INTEGRATING THE REAL WORLD INTO THE CAPSTONE EXPERIENCE

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Abstract
The capstone design course has traditionally been intended to be an experience that brings together all of the design tools that students have learned over the four years of course work. There is a strong incentive to incorporate more "real world" experiences into the class. This paper revisits this design experience and shares some thoughts regarding introduction of a consulting engineering environment into the classroom setting for capstone design experience. Issues of interest are team selection, project load distribution within teams, personal billable time, engineer/manufacturer interaction, permit procurement, client interactions, understanding plans, specifications, and contract documents, and presentation of the final product to the client.

Introduction
The goal of capstone courses is to have students experience the overall design process as a whole and realize the different components of an engineering design project. In general, the design process is an interactive process with the client and regulatory agencies to define a problem, solve the problem, and present the solution to the client. However, due to time and resource constraints, a number of steps in the "real life" engineering design processes, such as interactions with clients, permit applications, specifications, contract documents, etc. have traditionally been omitted from capstone class syllabus. This paper describes the authors' approach to present a complete overview of the design process to the students. For this purpose, engineering consulting office was used as a model. The students were asked to complete the design assignment just like in a consulting office, where they would be required to meet with the clients, interact with the regulators, turn in time sheets, regularly meet with their peers, and complete the design considering the regulatory as well as the cost issues.

In general, the capstone design classes at New Mexico State University (NMSU) and the University of Arkansas (UofA) are similar in nature; but, has the difference that at NMSU, the class discussed in this paper is offered only to the students enrolled in the environmental option under the civil engineering department; whereas at the UofA, the capstone class is multi-disciplinary within civil engineering. The following sections present the various activities employed during the capstone classes in both NMSU and UofA, without differentiating between the universities.

In the beginning of the semesters, the authors separately met with members of the local consulting engineering communities and asked the consultants what they believe should be included in the capstone course. Specifically they were asked to identify areas of deficiency found in recent graduates and to comment on how they feel these shortcomings might be eliminated. At both campuses, the consultants felt that recent graduates lacked an understanding of the overall design process, communication skills, and AutoCad experience. The classes at both UofA and NMSU were restructured to correct these shortcomings by incorporating class exercises, which simulate everyday activities of practicing engineers. These additional activities included: team assembly, permit application, project scoping, estimating and tracking engineering costs, reviewing submittals, weekly project meetings, mid-design review, and project presentation. In addition, the local engineering consultants were asked to participate in the development and guidance of the class as well as to provide appropriate projects for the class.

Team Assembly

During the first class period the students were asked to write a one page vitae highlighting their technical strengths and weaknesses in pertinent areas (e.g. hydraulics, hydrology, AutoCAD, transportation, economics, and construction). The vitas were evaluated by the instructors and used to assemble teams. The team assembly process performed a number of functions. It provided the students with a context for performing a meaningful self-evaluation and it provided them with some experience in the concept of team building based on skills rather than relationships. In addition, the students discovered the consequences of misrepresenting their skills. It was observed that the students claimed to have expertise in certain areas, such as AutoCAD; but yet, had very little knowledge of the software. Therefore, the team had to make up for the short-falls due to misrepresentation of skills by a student.

Plans and Specifications Training

Very few undergraduate students come into a capstone course with the skills required to read plans and specifications. The authors believe that a minimum level of familiarity with plans and specifications is required if the students are going to participate in a "real-world" design exercise. Each of the teams was provided with a set of plans and specifications from a recent design project that was provided by the local consulting firms. They were given an overview of the project and then an overview of the plans and specifications structure as prescribed by Construction Specifications Institute (CSI). They were then assigned an exercise that required them to perform a number of tasks using the plans and specifications. The exercise included finding dimensions, elevations, flow paths, checking hydraulic profile, and checking cross-references between the plans and specifications. They were also asked to determine how the contractor would be paid for extras and deducts according to the plans and specifications. The process of issuing change orders and claims were discussed using examples from different projects.

Another exercise involved a review from a regulatory point of view. One section of the available set of plans was compared to Ten States Recommended Standards for Wastewater Facilities to demonstrate the use of standards by a regulator who is performing a technical review of the plans and specifications.

Although the engineer's product is the plans and specifications, the ultimate goal is successful construction of an engineering project. If the students are going to successfully design a project, the authors believe that they should have seen a number of completed projects and understood how the plans and specifications relate to the finished project. The students were taken to a number of actual wastewater treatment plants, and where possible, they were provided with the plans and specifications for the plants. This exercise was intended to start the development of an experience base for writing and using plans and specifications.

Permit Applications

The primary driver in many design projects is the regulatory constraints. This is a difficult concept for students who have spent four years developing an understanding of the theory of engineering design. In the capstone classes, students were asked to determine which permits were required for their projects, to fill out the applications for the permits, and to estimate the impact of permit acquisition would have on their project timelines. Although this step is not technical in nature, it can control the design timeline, and young engineers need to be aware of the permitting process.

Project Scoping

Engineering students are accustomed to having boundaries placed on problems for them by the faculty or by a textbook. In these capstone design exercises, the faculty allowed the student teams to determine the extent of the project, scope the project, and assign work-load for the members based on their evaluation of the design project. The student evaluation and assignments were critiqued by the faculty, but not controlled. The students were required to estimate the time that would be required to complete the design of the project and to assign tasks to team members. During the semester, the students received feedback through a team leader and at team meetings, which occurred on a regular basis such would be expected at a consulting office.

Project Time Accountability

All engineering firms require that employee's time be accounted for and billed. This is an activity that is completely foreign to most engineering students. As a part of the capstone class, the students were required to keep a journal in which the minimum billable interval was 15 minutes.

Practicing Engineer

At NMSU, the student groups were given the opportunity to meet with the practicing engineer who designed the real project that was assigned to them. This meeting started out as a short lecture from the engineer regarding engineering practice, the significance of registration, and ethics. The students were then given time to ask questions regarding their specific project, and achieved input on the construction and operation of the project as the students have designed.

At the UofA, each student group was assigned a different project and each team met many times with the practicing engineer who designed the real project. The initial meeting was an orientation and data gathering meeting. Subsequent meetings were requested by the design team as deemed necessary by the team. These meetings were held at the practicing engineer's office as their schedule allowed.

Mid-Design Review

As with many design firms, the students were required to complete a preliminary design (approximately 15 percent) for review to catch any major errors. On all calculations, the designer and a checker were asked to sign off on a signature block for each design calculation.

At NMSU, the mid-design review included all of the unit operations sizing calculations. The calculations were checked and then the design was presented to the other teams. This was a quality circle exercise that allowed the students to critique each other and make corrections prior to investing a large amount of time in selecting hardware and making drawings.

At the UofA, the mid-design review, depending on the type of project, included development plating, road and utility layout, comparison of structural building material (steel vs. concrete), process selection and sizing, project scoping, and rough construction cost estimate. The mid-design review was given in the form of a presentation to the "client." The presentation is attended by all student groups, a cross-section of faculty from the department, and the practicing engineers associated with each project.

Reviewing Submittals

The students were required to submit all drawings in an AutoCAD (or equivalent) format. They were not required to actually draft the images. The students were encouraged to utilize the manufacturer representatives (MF) as much as possible to lighten their work-loads. There is an appropriate balance between working with the MF and relying on the designs provided by the MFs. In an effort to make the students understand the delicate balance between engineers and MFs, some consulting engineers and MFs were invited to the class to discuss their view of the design process and the relationship between the design engineer and the MF in the process. It is hoped that the students came to understand that, although the MFs are useful information sources, the design engineer carries the liability of the decisions made in the design process.

Manufacturer's materials were made available to the students and they were encouraged to utilize this material as a design resource. Depending on the manufacturer, this information was made available as three-ring binder rip-sheets, e-mail files, CDs, or web-based materials. The students were cautioned that they should compare the manufacturer's recommendations to their own theoretical calculations.

Estimating and Tracking Construction Costs

There is little in the students lives that has prepared them to anticipate and estimate costs associated with construction. The plant tours coupled with real cost data for the plant being toured makes the cost data more understandable. The authors provided the students with numerous costing methods (e.g. Means Cost

Index, the City of Albuquerque NM Cost Database, Arkansas Highway and Transportation Department Cost Schedule, Craftsman costing web page) as costing resources.

At NMSU, other than the design project cost estimations, as an exercise, the students were asked to participate in a detailed construction costing study for a rectangular reinforced concrete basin with no hardware. In spite of the focus put on the cost estimation issues, the authors felt the students did not make the fundamental connection between the engineering pre-bid cost estimate, and the funding for the project. This is an area that still needs some serious consideration.

Project Presentation

The design team presented the final design to a diverse group of professionals including county planners, consulting engineers, manufacturer's representatives, the other student design teams, and faculty. The presentation had to include an overview, specifics about the design of key components, AutoCAD quality drawings, and the engineer's estimate of construction costs. The presentations were done using presentation software and had to resemble the presentation a consulting firm would give to a client when presenting the final design product prior to bidding. The audience was asked to provide the design team with a honest critique of the project and these evaluations were incorporated into the presentation grade.

Un-resolved Issues

One of the major issues that continues to plague group activities in academia is assessment of individual effort of the students by the faculty. It is clear to the casual observer that there are frequently non-performers in a group as well as over-performers. Educators are encouraged to minimize self-evaluation by the students. The experts tell us that this may squelch interactive creativity, since the students may feel they are competing with each other. In addition, the students often are not comfortable assigning fair grades to their peers. Therefore, it is a hard task for the faculty to determine the actual effort of students and provide fair evaluations for different members of a team. Grading of individuals is an issue that the authors did not feel was resolved to their satisfaction in their classes.

The authors did not always have the experience necessary to fairly evaluate the student's performance and this made grading rather difficult. Therefore, the authors relied heavily on the practicing engineers who had volunteered their time and resources to assist with the class.

Conclusions

Design group meetings, project leader meetings, and class discussions provided the interactive feedback during the design capstone courses at NMSU and UofA. A sample syllabus which shows the mix of lecture, lab, and field trips for the NMSU environmental class capstone is attached. It also illustrates the timeline associated with the design activities. The plans and specifications activities were extremely valuable and could even be expanded. The field trips and visits by planners, engineers, and manufacturer's representatives were critical to the success of this class. These activities helped expand the students' engineering intuition. The students seemed to enjoy and responded well to the consulting environment that the instructors attempted to create in the classroom. The professional involvement in the class was key to making the class a success. Besides providing guidance as to the content of the class, the professionals donated significant amounts of time and resources during the semester.

Sample Syllabus

Environmental Engineering Design At New Mexico State University
Capstone Design Course

CATALOG DESCRIPTION: Design of chemical, physical, and biological operations and processes involved in water and wastewater treatment.

INSTRUCTORS:	Dr. Adrian Hanson, P.E.	OFFICE	EC II, Rm 231
OFFICE PHONE:	646-3032	OFFICE HRS:	M-W: 1:00-3:30
	Ege Egemen, EI	OFFICE	EC II, Rm 248
OFFICE PHONE:	646-6012	OFFICE HRS:	M-W-F: 9:30-11:30

CLASS MEETING SCHEDULE AND LOCATION:

Lecture:	MW, 3:30 - 4:20	Room ECII 106
Laboratory:	F, 2:30 – 5:20	Room ECII 226

PREREQUISITES: CE 256 Environ. Science; CE 356 Intro. to Environ. Engineering

TEXTS:

COURSE GOALS: This course is designed to teach the civil engineering student the process of establishing boundaries on a problem and the applying engineering design principles of water treatment (physical-chemical treatment), wastewater treatment (biological treatment) to solve the problems in a team based project formats. Given the tools available to our students, and the depth at which they are covered in the background course materials, the student should be able to successfully complete a full water treatment plant design and a full wastewater treatment plant design during the semester. Presentation skills and team skills are also critical and will be stressed in this course.

CONTRIBUTION OF COURSE TO MEETING THE PROFESSIONAL COMPONENT:
This course provides the student with their first entry-level team environment design experience in environmental engineering.

RELATIONSHIP OF COURSE TO PROGRAM OBJECTIVES:
ABET category content as estimated by the faculty member who prepared this course description:
Engineering Science: 0 credits; Engineering Design: 3 credit or 100 %

GRADING:

Component	Percent
5 open-book quizzes	18.3 %
5 field trips	15.0 %
2 projects	66.6 %
TOTAL:	**100 %**

COURSE TOPICS AND SCHEDULE:

Class	Date		Topic	Assignment
1	Jan.	12	Introduction	
2		14 (L)	Field Trip LC, West Mesa Industrial Park, & Cheese Plant Wastewater Treatment	
3		19	Wastewater project assignment and team selection	
5		24	Regulations and permits (FONSI, NPDES…)	
6		26	Project Management and Coordination (Guest)	
7		28(L)	QUIZ; Plans and Specifications (Soldier Canyon)	Preliminary design
8		31	Flow measurement and headworks	
9	Feb.	2	Aerated and centrifugal grit chambers	
10		4 (L)	Field trip to Hatch & Casa de Oro Wastewater Plant	Draft P&P sketches
11		7	Plant Hydraulics (Pipes & Channels)	
12		9	Pumps (Sewage vs water pumps)	
13		11(L)	Equipment Rep Presentation (Guest)	Initial calcs
14		14	Disinfection (Cl, O3, UV)	
15		16	QUIZ; Thickening	
16		18(L)	Group Design Presentations/Discussions	Draft text and pre drawings
17		21	Wastewater sludge handling	
18		23	Rip Sheets & Shop Drawings (Guest)	
19		25(L)	How to present a final project to a client (Guest)	
20		28	Later phases of a project: bidding, construction, field inspection (Guest)	
21	Mar.	1	Final presentations	
	Sat.	4	Field trip to Jonathan Rogers and Bustemante Plant	
23		6	Water project assignment and team selection	
24		8	QUIZ; Water reuse and reclamation	
25		10(L)	Review of water treatment plant design. At end of the lab turn in 356 level design calcs	Process Schematic
26		13	Regulations (SDWA)	
27		15	Groundwater vs surface water plants	
28		17(L)	Field trip to Alomogordo (La Luz Plant and Oxidation Ditch with surface discharge)	Preliminary Design
29		20	Flow measurement and headworks (pump, pH adj.)	
30		22	Rapid mix and flocculation	
31		24 (L)	Field Trip to Anthony & Sunland Park	Draft P&P sketch
32	April	3	Filtration	
33		5	Plate and tube settlers	
34		7 (L)	QUIZ; Equipment Rep. Presentation (Guest)	Initial Calcs
35		10	Registration Issues: ethics, E&O, responsibility (Guest)	
36		12	Membrane processes (Guest)	
37		14(L)	Group Design Presentations/Discussions	
38		17	Disinfection bi-products and their removal	
39		19	Water plant sludge handling	Draft text and pre drawings
42		28(L)	Cost analyses	
43	May	1	Auxiliary units of treatment plants	
45		5(L)	Final presentations	Final Water Project

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