working with students and he has taught undergraduate and graduate courses in the area of Transportation systems as well as the undergraduate capstone design course sequence. An active researcher, Shashi has led efforts on over 130 research projects that have addressed and responded to local, statewide, regional and national issues in transportation and information systems management related to policy analysis, management, planning, infrastructure development, safety and operations.

Enhancing the Capstone Design Experience in Civil Engineering

Abstract

This paper documents efforts in and outcomes from a two-semester sequence senior design experience to address some of the programmatic needs and accreditation criteria established by ABET. The capstone design course sequence described herein was enhanced based on an evaluation by the department faculty that included internal and external feedback on the previous structure. The paper documents the process implemented to help address several program specific accreditation criteria and objectives. Key criteria addressed include demonstrating the ability to work on design projects, to work on teams, to communicate effectively, to manage resources, and to work on complex projects. The paper documents details regarding the course background, course content, course administration and management (including schedules, deliverables, and grading considerations). It describes the methods used to form student teams, select projects, roles of faculty and client advisors / mentors, specific expectations of the student teams. Instruments used to administer and manage the courses are presented, including illustrative assessment tools. Results of some of the assessment conducted on the course offering in the Spring and Summer 2006 offering of this course sequence are also presented. The evaluations of the effectiveness of the course to help students develop or enhance the abilities stated as course objectives indicate that the changes made to the course were effective. The participation of practitioners as clients / mentors, who served in supplementary roles to the faculty advisors and the course instructor, was seen to be beneficial.

Introduction

The need to provide undergraduate engineering students a well rounded educational experience, and to prepare them for success in the future (be it in industry or in graduate programs) has been well documented in the literature. These have been identified by a wide range of organizations such as ABET[1], the National Science Foundation [2]and the National Academy of Engineering[3]. Key areas of interest have been to help students appropriately apply concepts and theoretical principles, and to help students develop effective team work, management, and communication skills. Civil Engineering (CE) programs use a wide range of strategies to address such needs throughout the undergraduate curriculum. Design elements are typically incorporated across various courses. Examples of strategies used to help relate theory to practice include service-learning projects, experiential-learning, case-based projects, and industry-based or industry-sponsored projects [4, 5, 6, 7, 8, 9] . The capstone design course is an integral part of the approach of many undergraduate CE programs. CE programs typically use their Capstone or Senior-Design Course(s) is to demonstrate compliance with several of ABET's required accreditation criteria[10]. Various styles can be used to for the capstone design courses [11, 12]. The Civil Engineering program at <university> utilizes its Senior Design courses to help address several program specific accreditation criteria and objectives. This paper summarizes the Senior Design Course contents, administration, management, and evaluation of student performance.

Course Background

The subject capstone experience at <university> is open to undergraduate students in their senior year of their Civil Engineering degree program (i.e., based on their standing in the program and not based on the total number of credits completed at the university). The Senior Design experience is 2-course sequence: CEE 497 – Senior Design Project I, a 3-credit course in the first semester, followed by CEE 498 – Senior Design Project II, a 2-credit course in the next semester. CEE 497 has been offered every Fall and Spring semester. Students who complete CEE 497 in Fall are required to enroll in CEE 498 during the subsequent Spring semester. Likewise, Students who complete CEE 497 in Spring are required to enroll in CEE 498 during the subsequent Summer term.

Contribution to Professional Component

The Senior Design Project courses (CEE 497 & 498) are required of civil engineering majors and are taken in the student's senior year. Students are prepared for engineering practice by participating as a team in a major design experience. Teams are guided by a civil engineering faculty advisor and a practicing engineer advisor (client / mentor).

The CEE 497 and CEE 498 courses are intended to introduce civil engineering students to engineering project management and to provide a meaningful design experience. These courses were redesigned a few years back based on input and feedback from practitioners and the accreditation process, and in keeping with the department's programmatic approach. Two-thirds of the first course (2 semester credit equivalent) is an introduction to engineering project management. The remaining one-third is devoted to preparing a Design Proposal in response to one of several requests for proposals (RFPs) presented in class. The selected project is worked on and completed during the following semester in the second course - Senior Design Project II, which amounts to 2 semester credits of design.

The prerequisites for the first course in this sequence require students to have completed all their junior level Civil Engineering Courses, and all but one of the core Civil Engineering courses at the Senior level. Students who had not completed the Senior level core courses were required to complete them as co-requisites for the first of the two course sequence.

Specific requirements for this Senior design experience are that the students need to complete a project based on the following criteria:

1. The project must be based on the knowledge and skills related to the design process acquired in earlier course work. This explains the lengthy prerequisite list.
2. The project must incorporate engineering standards and be responsive to local codes and regulations. This explains why proposals are presented by practicing engineers.
3. Consideration must be given to the recognition of reasonable constraints imposed by economic, environmental, sustainability, manufacturability, constructability, ethical, health, safety, reliability, social, political, and aesthetic concerns. Not all projects lend themselves to consideration of each of these concerns but several should be addressed.
4. Students must work in teams.

As an outcome of the two courses, students must demonstrate an awareness of engineering practice issues such as:

a. marketing and procurement of work,
b. bidding versus quality based selection processes,
c. interaction of design and construction professionals,
d. importance of professional licensure,
e. importance of continuing education,
f. teamwork, motivation, and leadership,
g. project scope, budget, and schedule.

Course Details

This section addresses how the key criteria related to helping students develop or enhance specific were incorporated in the capstone design course sequence. While some of the accreditation related matters were already addressed in the capstone design experience at the university, it was felt that this experience could be significantly improved. Thus, an evaluation of the capstone design experience offered to the students was conducted several years ago. This evaluation included addressing comments from the last accreditation review by ABET, feedback from students and external constituents, and discussions among the faculty. This evaluation resulted in modifying the capstone experience at the university.

The enhancements to the course sequence include the following: in CEE 497 course including discussions on subjects such as engineer as a manager; engineering organization; motivation, leadership, delegation; communications and meetings; project management; licensure and ethics; engineers and law, contracts, engineering contracts, liability; ethics; Total Quality Management (TQM). Most of these are typically introduced and discussed in one or two class meetings. Specific project management and related topics discussed include the following: planning, scoping, scheduling, costing; identification of design project topics, team formation, proposal preparation, written and oral communications. Several class sessions are typically devoted to presentations of "project proposals" (RFPs) by practitioners, to team presentations on a case study and management topics, progress on project selection, proposal preparation and presentation.

One enhancement to the course sequence was the inclusion of guest speakers (who were practitioners. The guest speakers met with the class to discuss several topics and to impress upon them the importance of these matters in the practice of engineering. The philosophy adopted in this case is as follows: children are more likely to accept guidance about matters of significance or importance from "trusted" individuals other than their parents; likewise, students are more likely to "accept and learn" materials about the practice of engineering from practitioners than from their faculty instructors. The guest speakers were drawn from members of the Department's advisory board, leaders of local / regional engineering professional societies, principals / office managers of engineering firms (some were officers of national companies), and also administrators and managers from the public sector. The following are examples of topics addressed by these speakers:

- Engineering organizations;
- Licensure and ethics;
- Motivation, leadership, delegation;
- Communications and meetings;

- Project management;
- Costing and scheduling projects;
- Engineering contracts, liability; ethics;
- Procuring projects;
- Continuing education

By the end of the first semester, students had to form teams, identify a design project, develop a written proposal and present the same during a 15 minute oral presentation. Teams for the term project generally consist of two or three individuals per team. Strategies used for the selection of teams include self selection by students, and assignment of teams by the instructor. Each team is to work jointly on a term project for the entire semester. In order to form teams, students submitted requests to the instructor for their preferred team mates. The instructor reserved the right to accept or modify such requests. Such decisions were made based factors such as the need to balance teams with respect to the following criteria:

- Balanced GPA for teams across the class
- Mix of gender, ethnicity
- Personal preferences (especially to avoid strong personality conflicts)
- Schedule compatibility

Identifying a project included obtaining commitments from an "external" client / mentor, and a "faculty advisor" to work with the student team. A simple "form" was used to document the same. This form is shown in Figure 1. This form served the following purposes:

- Documenting consent of individuals on the team
- Documenting consent of the client / mentor for the team
- Documenting consent of faculty advisor for the team
- Obtaining contact information for the client / mentor
- Obtaining contact information for the client / mentor

In the second semester, the teams completed their projects by presenting written and oral progress reports (corresponding to approximately 30 percent, 60 percent, and 90 percent completion), along with a final report (written and oral). Each progress report was to include a technical section and a management section. The technical section was to document technical progress, problems encountered, and the proposed work plan for the next stage. The management section was to document the percent of the project completed compared to the percent of the resources expended (reconciled with the budget identified in the proposal), any problems encountered, changes to scope, schedule, and budget. Each progress report was evaluated by the client, the faculty advisor, and the instructor. A simple form was used to document these evaluations and provide feedback to the teams. An example of the Evaluation form used by the Client is shown in Figure 2. Each team was required to address these comments in their ensuing report.

Technical Advisors / Mentors: Each project team was required to have a departmental faculty member as a technical advisor. Each team also had to have a client advisor. The client advisor also served as a mentor. This individual typically was the presenter of the RFP (Request for Proposals) to which the teams responded. Advisors were required to be in the dominant technical areas of the proposed project.

In the second semester, the teams completed their projects by presenting written and oral progress reports (corresponding to approximately 30 percent, 60 percent, and 90 percent completion), along with a final report (written and oral). Each progress report was to include a technical section and a management section. The technical section was to document technical progress, problems encountered, and the proposed work plan for the next stage. The management section was to document the percent of the project completed compared to the percent of the resources expended (reconciled with the budget identified in the proposal), any problems encountered, changes to scope, schedule, and budget. Each progress report was evaluated by the client, the faculty advisor, and the instructor. A simple form was used to document these evaluations and provide feedback to the teams. Each team was required to address these comments in their ensuing report.

While the instructor played a significant role in forming teams and helping teams identify project, students were responsible for working as a tem and not as a set of individuals. Responsibilities in this regard included project identification, project management (including tracking resources), communications (internal to the team and external to the team), integrating different technical elements to address the project needs as a whole, and meeting project schedules and deliverables.

These activities clearly were intended to help students enhance their abilities to work as teams, document their efforts, communicate effectively, manage resources and integrate individual technical components of a larger, more complex project. Although simple forms were used to evaluate the teams' performance, they serve as important assessment tools. These were also parts of the enhancement to the capstone design experience.

Course Administration and Management

The course administration included several elements. The following are some course administration and management excerpts from the information provided to the students in the course.

Ground Rules for the Project

1. The Senior Design course is a two-semester, five credit experience.
2. Students must meet all pre-requisite course work requirements to enroll.
3. The project must be a team effort. Interdepartmental teams are encouraged.
4. Students who complete CEE 497 in one semester will be required to register for CEE 498 Senior Design Project II (2 credits) during the next academic term.
5. The team must remain intact for CEE 498 - all team members must register for CEE 498 during the next Semester, and complete the project during that semester.

<University>
Spring Semester 2006

Department of Civil and
Environmental Engineering

CEE 497: Senior Design Project - I
Client / Mentor and Advisor Approval Form
Due: Friday, April 14, 2006

This form is to document the participation and roles of individuals on the proposed Senior Design Project for each team.

Names of Team Members (Last Name, First Name): Signature

1. _____ _____
2. _____ _____
3. _____ _____
4. _____ _____

Project Title: _____

_____

Name, Signature, and Contact Information of Client / Mentor:

Name: _____ Signature: _____

Professional Title: _____

Organization: _____

Address: _____

City: _____ State: _____ Zip code: _____

Tel. Number: _____ Fax Number: _____

E-mail Address: _____

Date:

Name, Signature, and Contact Information of Technical Advisor:

Name: _____ Signature: _____

Professional Title: _____

Organization: _____

Address: _____

City: _____ State: _____ Zip code: _____

Tel. Number: _____ Fax Number: _____

E-mail Address: _____

Date:

Figure 1: Client / Mentor and Advisor Approval Form

<University>
Spring Semester 2006

Department of Civil and
Environmental Engineering

CEE 498: Senior Design Project II
Progress Report Evaluation Form – Advisor's Evaluation

Progress Report Date:

Project Title:

Team Members:

Client / Mentor:

Faculty / Technical Advisor's Name:

Faculty / Technical Advisor's Comments:

Grade for Progress Report (maximum = 10)

Faculty / Technical Advisor's Signature:

Date:

Please complete and return this form to Prof. FN LN, P.E.,
Department of Civil and Environmental Engineering, <University>

Fax: 123-456-7890

Figure 2: Progress Report Evaluation Form – Advisor's Evaluation

Project Expectations and Selection Criteria

One or more "Problem statements" are posed to students in the Senior Design course in the Civil Engineering program at the university. A student team (2 or 3 individuals) may select one of these as the topic for their project, or identify a potential topic on their own (subject to approval by the instructor). The following is some background / information on the expectations for the course (academic requirements) for the Senior Design course.

1. Students must work in teams (typically 2 or 3 individuals per team). Each student would work for about 100 hours on this project.
2. The project MUST address more than one area of civil engineering (e.g., construction, environmental, geotechnical, hydrology / hydraulics, materials, structures, surveying, transportation, water resources, etc.) although much of the focus may be on one area (i.e., not all areas need to have an equal focus / level of effort).
3. The project MUST address safety and economic considerations. Additionally, consideration must be given to the recognition of reasonable constraints imposed by environmental, sustainability, manufacturability, constructability, ethical, health, reliability, social, political, and aesthetic concerns. Not all projects lend themselves to consideration of each of these concerns but several should be addressed.
4. The project must incorporate engineering standards, and be responsive to local codes and regulations.
5. The "Design" project must be open ended and consider at least 2 alternatives other than a "do-nothing" alternative.
6. Each team must conduct a preliminary investigation of the identified alternatives, and select a preferred alternative for detailed design. The identification of the preferred alternative should be based on a “decision matrix” that takes into account various criteria and constraints (see item above).
7. Each project MUST have a Client / mentor who is external to the university. It is desirable that this individual is a P.E., but this is NOT required. The client / mentor serves two roles: a) presents the “problem” to the team and reviews their “products” for acceptability; and b) serves as a “mentor” by advising the team on technical approaches and practical considerations to be addressed, reviewing and commenting on / evaluating the team’s proposal, progress reports, and final report. The client / mentor is expected to meet with the team periodically (at least once every 2 to 3 weeks), attend the proposal presentation, and the final presentation. Typically, the “client / mentor” would spend about 3 to 4 hours per month on these efforts.
8. Each project MUST have at least one Faculty advisor internal to the university. This individual is expected to provide technical guidance to the team and to complement the “mentor’s” role. The “advisor’s” responsibilities include the following: advise the team on technical approaches and practical considerations, review and comment on / evaluate the team’s proposal, progress reports, and final report. The advisor is expected to meet with the team periodically (at least once every 10 days), attend the proposal presentation and the final presentation. Typically, the “faculty advisor” would spend about 5 hours per month on these activities.

9. Students do NOT get paid for their work on the Senior design project, although they may apply for nominal funding from the university to pay for specific costs related to completing the project.
10. NOTE: Senior design projects were eligible to compete for cash prizes in a College of Engineering wide senior design competition which is held twice a year. This competition specifically recognizes projects that demonstrate creativity, entrepreneurship, and innovation, and also address marketability of the "product."

Each team was required to document in writing its team activities and meetings. Instructions for the same are summarized in Figure 3.

Project Schedule

The following is a summary of the process / logistics involved with the Senior Design project for the Spring 2006 and Summer 2006 terms.

1. Develop a "Problem Statement" to present to the students in the Senior Design class. This needs to be done by Wednesday, Feb 15, 2006.
2. Present the problem statements to the students on Wed, Feb 15, 2006 (2:30 to 3:45 PM is when the class meets).
3. Students select a topic / are assigned a topic by Mon, Feb 20, 2007. The topic may be based on problem statements presented or on self identified problems. Project topics must be approved by the instructor.
4. Students prepare and submit a detailed proposal for their work (due tentatively on March 22, 2006). This process would include consultations with the client / mentor and the faculty advisor. The proposal MUST include the following:
    1. Overall goals and objectives of the project; expected end product.
    2. Project background
    3. Scope of work broken down by individual task
    4. Staffing plan broken down by individual task identifying specific roles of individuals, and their corresponding levels of effort (number of hours)
    5. Project schedule, milestones, and deliverables
    6. Project budget with details of labor, materials, equipment, travel, etc.
5. The instructor, in consultation with the Client / Mentor, and the Faculty Advisor, provides feedback to the team and a "notice to proceed." (within 1 week of receipt of the proposal – tentatively March 29)
6. Student teams work on their project. Each team MUST submit the following reports as per the preliminary schedule identified:
    1. approximately 25 percent complete progress report: April 24, 2006 (Mon)
    2. approximately 50 percent complete progress report: May 18, 2006 (Thu)
    3. approximately 75 percent complete progress report: June 8, 2006 (Thu)
    4. pre-final draft (approx 85 percent complete) report: June 21, 2006 (Wed)
    5. final report (due July 5, 2006).
    6. final presentation (July 6 or 7, 2006)

<University>
Spring Semester 2006

Department of Civil and
Environmental Engineering

CEE 497: Senior Design Project I
Documentation of Team Activities

In order to help each team achieve its goals in an effective and efficient manner, it is very important to document team and individual activities on a regular basis. This documentation should be simple yet detailed enough to permit your instructor to recognize the relevant details, questions and concerns among the team members. This is best accomplished by recording short memos or meeting minutes for ALL team effort related activities / meetings, and sharing it with all the team members, the faculty advisor, and the instructor. Items of interest include the following:

1. Participants (attendees) at the meeting
2. Progress made by the team since the last team meeting
3. Items discussed (list with short descriptions for each item) at the meeting
4. Action items, responsible individuals, anticipated deliverables, and schedule for deliverables
    a. Problems encountered
    b. Changes to any agreed upon action items of the previous meeting(s)
    c. Concerns regarding progress on the project
5. Anticipated progress before the next team meeting
6. Tentative agenda, date, time & duration, and location of the next meeting
7. Feel free to add any other items of interest to your team

Preparing and sharing meeting minutes / memos with the aforementioned information will facilitate team activities, and help ensure that all team members on the team know their roles and responsibilities. It also will help document the contributions of each individual, and concerns / problems encountered by the team. Each team is required to submit one such "report" to the instructor (by E-mail) at least once a week: by 10 AM on Wednesday of each week. It is recommended that you use E-mail for such communications among the team members.

Figure 3: Documentation of Team Activities

Each report must document the technical activities and progress on the project, problems encountered, plans for the next reporting period, and a reconciliation of the projected budget & schedule with actual resources consumed and actual schedule. The final presentation should summarize the team's efforts, findings, and recommendations. All reports and presentations are expected of "near-professional" quality. The instructor, in consultation with the Client / Mentor, and the Faculty Advisor, provides feedback to the team typically within 1 week of receipt of the report.

***Grade Components*:**

Several major components make up the grade for CEE 497:

1. Preparation & presentation of a project proposal to be implemented in CEE 498. 45%
2. Preparation and presentation of an engineering management issue or technique. 10%
3. Preparation & presentation of a case study of a consulting firm or government agency. 10%
4. Final exam. 10%
5. Written assignments. 20%

Extra credit with prior instructor approval for a maximum of 5 percent of the course grade.

Together, these requirements make up 95 percentof the student's grade. Other requirements make up the remaining 5 percent and include evaluations of written progress reports and oral presentations, homework assignments, active participation in presentations, etc. Several of these were team assignments but some, such as the exams, will be individual assignments. Both written and oral communications were emphasized in this course. All such communications were expected to be of professional quality. Evaluations were made by the instructors and technical advisors, and in several instances by also by students in the class (peer evaluations).

The following components make up the grade for CEE 498:

1. Preparation & presentation of periodic project progress reports (written and oral) 30%
   Due: May 18, 2006; June 8, 2006; June 21, 2006;
2. Preparation and presentation of a final report for the project (due July 7, 2006). 45%
3. Assignments, Class Participation (e.g., summaries of Guest Presentations; others) 15%
4. Participate in a course / instructor evaluation and the Senior Design Competition 5%
   During the week of July 5, 2006, unless otherwise notified by the instructor
5. Participate in a comprehensive evaluation of the Civil Engineering program and participate in an interview with the Department Faculty 5%
   Between July 5 and 10, 2006, unless otherwise notified by the instructor

Assessment

The project requires several deliverables during the semester. These include the following:

- a written proposal
- two written progress reports
- a written final report
- an oral presentation

Each team was encouraged to submit draft versions of the documents for comments from the instructor and their faculty advisor and client / mentor. If these drafts are submitted at least one

week prior to the due date of the final report, comments were provided so as to enable to the teams to incorporate these comments in their "final" submissions. Each team's efforts was expected to be summarized in one "deliverable" - and not individually for each team member. For the final oral presentation, the instructor reserved the right to ask any team member to make any portion of the presentation (i.e, each team member must be prepared to make the entire presentation).

Each team's written work was evaluated and a grade was assigned to the entire team. However, this grade is distributed among the team members based on their respective contributions to the project. Individual contributions to the project were determined primarily based on self assessments by team members. The self assessments are reported with each interim progress report. This assessment required each team member to document his / her contribution to the team's product. Further, each student was asked to assign a score to each member on the team such that the total score adds up to 100 points. Individual team member assessments were tabulated and averaged for each student to obtain the student's contribution to the team. In case of significant differences between team member evaluations, the instructor met with the team as a whole to try to reconcile the differences. Each student's score was computed as the product of the team's total score and the student's score for contribution to the team. Each written progress report and the final report and the final oral presentation were also evaluated by the instructor, faculty advisor, and the client / mentor.

The aforementioned approaches have been assessed informally over the last three years. Assessment tools used include surveys to assess learning (both for the individual and for the team), and oral presentations. Some of these instruments are based on peer evaluations, and they all are shared with the class. These tools are "paper-based." Collecting the information is time consuming and the information is difficult to aggregate, thus making it challenging to provide timely and substantive feedback to students. As an illustration of the assessment of student performance, student learning, and experiences in team oriented activities, some results from surveys conducted during the Spring and Summer 2006 semester (the most recently completed terms where the for the Senior Design Project cohort) are presented next.

Prior to adopting the aforementioned process, the assessment was informal – it primarily consisted of verbal or short written updates provided by the team, with a majority of the evaluation coming at the end of the project and being based on the instructor's evaluation of the teams' final written report and oral presentation. This too is an enhancement to the capstone design experience.

Actual Projects

The actual projects completed in the past two years included the following main topics:

- Roadway design and hydrology considerations
- Design of a multi-use detention basin
- Development of a channel design and sustainable re-vegetation plan
- Re-design of an arterial roadway to enhance pedestrian safety and hydrology considerations

- Design of a parking garage, foundation, and transportation access
- Development of a new roadway and drainage system near the university
- Design of a water reclamation and reuse system for a new building (to meet LEED certification)
- Design of a water park
- Design of a low-cost water purification system for use in developing countries

Results

Each survey was one page long and consists of several statements / questions to which each student needs to provide a confidential response on a Likert scale. The first part of the survey is intended to assess "individual" performance, experience, and contributions to the team's activities. The second part of the survey is intended to assess "team" performance and effectiveness.

A summary of the individual performance assessment tool, and the results obtained from a survey using this tool during the Summer Term in 2006 semester is presented in Table 1. As can be seen from the results presented in Table 1, students in the class as a whole were very positive of their personal learning, participation on team efforts. The lowest average score (3.3/4.00) corresponded with item number 7 – "I felt encouraged by people on my team." This indicates that additional efforts are needed from the instructor to help team understand the importance of encouraging (and supporting) one another. Several Questions recorded scores of 4.0 the maximum possible). These include participation on team efforts, listening, and their individual role on the team.

A summary of the "team" assessment tool, and the results obtained from a survey using this tool is presented in Table 2. This survey is to be used in conjunction with the survey results shown in Table 1. As can be seen from Table 2, students in the class as a whole were very positive of the performance and effectiveness of their teams. The lowest score (4.33) was for "effective use of time" and the highest score (4.83) was "the ability to decide issues." The low score on the "effective use of time" is not very surprising, given that some students are very driven and goal oriented, and wish to focus on the task at hand, and there may be others on the team who may not be as driven or motivated. This is influenced by the team composition and since the instructor tried to maintain a "balance" across teams so that no team was dominated by students with "superior" academic skills (GPAs) or loaded with individuals with "weak" GPAs (the GPA being used as a surrogate indicator of the level of drive or motivation).

Table 1: Summary of Survey of Personal Evaluation of Working on Teams
(CEE 498: Senior Design Project II, Summer 2006**)**

Team ----->	Total		
Individual ---->	Min	Ave	Max
Question			
I felt comfortable working with this team	3	3.8	4
I was an active participant in my team	4	4.0	4
I listened to everyone on my team	4	4.0	4
I encouraged and praised others on my team	3	3.8	4
I explained/helped someone who didn't understand	3	3.8	4
I asked for an explanation or help when I didn't understand	3	3.7	4
I felt encouraged by people in my team	2	3.3	4
My role was _____. I felt comfortable with this role	4	4.0	4
I found this group activity to be a worthwhile experience	3	3.7	4
I enjoy working with my classmates on teams	3	3.7	4
Minimum	2	3.3	4
Average	3.4	3.8	4
Maximum	4	4.0	4

Note: Survey responses were on a scale of 0 to 4. A response of 0 indicates "No, not at all" and 4 indicates "Yes, a lot."

The Team Performance survey also required each student to provide confidential quantitative scores for each member of the team to reflect each person's contributions to the team's activities. In general, there was consistency among team members evaluation of each other's contributions to the team's activities. Respondents with poor "scores" on the survey regarding effectiveness of teams also had poor scores on "individual performance" surveys. Thus, a direct correlation is noted on student responses between complaints and low scores.

The descriptive comments provided by the faculty advisors were generally more critical than those provided by the Clients / Mentors. In essence, they indicated the following:

- Student teams worked well in general,
- Students addressed well fairly complex problems from a technical perspective
- Design parameters and assumptions need to be better justified and documented
- Results were not thoroughly presented / discussed

Some of the specific Client / Mentor and Faculty Advisor comments are presented next.

- *The Final report was very prepared and organized. The technical analysis was thorough and complete and addressed technical requirements for an actual report submitted for approval.*
- *The discussion of the design matrix should have been expanded.*
- *The description of channel linings was informative, but the evaluation … did not include time and cost estimates*
- *Some figures used during the oral presentation were hard to read.*
- *There were spelling errors in the final report*
- *The students worked really hard to bring in the HEC-1 mode to HMS and then read in real-time precipitation data. I cannot emphasis (ze) enough that this was a lot of work and typical(ly) something that graduate students do.*
- *Nice maps and presentation in the report*
- *The report is a good start for a pre-design report <for an actual / real life project>, but falls short of a true design plan.*

The Team Performance survey also required each student to provide confidential quantitative scores for each member of the team to reflect each person's contributions to the team's activities. In general, there was consistency among team members evaluation of each other's contributions to the team's activities. Respondents with poor "scores" on the survey regarding effectiveness of teams also had poor scores on "individual performance" surveys. Thus, a direct correlation is noted on student responses between complaints and low scores.

Both the Personal Evaluation survey and the team performance survey also asked for qualitative comments and feedback. Comments provided in this regard typically focused on issues related to coordination of team activities and team member schedules. Occasionally, they also reflected complaints about "unbalanced" work loads among team members regarding contributions to the team's activities. Such complaints also correlate with discrepancies regarding scores given to team members by each other.

Table 2: Summary of Survey of Team Performance Evaluation

Team ----->	Total		
Individual ---->	Minimum	Average	Maximum
Effective Use of Time	4.00	4.33	5.00
Development of ideas	4.00	4.50	5.00
Ability to Decide Issues	4.00	4.83	5.00
Overall Productivity	4.00	4.67	5.00
Minimum	4.00	4.17	5.00
Average	4.00	4.58	5.00
Maximum	4.00	4.83	5.00

Note: Survey responses were on a scale of 1 to 5 with 1 being the worst (lowest productivity or least desirable) and 5 being the best (highest productivity or most desirable).

The overall learning experience from the course was evaluated using an end of the semester survey instrument. This survey addressed the key objectives of the course. The results from the survey are summarized in Table 3. The responses indicate there is strong support for the notion that students believe that they were learning in the class, and applying the concepts learned.

OBSERVATIONS AND CONCERNS

The use of practitioners as clients and mentors was rewarding and challenging. They played an important role in helping student teams understand and apply theoretical concepts to practical problems. They provided valuable guidance regarding the use of appropriate tools and guidance on the level of effort expected to tackle design projects. In some instances, they advised students to reduce their efforts on some tasks, and on others to spend more time. While they were supporting and encouraging of the students, they were critical of their written and oral communication skills. In particular, they emphasized the importance of the use of graphics in such presentations and reports. The faculty advisors played an important role in supporting the teams with their problem formulation, evaluation of alternatives, development of decision matrices, and analytical procedures.

Key problems encountered include the lack of responsiveness of some student team members. This has been well documented in the literature, and the grading mechanism used tried to reward those students who contributed more than their fair share on the project, and to penalize those who did not pull their share of the load. Further, while involving practitioner “clients / mentors” added significant value to the courses, it was sometimes difficult to obtain significant and timely responses from such individuals. This was especially true of written reports submitted by the teams. The assessment tools are “paper-based.” Collecting the information is time consuming and the information is difficult to aggregate, thus making it challenging to provide timely and substantive feedback to students. Since the class sizes were relatively small (with a total of 11

students who made up 4 teams), the efforts required were significant, but not unreasonable. This method might prove to be cumbersome for larger class sizes (say more than 30 students).

Table 3: Summary of Course Outcomes assessment (CEE 497 and 498, Spring 2006)

No.	Question	Mean	Median	Standard Deviation
1	Did the course increase your ability to apply knowledge of math, science, and engineering?	4.056	4.000	0.802
2	Did the course increase your ability to design and conduct experiments, as well as to analyze and interpret data?	3.778	4.000	1.263
3	Did the course increase your ability to design systems, components or processes to meet desired goals?	4.000	4.000	0.907
4	Did the course increase your ability to function on a multidiciplinary team?	4.059	4.000	1.029
5	Did the course increase your ability to identify, formulate, and solve engineering problems?	4.056	4.000	0.873
6	Did the course increase your understanding of professional and ethical responsibility?	4.111	4.000	0.963
7	Did the course increase your ability to communicate effectively?	4.111	4.000	0.832
8	Did the course help provide a broad education necessary to understand the impact of engineering solutions in a global and societal context?	4.000	4.000	0.97
9	Did the course increase your recognition of the need for, and to engage in, life-long learning?	3.944	4.000	0.938
10	Did the course increase your knowledge of contemporary issues?	3.889	4.000	1.183
11	Did the course increase your ability to use techniques, skills and modern engineering tools necessary for engineering practice?	4.222	4.000	0.647

The Statistics are based on a 5 point Likert scale, from Excellent (5) to Poor (1)

CONCLUSIONS

This paper has presented a detailed overview of a two-semester sequence senior design experience as it relates to some of the programmatic needs at the university and accreditation criteria established by ABET. The paper summarized the course content, structure, administration and management, as well as assessment methods used. In addition to providing the students a capstone design experience, these courses also help them hone their ability to work on design projects, to work on teams, to communicate effectively, to manage resources, and to work on complex projects. The evaluations of the effectiveness of the course, with respect to the aforementioned abilities, indicate that these changes to the course certainly enhanced the capstone design experience for the students. The role of practitioners as clients / mentors was discussed and seen to be beneficial. They served in important supplementary roles to the faculty advisors and the course instructor.

REFERENCES

[1] ABET. Engineering Criteria 2000, Accreditation Board for Engineering and Technology, 111 Market Pl., Suite 1050, Baltimore, MD 21202, (http://www.abet.org/eac.html)

[2] Fortenberry, N.L. (1994). 'Troubles with Undergraduate Education," *What's Due*, Vol. 2, No. 6, National Science Foundation, Division of Undergraduate Education, Arlington, VA, DUE Staff Report NSF940621.

[3] National Academy of Engineering, Committee on the Engineer of 2020. (2005) Educating the Engineer of 2020, the National Academies Press, Washington, D.C.

[4] Brunell, Leslie. Effective Implementation of Industry-Sponsored Senior Design in a Civil Engineering Program. *Proceedings of the 2005 ASEE Annual Conference & Exposition* and Exposition *(2005-1326).*

[5] Kolar, R.L. and D. A. Sabatini, "Changing from a Lecture-Based Format to a Team Learning/Project Driven Format: Lessons Learned," *Proceedings of the 1998* American Society for Engineering Education Annual Conference and Exposition*,* ASEE, Session #1675, CD-ROM.

[6] Chinowsky, P. S. and J. Robinson (1997). "Enhancing Civil Engineering Education Through Case Studies," *Journal of Engineering Education,* January. pp. 45-49.

[7] Mahendran, M. (1995). "Project-Based Civil Engineering Courses," *Journal of Engineering Education,* January. pp. 1-5.

[8] Brackin, Patricia; Gibson, J. Darrell, "Capstone Design Projects With Industry," Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition. (Paper Number 2005-2337).

[9] Piechota, Thomas and Nambisan, Shashi. Integration of Service-Learning into Civil and Environmental Engineering Curriculum. Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition. (Paper Number 2005-2564).

[10] Quadrato, Craig; Welch, Ronald, "Capstone Design Grading - On Time and On Target," Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition. (Paper Number 2003-631).

[11] Drnevich, Vincent. The Senior Design Process at Purdue University. Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition. (Paper Number 2005-2510).

[12] Farr, J., et. al, "Using A Systematic Engineering Design Process to Conduct Undergraduate Engineering Management Capstone Projects," Journal of Engineering Education, vol. 90, no. 2, 2001, pp. 193-197.