Innovative Design-Build Approach to Project-Based Learning

Susan M. Bogus
Civil Engineering Department
University of New Mexico

Kerry J. Howe
Civil Engineering Department
University of New Mexico

Abstract

All undergraduates in the Civil Engineering Department at the University of New Mexico must take a senior capstone course in the last semester before graduation. The purpose of the capstone course is to require students to integrate the knowledge they have gained from their undergraduate curriculum into solving a real-life problem. One challenge at the University of New Mexico is providing this experience to students while satisfying the accreditation requirements for three separate undergraduate degree programs. Starting fall 2007, a new design-build approach was implemented in the capstone course that teams students from all three undergraduate degree programs to solve real-life engineering and construction problems. This innovative design-build approach provided additional education for the students, but also required assessment of accreditation criteria for two different accreditation agencies (ABET and ACCE). Based on faculty observations and student feedback, the design-build approach was successful because it introduced students to project aspects outside of the typical classroom environment. The engineering students were exposed to construction issues and forced to think about how their designs affected construction. The construction management students were exposed early to design decisions and the process of design. However, there were also lessons learned from this experiment that will improve future offerings of this course.

Introduction

Project-based learning allows students the opportunity to apply what they have learned in the classroom to real-life projects.[1] The Civil Engineering Department at the University of New Mexico has three accredited bachelors degrees: civil engineering, construction engineering, and construction management. For many years, it has used project-based learning in their senior design course and their senior construction management course. These courses are often referred to as capstone courses, as they are the culmination of a diverse curriculum. The senior design course is taken by civil and construction engineering students and includes the preparation of design proposals and preliminary design of a real-life project. The senior construction management course is taken by construction management students and includes the preparation of bid documents such as schedules, cost estimates and management plans for a recently designed project. Both courses require students to integrate the knowledge they have gained from their undergraduate curriculum into solving a real-life problem. In both courses, the project is a real project in progress at a local engineering or

construction company, and engineers or construction managers from the company act as mentors to the students.[2]

The challenge with using real-life projects is that project approaches are always changing. One fairly recent change in the way that civil engineering projects are delivered is the move away from design-bid-build to design-build. Design-bid-build is a traditional project delivery method where design and construction services are separated from one another. This method of delivery can produce problems due to a lack of communication between the design and construction components, as well as foster an adversarial relationship. The design-build project delivery method addresses the communication issue by placing the designers and constructors on the same team. This allows design and construction to proceed concurrently, thus saving the project time and money. Because of the growth in design-build, it is important to expose students to this project delivery method.

To introduce students to design-build, a new approach was devised for the senior design and construction management courses. In the fall of 2007, these courses were co-taught and the students worked in teams that integrated engineering and construction management students. The teams still worked on real-life projects, but the project requirements included both preliminary design and construction management documents. This innovative design-build approach provided additional education for the students, but also resulted in some lessons learned for future semesters.

In addition, co-teaching this course required that assessments be performed for two separate accreditation entities, since the engineering programs are accredited through the Engineering Commission of ABET and the construction management program is accredited through the American Council for Construction Education (ACCE). To address accreditation concerns, course requirements were developed with accreditation needs in mind. In addition, a grading rubric was developed and used to assess accreditation outcomes.

Course Background

Two separate senior capstone courses were developed and taught at the University of New Mexico for many years. Each course was designed to address outcomes and criteria related to program accreditation. The senior design course was required for all students in the two ABET-accredited programs, and the senior construction management course was required for all students in the ACCE-accredited program. These courses are briefly described below.

Senior Design Course

The senior design course was attended by all students in the civil engineering and construction engineering undergraduate programs. This project-based course requires students to act as a team of engineering consultants who first propose on a real-life project and then prepare a preliminary design for the same project (Figure 1). Each semester new projects were used based on suggestions from local consulting firms. The types of projects used for this course included the redesign of a downtown intersection, redesign of a highway offramp, design of a stormwater diversion channel, and design of a railroad alignment. The local consultants who were hired to design the project in real life volunteer to act as technical advisors to the student teams. The purpose of the course is to require students to apply the knowledge they gained throughout their engineering curriculum to a real life project. Typically, students within a team divide the responsibilities by technical area. For

example, one student acts as the structural engineer while another student acts as the geotechnical engineer. The final deliverable – a preliminary design report with approximately 30 percent design drawings and specifications – requires the entire team to work together to combine each of their technical areas.

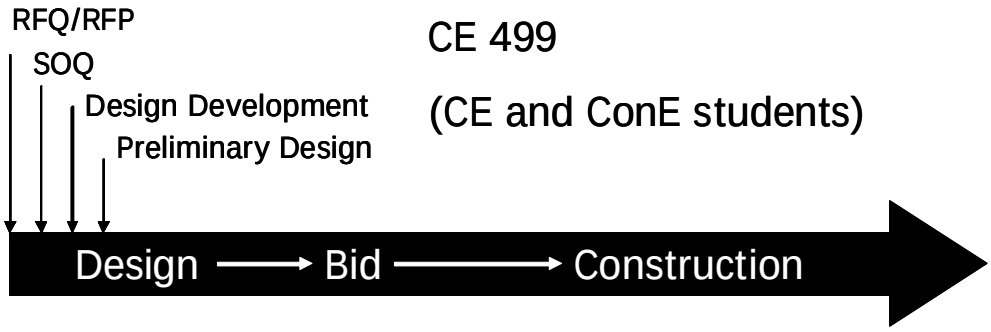

Figure 1. Senior Design Course (CE 499) Elements

At the end of the semester, the students are asked to provide feedback on the course, which is then used by the department to improve the curriculum for the civil engineering and construction engineering programs. One of the factors that contributed to the development of the design-build approach is feedback from the construction engineering students. The construction engineering students have traditionally been required to take the senior design course because their program is accredited by the Engineering Commission of ABET. However, this course typically focuses purely on design of the engineered product and does not include design of the construction process. Therefore, the construction engineering students in the senior design course have not been provided adequate opportunity to apply their knowledge in the design of construction processes.

Senior Construction Management Course

The senior construction management course was attended by all students in the construction management undergraduate program. This project-based course requires students to act as a general contractor to bid on a real-life construction project (Figure 2). Projects are suggested by local general contractors, who provide the university with copies of the actual plans and specifications for a real project. The students use this design information to prepare a cost estimate, project schedule, safety plan and project management plan for constructing the project. Traditionally, the projects in this course have been limited to commercial and institutional buildings, including several University of New Mexico buildings.

The students in the senior construction management course provide feedback on the course at the end of the semester. As with the senior design course feedback, the feedback from the senior construction management course is used to improve the curriculum for the construction management program. One idea for improving the construction management program was to increase the integration of the construction management students with the civil engineering and construction engineering students. This would give the construction management students a better idea of the design process and how design and construction can work together for project success. Therefore, an integrated design and construction capstone course was developed using the design-build project delivery method.

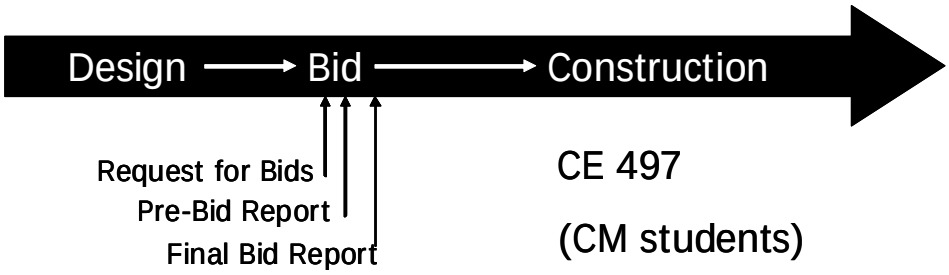

Figure 2. Senior Construction Management Course (CE 497) Elements

Course Redesign

Starting in the fall semester of 2007, an innovative design-build approach to project-based learning was implemented in the Civil Engineering Department. The design-build approach called for co-teaching the two separate senior capstone courses (the senior design course and the senior construction management course). As its name implies, design-build is a project delivery method that integrates the design and construction elements into one project. A design-build team consists of both designers and construction managers, who work together to provide the project owner with a finished product – from design through construction. This project approach is sometimes referred to as "turnkey" delivery. The use of design-build in the U.S. is growing, so it is important that the students understand the concepts of integrated design and construction.

The design-build course was developed to keep the strength of the previous capstone courses, which was the project-based approach where students worked on real life projects. One improvement to the previous courses was that the design and construction components were now combined, and likewise, the engineering and construction management students were combined onto design-build teams. For many students, this was the first time they had to work with someone outside their degree program (i.e., engineers with construction managers and vice versa). The design-build teams were truly multi-disciplinary.

Figure 3. Design-Build Course Elements

In the design-build course, students were given a real-life project and asked to participate in a two-step selection process (Figure 3). The first step required each team to prepare a Statement of

Qualifications to illustrate that they had the background and experience to successfully complete a design-build project. The second step required each team to prepare a Design-Build Proposal. Different from traditional design proposals, the design-build proposal process has elements of a construction bid, where teams must provide both a design and guaranteed maximum price for the construction of the project. Table 1 lists the required elements of the design-build proposal for this course.

Table 1. Design-Build Proposal Contents

Section One	**Company Data**
	1.1 Corporate Profile
	1.2 Financial Statement
Section Two	**Project Organization**
	2.1 Staffing Plan
	2.2 Organization Chart
	2.3 Staff Time Allocation
	2.4 Resumes
	2.5 Consultants and Subcontractors
	2.6 Licenses and Registrations
Section Three	**Previous Experience**
	3.1 Introduction to Project Experience
	3.2 Representative Projects Table
	3.3 Project Profiles
	3.4 References
Section Four	**Project Approach**
	4.1 Overview of Project Approach
	4.2 Quality Assurance Plan
	4.3 Safety Plan
	4.4 On-Site Storage Requirements and Operations
	4.5 Phasing Plans
	4.6 Project Approach and Methods
	4.7 Cost Control Approach
	4.8 Value Engineering Approach
Section Five	**Schedule**
	5.1 Project Schedule Overview
	5.2 Schedule
	5.3 Resources, Manpower, and Equipment
Section Six	**Design**
	6.1 Renderings
	6.2 Design Narrative
	6.3 Drawings
	6.4 Outline of Specifications
Section Seven	**Pricing**
	7.1 Guaranteed Maximum Price
	7.2 Schedule of Values
	7.3 Bid Bond

Since each team had both designers and construction managers, the work was to be divided by student strengths. The civil engineering students concentrated on the design, while the construction management students concentrated on the construction approach, schedule and cost estimate. In fall 2007 there were no construction engineering students in the course; however, these students would be expected to design the construction process.

While introducing students to the design-build project delivery approach was one objective of this course, another key objective was to be able to assess student abilities for program accreditation. Combining the two senior capstone courses meant that the new design-build course would need to be able to assess abilities for students in the ABET-accredited programs as well as students in the ACCE-accredited program. Since the design-build proposal constituted the primary deliverable for the course, the contents were selected to allow for assessing the requirements of both ABET and ACCE.[3,4] These requirements are listed in Tables 2 and 3.

Table 2. ABET Outcomes Assessed for Engineering Students[1]

Item	ABET Section	Outcome
1	3.c	Able to design components.
2	3.c	Able to integrate components into a system.
3	3.c	Comprehends the design process and constraints.
4	3.d	Share equal responsibility
5	3.d	Communicate effectively among team members
6	3.d	Make effective decisions as a team
7	3.e	Comprehension of the types of problems encountered/solved by civil engineers.
8	3.e	Ability to formulate an approach to solve a problem.
9	3.e	Applies solution methods to solve a problem
10	3.g	Effective at technical writing.
11	3.g	Effective at oral presentation
12	3.g	Engages in classroom discussions
13	3.i	Comprehends the need for lifelong learning.
14	3.i	Demonstrates ability for independent and self-directed learning.
15	3.i	Demonstrates ability to engage in lifelong learning.
16	3.k	Knowledge of the capabilities of contemporary engineering tools.
17	3.k	Comprehension of the process for selecting engineering tools for specific goals.
18	3.k	Applies engineering tools for solving problems.

Table 3. ACCE Criteria Assessed for Construction Management Students[2]

Item	ACCE Number	Criteria
1	5.1	Estimating (quantity takeoff, pricing, direct and indirect costs, bid preparation, computer applications)
2	5.2	Planning and Scheduling (network diagramming and CPM calculations, resource allocation, computer applications)
3	5.3	Construction Accounting and Finance (accounting formats, fixed and variable costs, record and report practices, forecasting costs, bidding and procurement practices)
4	5.4	Construction Law (construction contracts)
5	5.5	Construction Safety (safe practices, mandatory procedures and training)
6	5.6	Project Management (concepts, roles and responsibilities, cost control, quality control)

Primarily data were collected from faculty assessment of the final project deliverable (i.e., the design-build proposal) and the final oral presentation of the design-build proposal. In addition, some of the ABET outcomes were assessed through homework assignments, consultant assessment, and self-assessment. For this first semester, a rubric was developed to assess the design-build proposal (written document) against the ABET outcomes (Table 2).[5] The rubric evaluated student performance on a 3-point scale – exemplary (3), satisfactory (2), and unsatisfactory (1). An excerpt from the rubric is shown in Table 4.

Table 4. Rubric for Assessing ABET Outcomes

Item	ABET Section	Outcome	3 (Exemplary)	2 (Satisfactory)	1 (Unsatisfactory)
1	3.c	Comprehends the design process and constraints.	Development of design in logical and systematic process is evident, assumptions are stated, constraints are listed. Iterative progression of design improvement is evident where appropriate.	Development of design in logical and systematic process is evident, but may not consider all possible constraints.	No systematic approach to the design.

2	3.c	Able to design components. (List components assessed here):	Individual component will work well, is cost effective, is safe to build and use, uses sustainable materials, and does not trigger ethical, social, political, or environmental concerns.	Component will work well but has aspects that are less practical, such as overly expensive, difficult to implement, poor choice of materials, or triggers other concerns.	Design of component violates basic scientific or engineering principles.

A similar rubric is under development for the ACCE criteria listed in Table 3.

Summary and Conclusions

Initial feedback from students, faculty and the consultant mentors was mixed regarding the success of the integrated class. When the students were asked if they would recommend combining the two separate capstone classes in the future, 50 percent said "yes" and 33 percent said "no" with the remaining students not answering the question. Student satisfaction was highly dependent on which project team the student was on. Of the two project teams, one team had a much more positive view of the combined class than the other team. The faculty and consultant groups both thought the combined design-build approach was beneficial and should be continued. The Civil Engineering Department is committed to continuing the combined approach to the capstone course and plans to use feedback from this first experience to improve the course in future semesters.

In summary, we have presented an innovative design-build approach to project-based learning. This approach was first implemented in the Civil Engineering Department of the University of New Mexico in fall 2007. The design-build approach adds to the strength of the department, namely that is offers undergraduate programs in civil engineering, construction engineering, and construction management. Having all three programs in a single department increases the opportunities to integrate design and construction experiences for all of the students. The design-build approach to the senior capstone course does this by combining the senior design course and the senior construction management course into one co-taught course. This course is also designed to address accreditation criteria for both the ABET-accredited engineering programs and the ACCE-accredited construction management program.

References

1. Dutson, A.J., Todd, R.H., Magleby, S. P., and Sorensen, C.D., 1997, "A Review of Literature on Teaching Engineering Design through Project-Oriented Capstone Courses," ASEE Journal of Engineering Education, January 1997.
2. Knox, R.C., Sabatini, D.A., Sack, R.L., Haskins, R.D., Roach, L.W., and Fairbairn, S.W., 1995, "A Practitioner-Educator Partnership for Teaching Engineering Design, ASEE Journal of Engineering Education, January 1995.
3. ABET, 2007, "Criteria for Accrediting Engineering Programs," Engineering Accreditation Commission, Baltimore, MD, March 17, 2007. URL: http://www.abet.org/.

4. ACCE, 2006, “Standards and Criteria for Accreditation of Postsecondary Construction Education Degree Programs.” American Council for Construction Education, July 2006. URL: http://www.acce-hq.org/.
5. Briedis, D., 2002, “Developing Effective Assessment of Student Professional Outcomes,” International Journal of Engineering Education, Vol. 18, No. 2, pp. 208-216.

SUSAN M. BOGUS
Dr. Bogus currently serves as an Assistant Professor of Civil Engineering at the University of New Mexico. Her research interests include design-build, concurrent engineering, sustainable design and construction, and asset management. Prof. Bogus is a registered Professional Engineer in Wisconsin.

KERRY J. HOWE
Dr. Howe currently serves as an Assistant Professor of Civil Engineering at the University of New Mexico. His research interests include environmental engineering, physical chemical treatment processes, membrane technologies, and engineering design. Prof. Howe is a registered Professional Engineer in Wisconsin.