AC 2010-552: UNIVERSITY OF WISCONSIN-MADISON CIVIL & ENVIRONMENTAL ENGINEERING CAPSTONE DESIGN CLASS A CLASS IN CONSTANT REDESIGN AND IMPROVEMENT

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Civil & Environmental Engineering Capstone Design Class

A Class in Constant Redesign and Improvement

ABSTRACT

Instilling an understanding of design and the design process are key aspects of preparing civil engineering students for professional practice. The Civil & Environmental Engineering Capstone Design Class has been offered at the University of Wisconsin-Madison for more than 15 years. The focus of this Senior Level class is to immerse students in a situation where they work on a major design challenge in multi-disciplinary teams. This course integrates prior course work and skills, allowing students to solve problems taken from a "real world" context. Consistent with ABET criteria, this class prepares students for professional practice though a comprehensive experience involving design, management, economic, social and leadership aspects. The success of this class is directly attributable to the evolution of content, curriculum integration and cross-curricular collaboration developed and refined by faculty and mentors. The focus of this paper is to delineate and illustrate the evolution of the class resulting in positive impacts upon student outcomes and expectations.

INTRODUCTION

Instilling an understanding of design and the design process are key aspects of preparing civil engineering students for professional practice. This is the focus of the Capstone Design class at the University of Wisconsin-Madison, Department of Civil & Environmental Engineering (CEE). The evolution of this curriculum has resulted in positive impacts upon student outcomes and expectations as well as helping the department to comply with ABET accreditation criteria.

The ABET Civil Engineering (CE) Program criteria state that "the program must demonstrate that graduates can apply knowledge of mathematics through differential equations, calculus-based physics, chemistry, and at least one additional area of science, consistent with the program educational objectives; can apply knowledge of four technical areas appropriate to civil engineering; can conduct civil engineering experiments and analyze and interpret the resulting data; can design a system, component, or process in more than one civil engineering context; can explain basic concepts in management, business, public policy, and leadership; and can explain the importance of professional licensure." The criteria further states that: "The program must demonstrate that faculty teaching courses that are primarily design in content are qualified to teach the subject matter by virtue of professional licensure, or by education and design experience. The program must demonstrate that it is not critically dependent on one individual." (ABET 2008).

Clearly, design and the process of formulating and delivering a design project are key aspects of preparing a civil engineering student for professional practice. The ABET definition of engineering design is as follows: "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs."

More specifically, general criterion 3 (c) states that, "Engineering programs must demonstrate that their graduates have...an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability," and hence design is essential to preparing civil engineers. Below we will describe in more detail the evolution of the capstone design class.

I – CREATION (1994-2004)

A new department-wide capstone design class was created as a result of our ABET visit and feedback in 1994. The capstone design class, at that time, was discipline-specific and with a narrow design context (i.e., a structure, foundation, water system, etc.) and failed to comply with the CE program criteria. The department embraced the ABET feedback as a means to improve the curriculum and student preparation for professional practice.

The selected instructional strategy was to evolve a curriculum that develops young engineers through more hands-on experiences with real world projects. The scope and depth of the course involves both formal lectures and active practical investigations within a team environment. The 4-credit course meets on Tuesday and Thursday mornings from 7:45 to 9:25 am. The Tuesday professional practice lectures provide a broad overview of applicable topics with some in-depth case study, with content in part, geared towards the informational needs of student teams in completing upcoming assignments. The Thursday hands-on group work sessions bring critical thinking and design skills into focus though the student's integration of prior learning and applying it to a real project.

The students are organized into teams of four individuals. This small group arrangement helps to ensure students are effectively engaged in the learning process throughout the semester. Each student group has at least one industry mentor (and in many cases two) that works with the group throughout the semester.

Before the semester begins, students respond to a questionnaire and provide a brief resume to instructors. Instructors review the information and assign students to teams in one of three areas of focus; General Building, Transportation or Environmental, based upon their academic coursework and performance, practical experience, and career goals.

Active student involvement is the key to successful engagement of students in this course. Twelve of the 17 class assignments are design team related. This ranges from preparing written proposals and summaries to the development of drawing specifications and contract documents. Class presentations to peers and formal presentations to judges also are important group activities. The class fosters essential joint learning activities such as role-playing, small group discussion, and collaborative problem-solving. Mutual responsibility for the overall team effort and work product is cultivated within the group setting.

The capstone design class is intended as a melding of components from multiple mid-level courses that connects and uses prior accumulated knowledge, background, concepts and experiences. Prior course experiences, such as *Technical Presentation and Writing*, are linked with base knowledge from courses such as *Construction Systems*, *Geotechnical Engineering*, *Structural Design, Transportation Engineering*, and *Environmental Practices*. The integration of design, teamwork and communication meets ABET criteria and desired outcomes. Also, consistent with ABET criteria and desired outcomes, design project requirements are presented to the design teams in such a manner as to encourage consideration of contemporary issues and concepts of sustainability by the teams in their formulation of a design solution.

At the end of each semester course improvement feedback is solicited in two ways. Individual students complete a course evaluation and each student team has a personal interview, or debriefing session, with instructors and mentors. This constructive feedback is timely, honest and information-specific. This provides the course instructors with the opportunity to continually improve the effectiveness of the course through gradual refinement of course content and processes leading toward consistent improvement in positive outcomes.

The course instructors also develop a self evaluation of course outcomes based upon detailed observations and notes made during the semester, and from comments provided by judges of the final student team presentations.

The weeks between semesters are used by instructors to meet and review the feedback and plot a strategy and course of action for improvement. Implementation occurs in precise manageable increments each semester.

A large number and a wide variety of practitioners serve as mentors for the course. These trusted advisors are experienced industry professionals who devote time to the students within the university setting. Their varied design expertise and experience in multiple civil engineering disciplines provides a unique breadth as well as depth to the course. Although mentors can fill any number of different roles, mentors share a common goal: to help students achieve their potential and expand their knowledge, skills, and attitudes within the real world experience of the capstone class.

The introduction of real world team-based design projects into the course has a dual benefit. It is an excellent way to involve industry practitioners in education and it provides practical experiences and challenges for the students as part of the learning experience while they prepare to transition to the real world. Team-based projects provide opportunities for students to learn individually as well as teach others in small learning groups, and also introduce the students to the need for effective team leadership, project management, and teamwork required in actual professional practice.

Project-based learning is an effective and comprehensive approach to teaching in which students explore real world problems. They meet these challenges using an array of skills from basic math and language arts to team dynamics and computer technology.

The project is open-ended and is not defined in advance for students. They must find their way through the project design process with the guidance of instructors and mentors. With this type of active and engaged learning, students are inspired to obtain a deeper knowledge of the subjects they are studying. The project team environment facilitates positive communication and collaborative relationships among diverse groups of students. The instructors guide students in learning and practicing skills in problem solving, communication, and self- and team-management through the project. Project-based learning encourages the development of problem seeking and problem solving abilities associated with lifelong learning and career success.

II - EVOLUTION (2005-2006)

After the initial establishment of the course, the goal has been to cultivate constant evolution, adaptation, and improvement to maintain course relevancy. In 2005 via a solicitation to CEE graduates to get more involved in the department, a senior engineer and principal from a large engineering firm stepped forward with an interest in helping with the capstone class. His involvement led to changes in the class including how the mid and final class presentations were handled, providing weekly feedback to the groups on their progress, and the selection of appropriate projects for the class.

Prior to 2005, mentors normally provided the instructional team with two or three project choices that they believed would make good class projects. Typically these were projects that the mentors had in progress within their firms or had completed. Most projects that the instructional team selects have been very successful, but there have been projects chosen that have caused problems for the class teams.

But because the projects are selected at the beginning of the semester and have a major influence on the total semester experience, it is important that appropriate care and thought go into class project selections. The scale of the project is the most important aspect relative to success. Projects that have not worked well in the past have been both too large or too small. The course seeks "Goldilocks" projects, sized just right. Projects too small often lack substance or significant issues to explore. This limits the team's ability to develop a full comprehensive project. Large projects often are difficult or too complex for a group to address all the important issues in the class time allotted and results in doing multiple tasks with none being done well. Our experience tells us medium size projects work best.

Beyond the scale of the project, diversity of project issues is also important for the learning experience. As is the case in the real world, project teams need to consider engineering and non-engineering issues within the scope of their work. As the project is developed from beginning to end, students should be exposed to many non engineering issues to reflect real life situations. These issues include: legal, financial, political, environmental, social, scheduling, construction phasing, future expansion, and many others. The key point is this: real world projects are not just about engineering design.

Appropriate projects should present multiple design challenges for the team, especially related to investigating and presenting options or alternatives to the client. For example, the project design may generate multiple layouts, provide optional selections of materials, and develop several phasing alternatives for construction. These kinds of challenges provide the team an opportunity to show a depth of design thought. It works particularly well if all group members have an opportunity to present at least one design challenge during the final presentation.

Practitioners and members of the local business community act as judges and play the role of the client at the mid semester and final presentations of the projects. This too has evolved from primarily civil engineering graduates judging at the end of the semester, to engineers and non-engineers which represents a realistic client profile. We have the same judges playing their client role at mid-semester and final presentations which further develops the "client relationship" for the student groups. The mid-semester presentation feedback also helps shape the content of the project considerations as the judges pose questions of the student groups.

It is important that most of the judges return from year to year and their input to the instructional team has become quite valuable. They are complimentary with regard to the quality of work the students are presenting and have ideas and suggestions about course content and project types for future years. They also help us with the comparative evolution of the course as they see the program change from year to year.

III - EVOLUTION (2007-2008)

There has been a logical, coherent, and timely progression of content and curriculum towards 21st century student outcomes. These are a blend of societal challenges, specific skills, content knowledge, and expertise. The focus is not only on critical thinking and problem solving, traditional areas of strength for engineers, but also the communication and collaboration skills, creativity, and innovation that contemporary industry seeks.

The formation of a strong Adjunct Faculty in the Department of Civil & Environmental Engineering has facilitated the constant evolution and maturity of the class in terms of prescribed outcomes, complexity of semester long projects, and critical feedback to students. The Adjuncts, by virtue of professional licensure, education, and years of design experience, bring real life experience and expertise to the course and elevate the expectations resulting from the class. The adjunct faculty widens the portfolio of the instructional team participating in the class. Currently six adjunct faculty are involved with the course.

The role of mentors has also evolved. The mentor function comprises multiple roles; these alternate between receptive and active roles. Mentors offer guidance and allow student discovery, but do not generally provide answers directly. Mentors sometimes assume a teaching or coaching role around a particular skill-set, helping the student to learn quickly, in the format and style appropriate. Mentors provide opportunities for their students to articulate and develop ideas without fear of pre-judgment, criticism, or ridicule. Mentors may choose to do more than just interact with their students. They may actively and wisely foster support for the students' activities within the college setting, influencing and promoting the students' capabilities and self worth.

Perhaps the most significant change affecting course outcomes has been the focus on real world projects. Within a broad set of themes including general building design, transportation design and environmental design, students are provided with a variety of project opportunities. Students generally work in teams of four, each with varying roles and responsibilities to the broad project. The types and complexity of these real world student projects has advanced dramatically since the earliest days of the course.

Traditionally projects have been brought into the course by the mentor from his or her own experience. Although the majority of these projects adequately challenged students, many projects possessed a loosely defined scope and illusive goals or did not fully meet class objectives. Some projects were hypothetical or out of scale with reasonable student work expectations.

The course seeks out "real" projects that provide students with a variety of experiences, significant challenges and real user-client interaction. These real projects came to us initially through two primary clients: The University Office of Facilities Planning and Management (FP&M) and the Regional Emergency All-Climate Training Center (REACT). Each client has provided a new project in each of the last several years.

Projects have a willing client, clearly defined scope, specific time frame, program and budget. The scope of these projects are consistent with the capabilities of the students and the length of the academic semester, yet broad enough to be consistent with the goals, objectives, and desired learning outcomes of the course. These projects provide a significant challenge to the communication and collaboration skills, creativity, and innovation of the student teams.

As part of the real world design project, student teams must present the project to a jury at the midterm and final milestones of the semester. Communication skills are a significant key to these presentations as they are in the 21st century workplace. Students have been exposed to and explored a wide variety of soft skills and graphic communication skills in previous courses. The Capstone course enhances these student skills with three separate class time presentations related to graphics, selling ideas, and making effective presentations. These hands-on sessions help prepare student teams for the formal mid term and final presentations.

IV - THE NEXT GENERATION (2009 and beyond)

One of the unique aspects of this class is the development of cross-curricular collaboration with students in other disciplines. Through synergistic projects, students from other disciplines work collaboratively and collectively from project inception through completion. They cooperate advantageously for a final outcome. This includes students from the fields of engineering, architecture, and landscape architecture providing additional real world exposure.

The collaboration is made possible through projects provided by the FP&M. Through a cooperative win-win arrangement with FP&M, the students from different disciplines undertake "real" projects that the campus is planning to implement several years in the future. The students benefit from real world projects and real clients close to their home base. The FP&M benefits from the design insight the student efforts provide to their proposed projects. End-users are engaged earlier in the process allowing them to more clearly think about and define their needs, wants, and desires.

Interdisciplinary teams of students, one or two teams from each discipline, are assigned to projects of this type. Instructors maintain a close relationship with faculty and instructors in the other colleges. Instructors begin planning at least six months in advance of the proposed student work to coordinate scope, schedule, and deliverables between colleges and with the campus FP&M.

Two of the most recent projects included a renovation of a 1906-1932 vintage water science research facility for the College of Engineering and the adaptive reuse of an 1888 Horse Barn into an outreach center for the College of Agriculture and Life Sciences (CALS). These types of synergistic real world projects require a large sphere of disciplines that is reshaping how student teams are initially selected and assembled and then guided through the semester.

The adaptive reuse of the CALS Horse Barn is a good example of the Next Generation Senior Capstone Design project. This project derived from the College of Engineering's collaborative relationship with the campus FP&M office. This is a real project currently in the final planning stages within the campus architect's office. With the Capstone student involvement, the campus benefits from the design insight and reality check the student work provides while clients become more engaged in the design process providing more clearly articulate needs, wants and desires. The students benefit from real world project challenges and through interaction with their clients.

The project encompassed the rehabilitation of an 1880's era, 18,000 GSF barn into a social/conference/outreach center. The building is envisioned as a place for the CALS faculty and students to interface with the general community to showcase the past, present, and future of agriculture. It is the intent to focus the message of the facility on the sustainability of agriculture and food production within a green and sustainable edifice.

The challenges diagnosed by the students for this project included many issues not previously identified by the campus. These included: building envelope restoration,
significant structural system modifications, insertion of new mechanical systems into the existing architecture, designing a water reuse system, providing energy efficient lighting and daylighting, providing solar systems to meet water heating requirements, and extensive reuse of existing materials and components. Each of these issues was explored in multiple options before a course of action was recommended to the client.

The project progressed through two semesters of Capstone classes, with the second semester building upon and expanding the previous work. The compact scale, one year duration and manageable complexity of the project proved a good match to student, mentor, and instructor capabilities and resources.

As with many of these next generation projects the ongoing cross-curricular collaboration with students in other disciplines in a key element. Students from the fields of engineering, architecture, and landscape architecture work together on specific tasks, such as structural analysis and remedial design, to produce a unified and coordinated outcome. At four key points each semester they share on-site investigations and classroom and/or work session time. At other points they web share information. One of the primary deliverables from this collaborative effort is a comprehensive booklet of student work from all three disciplines. This is published post course completion and documents the project specifics, outcomes, and deliverables for the client.

These student teams research and design broader aspects of the projects, integrate the design of systems and components, and relate to the user group in a manner closely simulating real world situations, providing enhanced educational opportunities. The interplay, coordination, and cooperation between engineering, architectural, and landscape architecture students bring additional real world experiences to the educational environment.

In these multi-discipline teams, the role of mentors becomes more critical to successful outcomes. Instructors have traditionally met with mentors before the semester classes begin to discuss projects, curriculum, and expectations. As part of the constructive feedback and self critique, the instructors have been able to better align mentor needs and expectations for individual projects.

Feedback and assessment come in several forms. The client was an active participant in activities of both semesters. They attended many Thursday student work sessions with mentors, providing constructive feedback on concepts and issues in a timely manner. The client also participated in the review and assessment of mid term and final presentations. Feedback was provided to faculty, mentors, and students in the form of verbal communication at the end of each presentation and in the form of a written a critique. Overall client feedback was accomplished in a manner closely simulating real world situations for a professional design team.

The panel of six to eight jurors who evaluate each presentation also provided an assessment. Their primary assessment is of the students design, their presentation skills, and the graphics used to communicate the design. This is provided through a score sheet completed for each team during the presentations. Judges are also given a dedicated time at the end of each presentation to provide constructive feedback directly to the students, face-to-face. As a wrap up to each presentation session, jurors provide specific commentary to the instructors related to the students understanding of the project, their qualities, skills, and depth of knowledge. Many of the jurors have participated in this course for multiple years so instructors are given a good gauge on how this class compares to previous classes.

In addition to client and juror assessment, mentors also provided feedback at key points in the process. Instructors checked in with mentors at each Thursday work session. The purpose was to jointly gauge team progress and to review upcoming assignments. At the end of the semester mentors participated in the student debrief sessions illustrating their integration with the student teams. Most mentors later provided a brief written assessment of each team and the individuals within the team. The assessment, shown in Appendix II, provided a glimpse at the set of habits, approaches, styles, and skills that team member exhibited during the semester, how they evolved and how the team dynamics played out.

Student assessment of the course is also important to its refinement. Course improvement feedback is solicited in several ways. At the end of the semester, students complete a course evaluation and each student team has a personal interview, or debriefing session, with instructors and mentors. This is a one hour constructive feedback session. Through open ended discussion students articulate what went well and where they would like to see changes made in curriculum, schedule, and assignments. A summary of the feedback is provided in Appendix III. This information provides instructors with the opportunity to continually improve the effectiveness of the course through gradual refinement of content and processes. The assessments do influence the future. With the assessments and feedback information in hand, instructors formulate and implement incremental changes to the course. These changes include adjustments to class lecture content, the coordination of lecture topics and assignments and the selection of projects and mentors for each semester.

These multi-discipline, next generation projects require careful screening for scale, content, schedule, and complexity to be sure course requirements and goals align with project scope, schedule, and client expectations. Once a group of potential projects have been identified, instructors must align project types and needs carefully with mentor abilities and expertise. This is a critical step to overall successful course outcomes.

Instructors now carefully match mentors and projects and coordinate with teams (mentors and students) after the first week of classes to confirm project scope, specifics of assignments, and deliverables. Instructors also meet with mentors once a month during the semester to monitor progress and make adjustments to scope and deliverables as appropriate. Mentors are also providing work product examples and samples of actual project documents (specifications and drawings) that are made available to students in a central library location for their review and reference, and electronically via the class home page. The instructors have also established a set of guidelines and expectations for mentors to follow.

In addition to continuing to improve matching the mentors, projects, and teams and broader participation from students with expertise outside of CEE, the class needs to evaluate the professional practice lectures provided on Tuesday. Specifically, the topics covered need to be assessed to value student career development and application to the semester-long team project. How content of the topics is delivered is another key issue. Covering multiple PowerPoint slides on a given topic does not appear to be the most effective way to impart the concepts and demonstrate application to the design project. The timing of when the topics are presented is also important especially for the ones that have direct application to a project deliverable. Examples of topics that are time sensitive include contract documents, estimating and scheduling, and graphic communications.

V - MATURITY

After 15 years of evolution, this course is nearing maturity. We have guided its development with long-term values in mind. The model and structure are near full development but by no means near a perfected condition. The instructors and mentors now focus on providing students, those engineers of the future, with positive experiences and encouraging life-long learning. Students, faculty, mentors, judges, and clients consistently report positive experiences.

There is no regularity to this non-traditional course. Preparation and coordination are significant on-going tasks that are required on a weekly basis. In addition, the diversity and complexity of the scope and engagement of end-users into the projects has increased the role of the instructor from initial selection of projects through organizing and maintaining the daily momentum and coordination of the course.

The quality of work produced by the students has incrementally increased in terms of depth and breadth and consistency with norms of actual practice. The class has made progress in instilling life-long learning qualities including: self-directed and independent learning, participation in workshops and group learning events, taking initiative, participation in social and community activities, and a constant renewal and upgrading of attitudes, knowledge and skills.

Appendix I.--References

ABET Engineering Accreditation Commission (2008). Criteria for accrediting engineering programs effective for evaluations during the 2008-2009 cycle, Baltimore.

Appendix II.—Summary of Mentor Feedback from Fall 2009 Class

Mentors provided written feedback on individual student and student teams at the end of the semester. Included in their discussions were some specific feedback on the course and course outcomes. These are summarized below.

- Mentors would like access to the class web site. This will enable them to see instructor postings and monitor the semester schedule and assignment deliverables. Mentors would also be able to view grades posted by instructors.
- New mentors should be provided a short orientation session in advance of the beginning of semester to articulate expectations.
- In general the mentors believed that two mentors for each student team, working in parallel, proved to be ideal. The dual mentor arrangement allowed at least one mentor to participate in each of the Thursday sessions.
- Because each project is somewhat different that the others, instructors should coordinate with teams (mentors and students) after the first week of classes to confirm project scope

and most importantly specifics of assignments and deliverables.

- Mentors and instructors should meet on a regular basis, perhaps once per month, to monitor progress and discuss refinements. Meeting course goals and assignments.
- Mentors would like to provide examples of their completed past project drawings and specifications for the students to use as samples. Perhaps these materials can be cataloged and made available to students in the Adjunct Faculty office.
- Mentors should be encouraged to interact with their student team outside the classroom. This may include visits to their professional offices for hands on work sessions or review meetings.

Appendix III.— Summary of Student Feedback from Fall 2009 Class

Instructors and mentors met with individual student teams on December 17 & 18th, 2009 to discuss the semester. The following are the common issues identified for potential improvement:

- Instructors should coordinate with teams (mentors and students) after the first week of classes to confirm project scope, specifics of assignments and deliverables.
- Instructors should meet with mentors once a month to monitor progress and make adjustments.
- Examples of past student projects and samples of actual project documents (specifications and drawings) should be made available to students in a central location.
- A Tuesday class should be dedicated to providing an overview of the software applications being utilized in industry, how they are used and their potential benefit for the student projects.
- The Engineering Ethics class would benefit from the addition of small group discussions of one particular case and then a full class review.
- The three class sessions related to Graphics, Presentations & Communication should be scaled back to two sessions since students have already completed courses on presentations soft skills.
- Instructors should meet with each team for a brief critique session following grading of major assignments.
- The students would like to be kept current on the progress of the other teams. Some type

of an informal Thursday presentation is suggested perhaps twice during the semester.

- Communication and coordination between multiple teams assigned to the same project could benefit from a single project manager.
- Students recommended trying to cover material in the Tuesday lecture to a level of detail to assist in application through the semester long project.