AC 2010-899: INVOLVING INDUSTRY PARTNERS IN CONSTRUCTION ENGINEERING AND MANAGEMENT CAPSTONE COURSES

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Abstract

The objective of this paper is to share the experiences of faculty using a case study project in a construction engineering capstone course as part of a construction engineering and management curriculum. This case study may be used by others as a model for incorporating industry partners in capstone courses. Completing the case study project allowed students to demonstrate proficiency in the Accreditation Board of Engineering and Technology (ABET) Criterion 3c, 3e, and 3g, which were major objectives of the course. For the case study presented here, the students were required to design the construction process for an electrical substation project that had recently been completed by the industry partner. At the completion of the case study project, the students presented their results to a panel of professionals including the course instructor, two members representing the industry partner, and two members representing the local electrical utility company. The industry partner also conducted job interviews for all students that were interested in a career with their company. Thus, the industry partnering relationship had several positive results, including: 1) the students successfully completed the proposed learning outcomes of the course, 2) the students had an enriched learning experience by working closely with industry professionals, 3) the students were able to explore an exciting and emerging field in the area of construction engineering and management, and 4) the students were presented with an opportunity to begin their professional careers by interviewing for employment with the industry partner.

Introduction

All students in the Construction Engineering and Management (CEM)[1] curriculum in the Department of Civil, Construction, and Environmental Engineering (CCEE) at North Carolina State University (NC State) are required to take CE 469 Construction Engineering Project (CE 469). There are two primary learning outcomes for this course, which may be summarized:

1. Demonstrate an understanding of construction engineering and management principles and the ability to solve a broad set of engineering problems in construction; and
2. As a member of a team, apply the principles of professional communication to present the results of that design to a committee formed of the instructor and knowledgeable industry representatives.

The pedagogical methods for this course include an active learning and hands-on approach that requires the students to work with industry representatives in a way that reflects actual construction management practices. The students also use technology typical of the current state of construction practice.

As one of the largest undergraduate programs in the nation, the CCEE department at NC State has a broad and well-developed network of alumni. Many of these individuals are eager to invest their time and expertise in the development of the future generation of engineers and construction professionals, while also remaining loyal to their alma mater. Thus, it has not been

difficult to recruit industry partners to participate in CE 469. In fact, it is often more difficult to choose which industry partner will participate rather than finding a partner to participate.

Background of Capstone Course

In 1952, the Department of Civil Engineering at NC State University developed the first engineering accredited undergraduate program in Construction Engineering.[2] The CEM degree program, accredited by the Engineering Accreditation Commission of ABET, now graduates approximately 40 to 50 students each year and has accumulated over 2,000 graduates since 1952.

The overall purpose of the senior capstone Construction Engineering Project course is to provide the student with broadly based but realistic experiences in designing the construction process, interpreted as the process of devising a system, component, or process to meet desired needs while also meeting many realistic constraints including economic factors, safety, reliability, aesthetics, sustainability, ethics and social impacts. The construction process can also include the design of temporary engineered systems and components.

CE 469 seeks to provide a transition-to-practice experience preparing the student to be a successful practicing engineer. CE 469 emphasizes management-level decision making and learning to "think like the boss – think like the client." Development of alternatives, risk assessment, evaluation of opportunities and potential problems, cost control, professional documentation, and an analysis of cash flow are required. The students develop an appreciation for identifying critical, "make-or-break" aspects of planning and bidding a project in a time constrained environment.

The CEM faculty at NC State believes that a strong relationship with the construction industry is critical to the success of both the students and the program. One of the most valuable and unique aspects of the course involves interaction with practicing construction professionals which allows the students to develop a deeper understanding of concepts and interrelationships in construction engineering. This interaction has been a common element of the course for over three decades.

Structure of Capstone Course

CE 469 is a capstone course that involves an integrated team approach to the design of the construction process and uses computerized tools for cost estimation, planning, scheduling, process design, and management of two construction projects; one project focuses on the horizontal aspects of construction while the other project focuses on the vertical aspects. Furthermore, each student also selects an individual project. Lecture topics for this course include ethics, professionalism, marketing, bid presentations, business planning, finance, and other appropriate topics by guest speakers from the construction industry.[3]

In order to fully utilize the prior knowledge developed during the Construction Engineering and Management curriculum, the students are required to take CE 469 during the last semester of their senior year. By the end of the course, the students should be able to:

- Design the construction process for both heavy civil and building construction projects;
- Evaluate the effects of societal and economic impacts of construction engineering practice;
- Apply the principles of safety, quality, durability, and economic limitations;
- Demonstrate the professional and ethical responsibilities of the construction engineer; and
- Apply engineering judgment and the creative process of engineering design.

Based on these learning objectives, CE 469 includes both team projects and individual work. For the CE 469 course taught during the spring semester of 2009, these assignments included two team projects, one individual project, an ethics quiz, and a final exam. Table 1 summarizes the contribution of each assignment to the overall semester course grade for CE 469.

Table 1. Summary of Course Assignments

Assignment	% of Course Grade
Team Project 1	35
Team Project 2	35
Individual Project	20
Ethics Quiz	5
Final Exam	5
Total	**100**

As part of an ABET accredited curriculum, CE 469 must foster the attainment of the educational objectives of the curriculum, including the program outcomes set forth in Criterion 3a-k of the Criteria for Accrediting Engineering Programs[4]. Table 2 is a summary assessment of the degree to which CE 469 addresses these program outcomes. CE 469 makes major contributions to the program outcomes related to the ability to design a system, component, or process (3c), the ability to identify, formulate, and solve engineering problems (3e), and the ability to communicate effectively (3g). Achievement of these three criteria by involving industry partners is the focus of the case study presented in this paper.

Case Study Project

As part of the requirements for CE 469 during the spring semester of 2009, students were required to form teams to complete two construction related projects. The first project of the semester was a commercial building project that focused on the vertical aspects of construction. Although not discussed here, this project used a local general contractor as an industry partner to assist the student teams with the design-build delivery of the project. The second project of the semester serves as the case study for this paper and it focused on the horizontal aspects of construction.

For this case study, a recent CEM graduate from NC State that was employed with an energy systems solutions provider contacted the instructor and indicated the desire to serve as an industry partner for CE 469. This particular company is a nationwide firm with a primary focus on the planning, design, engineering, and construction of power systems, including transmission, distribution, substation, and smart grids. The industry partner agreed to play an interactive role

with the students during the completion of the project by responding to inquiries and providing guidance in technical areas. To complete this project, 21 students worked in three teams of five individuals each and one team of six individuals. The students were given approximately five weeks to complete the assignment.

Table 2. Relationship of CE 469 to Criterion 3 Program Outcomes

Program Outcomes	Contribution	Students must demonstrate an ability to:
a. Math, Science, Engineering	Minor	Use the principles of math, science and engineering in design
b. Design, Conduct Experiments	Not Applicable	Not applicable
c. Design System, Component, Process	Major	Design the construction process for two separate projects, one Heavy-Highway-Sitework and one Building construction
d. Multi-disciplinary Teams	Moderate	Analyze and prepare project bids working in a team; include MEP, architectural, structural and landscape design elements in plans
e. Engineering Problems	Major	Analyze and solve critical engineering problems associated with the design of the construction process
f. Professionalism; Ethics	Moderate	Apply the requirements of appropriate Codes of Ethics or Conduct to identify and resolve ethical issues during the bid interview and in written exam
g. Communication	Major	Develop a formal presentation to and negotiate a bid with a committee (contractor, instructor, and other professionals)
h. Impact of Engineering	Moderate	Evaluate impact of public needs and project constraints imposed by the owner and society on the design of the construction process
i. Life-long Learning	Minor	Demonstrate an understanding of the role of professional registration and PDH requirements for the Construction Engineer
j. Contemporary Issues	Moderate	Evaluate the effects of contemporary issues such as pollution abatement, permitting, sustainability, and value engineering in the design
k. Modern Tools	Moderate	Demonstrate the use of modern scheduling and estimating software

The case study project was the design of the construction process for an electrical substation located on a multi-acre site. This was a project that the industry partner had recently completed; thus, there were adequate materials, such as plans and specifications, available for the student's use. The focus of this project was on the development of the site, including clearing, grubbing, grading, erosion control, stone paving, and concrete placement. Essentially, the students were asked to estimate, schedule, and prepare a bid for the work necessary to prepare the site for the delivery and installation of the substation equipment. At the conclusion of the project, the students were required to present their findings to a panel of industry professionals.

The case study project contributed to each of the program outcomes in Table 2. In accordance with the overall program outcomes for the course, the case study project had major contributions to program outcomes 3c, 3e, and 3g. Another distinct outcome of involving an industry partner in this project was the professional connection established between the industry partner and the students.

Program Outcomes of the Case Study Project

Program outcome 3c was achieved by allowing the student teams to use their abilities to design the construction process for a heavy sitework construction project based on plans and specifications provided by the industry partner. This process involved estimating quantities and costs of materials, labor, and equipment based on commonly used construction estimating handbooks; determining activity durations and scheduling them in a logical sequence using computerized scheduling software; and preparing a safety plan for the safe completion of these activities. The deliverables for this program outcome included paper and electronic copies of the estimate, schedule, and safety plan.

Program outcome 3e was achieved by allowing the student teams to use their abilities to identify, formulate, and solve the vast array of engineering problems associated with a project of this type. For example, the teams were required to design a dead-end pole structure for a high-tensile electrical transmission line that terminated at the substation. Each team was required to identify the necessary design criteria from the plans and specifications provided by the industry partner and then use their engineering skills to design an adequate pole and foundation for the transmission line. The industry partner indicated that this type of exercise is routinely expected of construction engineers and managers employed by this firm. The deliverable for this program outcome was a paper copy of the design calculations for the dead-end pole structure.

Program outcome 3g was achieved by requiring the student teams to communicate effectively throughout the case study project, culminating with a presentation to a panel of construction professionals. The primary deliverable for this program outcome was a 30 minute oral presentation by each team to a panel that consisted of the course instructor, two members representing the industry partner, and two members representing the local electrical utility company. The teams were required to present their estimates, schedules, and safety plans and were then asked to respond to questions from the panel. Each member of the student team was required to participate in the presentation.

Another outcome of the case study project was that the students were able to make a valuable career connection with a company in their area of specialization. The industry partner held job interviews for all students in the course that were interested in a career with their firm. This was an opportunity that the students would not have had otherwise if the industry partner had not agreed to participate in the course. Four members of the class interviewed with the industry partner on the day following the project presentations.

Results of the Case Study Project

The industry partnering relationship had several positive results, including: 1) the students successfully completed the anticipated program outcomes of the course, 2) the students had an enriched learning experience by working closely with industry professionals, 3) the students were able to explore an exciting and emerging field in the area of construction engineering and management, and 4) the students were presented with an opportunity to begin their professional careers by interviewing for employment with the industry partner.

Not only did the students demonstrate proficiency of program outcomes 3c, 3e, and 3g, but they also had to demonstrate success in the program outcomes, except 3b, shown in Table 2 while working on the case study project. The student teams' grades on the project ranged from 80 to 93 percent, demonstrating successful completion. Involving an industry partner in this capstone course helped ensure compliance with ABET accreditation requirements and strongly motivated the students to produce professional quality plans and documents.

Involving an industry partner in this course provided an enriched learning experience for the students by giving them exposure to professionals that are already doing what the students are being prepared to do. The case study project gave the students the opportunity to utilize the fundamental construction engineering knowledge that they had obtained from previous courses by applying it to a real-world construction project. Since the substation had recently been completed, the industry partner was able to provide insightful feedback on the students' performance and tell them how their results compared to the actual results.

The case study project provided by the industry partner gave the students exposure to the emerging issue of future energy solutions. Although the students were not required to design the electrical components of the substation, they were able to see how construction engineering and management plays an important role in meeting the nation's power demand. This particular project gave the students breadth in a multi-disciplinary area of infrastructure systems that they otherwise would not have been exposed to with a more traditional civil engineering project.

Perhaps the most positive result of the case study project was the relationships established between the students and the industry partner. The students were able to observe professional behavior of industry experts as well as have interpersonal communication with them via telephone and e-mail throughout the duration of the project and the face-to-face meeting at the conclusion of the project. As a result of these relationships, the industry partner conducted interviews for entry level permanent positions within their company for all interested students in the course. Consequently, four students had job interviews that they might not have had otherwise if the industry partner had not participated in the course.

Conclusions

Capstone courses are required and an important part of ABET accredited engineering programs at many universities. These courses allow students to put into practice the material that has been learned throughout the educational curriculum. Capstone courses are most effective when they closely represent the type of work that the students will be involved with early in their careers. To that end, capstone courses that involve industry partners often require the students to interact with industry representatives in a way that mirrors real-world engineering and construction practices.

Construction engineering and management is a practical, application-oriented field; thus, a hands-on, active learning approach is usually most effective for construction engineering capstone courses. Involving industry partners not only gives the students hands-on experiences with actual construction projects, the students also get personal experience in working with professionals in their field. The incorporation of industry professionals in the formal evaluation of student work provides a reality impossible to capture with academic faculty members alone. This reality is appreciated by the students, if not immediately, then at some future time, as evidenced by formal and informal contacts with alumni over the years. This reality also typically improves student interest and effort. The in-depth involvement of industry partners in capstone courses is an advantage that most fundamental engineering and construction courses do not have; therefore, it is imperative that construction engineering and management programs leverage industry partner involvement in their capstone courses to the fullest extent possible in order to provide the best learning experience for their students.

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