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Engagement in Practice: Capstone Design of a Real-world Transportation Interchange Project

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Abstract

Critical transportation and mobility needed to support a growing economy led local jurisdictional authorities to establish a $200 million airport infrastructure improvement program, which is solely focused on increasing roadway capacity for a critical area surrounding an international airport and associated industrial manufacturing facilities. The transportation improvement program includes three new interchanges and a realignment of the primary airport access road. The capstone design project at The Citadel focused on determining an optimal solution for one of the new interchange locations. The use of this real-world assignment as a capstone design project was enthusiastically supported by the region's airport authority, local jurisdictions, consulting engineering, and construction community. Students work in teams of 4-5 to develop design solutions to meet the needs of the larger community extending over two-semester course during their senior year curriculum. During previous year's course offering, 19 practicing professional engineers worked with students and provided design guidance for project sub-discipline areas. At the end of each semester, student teams presented their interchange designs including traffic, roadway, structural, geotechnical, drainage, construction, and project management. A professional engineer's expert review panel asked questions indicative of public meetings, evaluated presentations, ranked winning presentations, and provided valuable feedback. Students learned how to synthesize real-world design standards, use an engineering process to meet requirements, and address real world environmental, social, political, ethical, health and safety, constructability, and sustainability constraints. This project provided an academic enrichment and curriculum engagement for students to apply their knowledge to benefit the community. This paper discusses capstone design project objectives, student learning activities, educational outcome assessment mapping, faculty reflections and lessons learned.

Introduction

In professional practice, engineers build successful careers out of solving open-ended problems [1]. However, the well-structured and constrained problems that engineering students tend to solve at the early level coursework, do little to prepare them for the complexity of ambiguous and unstructured real-world problems [1, 2]. Capstone by design introduces ambiguous open-ended problems with uncertain and incomplete information. These types of problems challenge many students who are unfamiliar in dealing with this type of engineering ambiguity [3]. These problems are often supplied by outside sponsors, and students are exposed to industry workers and experts [4]. As a general practice, students work in small teams, and are responsible for their own project, time management, and solution path. The chosen problems require use of prior coursework, but often students need to acquire new knowledge, or learn new tools to solve them. Solutions are not obvious, and often first attempts will fail, or experiments are required to explore aspects of the potential solution set [3, 5]. Accreditation Board for Engineering and Technology (ABET) requires students to complete a capstone design project that prepares them for engineering practice through team-based projects incorporating the knowledge and skills acquired in earlier course work [6].

Civil Engineering (CE) faculty at The Citadel believes an optimal project type for students to learn intradisciplinary concepts is through design of an intradisciplinary transportation infrastructure project. This type of project involves several sub-disciplines of Civil Engineering (i.e., Structural, Transportation, Geotechnical, Water Resources, Environmental, Project Management, and Construction Engineering). The deign project allows students to apply their knowledge and skills to solving a complex real-world problem as a team and provides a useful transition from college to the challenges of professional practice in the real world. CE faculty believe this type of project best allows assessment of all student outcomes required by the ASCE Civil Engineering Body of Knowledge (ASCE BOK II) [7] and ABET 1-7 Student Outcomes. More specifically, although almost any Civil Engineering capstone design project can be used to demonstrate four foundational and 11 technical outcomes required by ASCE BOK II, transportation infrastructure projects also provide opportunities to assess outcomes in nine professional outcomes. The nine professional outcomes include: communication, public policy, business and public administration, globalization, leadership, teamwork, attitudes, lifelong learning, and professional and ethical responsibility.

The following sections delineate and discuss some of the approaches that the capstone project at The Citadel meet these outcomes. By having students work on a real-world ongoing project, this allows for meaningful communication between student team members and actual licensed professional engineers working on the project or similar related projects. Public policy and business administration are paramount in any transportation infrastructure project. Students gain knowledge from actual public meetings on the real project and work directly with agency officials on their student proposed design solution. Student teams are required to consider globalization and a few teams may end up proposing innovative design solutions implemented from other areas of the country, and in some cases, even other parts of the world.

Project Description and Student Learning Activities

The capstone design project was an actual interchange design project situated in a growing suburban area and located adjacent to an international airport. The area encompassing the airport was experiencing rapid expansion and changes in surrounding industrial land uses, which led local authorities to establish a $200 million airport infrastructure improvement program focusing on a series of critical roadway capacity improvements. The funding program involved three major roadway improvement projects, including three new interchanges and realignment of the primary airport access road. The capstone design project was specifically focused on one of the new interchanges, which is an ongoing project currently progressing through the public engagement and conceptual design phase. The goal of the project was to reduce travel time, increase mobility and connectivity for the surrounding area, and improve access to businesses and travel times of local commuter traffic.

Teams of 4-5 students worked collaboratively to address the following: 1) transportation planning, 2) traffic engineering, 3) roadway geometric design, 4) environmental engineering, 5) right-of-way, easements, utilities, 6) structural design, 7) geotechnical design, 8) storm water drainage design, and 9) construction engineering. Each team was required to design a specific interchange bridge, ramps, roadways, and intersections needed to create a new connect to an existing interstate route. Students first considered a range of possible interchange configurations, bridges, ramps, roadway alignments and intersections to establish an effective collection of feasible options. When selecting a bridge type, students determined all governing criteria so major structural elements could be designed. Governing criteria included: clearance, bridge span, bridge width, design speed, functional classification, traffic operations, and pedestrian/barrier requirements.

Furthermore, the project required student teams to research engineering criteria, regulations, guidelines, and standards, either federal or state, and ensure the project design met all appropriate transportation requirements. The project also included possible business/residential impacts and relocations. This required student teams to weigh moral and ethical considerations of impacting citizens or changing the design, which may result in higher project costs. Additionally, students developed and enhanced their engineering leadership skills by engaging their peers in a common vision, developing, and maintaining trust, and focusing on the use of appropriate means to effectively provide meaningful contributions to society, through their adopted design process that was reflective of professional engineering practice.

Course Format and Logistics

Student teams evaluated alternatives, identified a preferred alternative, developed designs to meet governing criteria, prepared interim/final engineering deliverables, and presented findings to an expert panel of professional engineers within the context of a public meeting. The expert panel recognized top presenting teams and provided feedback specifically reflecting real-world insight on how engineers should engage with the public, interact with jurisdictional decision makers, and lead productive conversations regarding infrastructure project design solutions.

Students interacted with practicing professional engineers from a variety of project perspectives including a public infrastructure owner, jurisdictional authority, permitting agency, consulting engineer, engineers from various design disciplines and construction engineers. Students determined interchange configurations, bridges, ramps, roadway alignments and intersection designs. Design criteria included vertical and horizontal clearance, bridge span, bridge width, design speed, functional classification, roadside safety, traffic operations, and pedestrian/ bicycle/transit requirements. Optimal student design solutions were influenced by economic, environmental, social, political, constructability and sustainability considerations.

County engineers and consulting firms provided base files of existing conditions including drawings, traffic reports, soil borings, wetlands delineation right-of-way and utilities. The real-world project was a three-leg interchange. The capstone design project assignment required a four-leg interchange to introduce an additional design component. Each capstone design team submittal was evaluated based on a detailed grading rubric, comprised of 46 technical categories. Milestone submittals included: 1) project proposal, 2) concept report and alternative evaluation, 3) 30% complete design, 4) 50% complete review, 5) 75%/95% /100% complete submittals, and 6) expert panel presentation. Each team submittal was graded and adjusted individually using peer evaluations. Team leadership rotated for each major project milestone and students were responsible for multiple disciplinary areas including transportation, structural, geotechnical, environmental, drainage, and construction. Each team worked to address all design components. Collaboration was encouraged across teams along major technical disciplines, sharing resources and design tools, similar to real-world networking among engineering professionals. Each year, 40-50 students take the capstone design comprised of 8-10 student teams. Formation of student teams was accomplished using CATME Team-Maker, described in the next section. Over a five-year period, this method of establishing teams resulted in the least amount of negative student feedback, as observed by faculty teaching these courses. The community for this student learning engagement is defined as local decision makers (elected officials), public agencies, (airport authority, county government, state DOT), and engineering professionals who perform technical services and create deliverables needed to develop effective transportation engineering solutions.

Team Formation
Student teams were formed using CATME (NSF team evaluation tool), a nationally recognized peer evaluation survey system, to assess leadership, teamwork, attitudes, and professional and ethical responsibility throughout the yearlong project. In the beginning of the Fall semester, students completed a survey across a range of questions including subdiscipline, software skills, writing skills, leadership preference, leadership role, and project perspective. Characteristics were weighed in a matching algorithm, CATME Team-Maker, to either be similarly aligned or disparate across a Likert-type rating scale. Student team members were matched based on selected criteria through calculation of a series of overall index scores. Additionally, special atypical personal considerations were considered in team formation as input by the professor. Of all the methods used over the years to create student teams, CATME Team-Maker has proven to be the most effective in reliably orchestrating productive teams, with minimal student concerns and/or complaints.

Figure 1 depicts organization of student capstone design teams. Each team selects an overall team captain. Additionally, each student selects a sub-discipline as their primary engineering responsibility for the design project, although students are required to serve across multiple roles, as defined in a team organization and responsibilities matrix. Leadership responsibility rotates for each of the five (5) major project submittals/deliverables with an individual student being in responsible charge and CATME evaluations reflecting their role as leader. For Fall semester, major submittals included: Project Proposal, Concept Report, Wetlands Permit, 30% complete drawings and final panel presentation. For Spring Semester, major submittals included: 50% complete design, 75% complete design, 90% complete design, 100% complete design and final panel presentation. CATME peer evaluations and peer comments were required for each of the five major submittals. Individual student grades were adjusted based on 1-5 Likert scale ratings for performance-based criteria including: 1) contribution to teamwork, 2) interacting with teammates, 3) keeping the team on track and 4) expecting quality. Furthermore, team performance was evaluated through three (3) criteria including team satisfaction, team collaboration, and individual satisfaction. In reviewing grades and feedback for each major submittal, the professor counseled design teams on student interaction, specifically identifying collaboration successes and concerns for correction in future submittals.

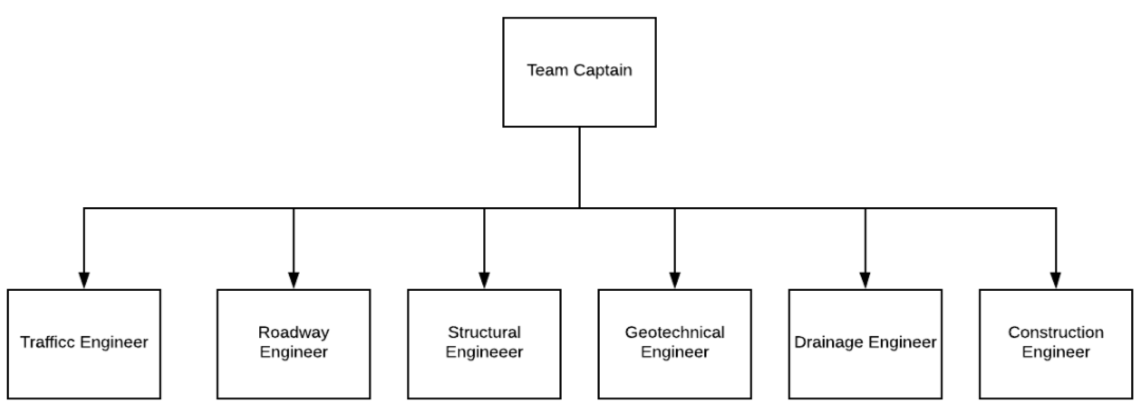

Figure 1 - Team Organization

Collaboration of Faculty, Students, and Licensed Professional Engineers
A critical component of the project was County Transportation Agency and engineering consulting firms, performing conceptual project design work, agreement to share base files, data,

and design materials for student teams to use in preparation of their capstone design projects. Students worked systematically to develop their project designs through discussions and feedback from faculty and professional engineers. On numerous occasions practicing professional engineers visited the class and presented their respective Civil Engineering technical fields. This interaction allowed students to ask specific questions about aspects of the project, engineering methods, engineering guidance and design decisions student teams were working to complete. The most tangible outcome from this student-to-engineer dialogue was that students gained skills and firsthand experience on how to solve problems in real time. These real time solutions meant that students were engaged with learning at higher levels of the Bloom's Taxonomy (i.e., analysis and evaluation). Table 1 summarizes the professional engineers who visited and supported the course. Each one of the professional engineers provided valuable insight concerning the project, current issues, and professional practice and many also served on the panels.

Table 1 - Summary of practicing engineer engagement, throughout two-semester capstone

1	Traffic Engineering – P.E. "A"
2	Drainage Engineering – P.E. "B"
3,4	Geotechnical Engineering - P.E. "C" and P.E. "D"
5	Field Trip, Design-Build Interchange/Road Project – PE "E", local engineers
6,7	Structural Engineering – P.E. "F" and P.E. "G"
8,9	County Government – P.E. "H" and P.E. "I"
10	State Dept. of Transportation - P.E. "J
11,12	Construction – P.E. "K" and P.E. "L"
13-19	Practicing Engineer Expert Panel (some engrs. spoke during class & served on panel)

Student teams had to collaborate with each other, faculty, and professional engineers to develop the most efficient design, with the least amount of impact to both the public and the environment. This required students to research possible alternatives to achieve the most efficient design. Each student design team gained experience in traffic, roadway, structural, geotechnical, hydrological, and construction engineering. In addition, students gained insight from accounting and marketing professionals to support the "selling" aspect of engineering design solutions as an optimal approach to meeting project goals and objectives. The professional skills emphasis led to invaluable insight and awareness of students to real-world problem solving and decision-making.

Assessment of Educational Outcomes

As this is a capstone course, several college and department curriculum outcomes were connected to this course. Course assessment includes six value rubrics from Association of American Colleges and Universities (AACU) and ABET Outcomes 2 and 5. Assessment mapping is summarized in Table 2. At the end of each semester, student teams presented their detailed interchange designs to an expert panel including traffic, roadway, structural, geotechnical, drainage, construction, and project management. The professional engineers' expert review panel asked questions indicative of public meetings, evaluated presentations, ranked winning presentations, and provided valuable feedback. Students learned how to effectively communicate (verbally, graphically, written) their design solutions to a panel of professionals in each of the subfields previously listed. Panel presentations served as course final exams and simulated presentation of project deliverables in an open forum that would normally be required for public engagement. During these presentations, a panel of professional engineers posed questions and voiced concerns that often arise during public Town Hall meetings. Student responses to the realistic questions asked by the panel was a powerful tool fostering a strong sense of self-reliance, cooperation, and responsibility for members of the student teams.

Reflections and Lessons Learned

The current format and content of the two-semester capstone design sequence has been taught each academic year beginning in 2016-17. Reflections and lessons learned from the experience of teaching this course and working to fulfill outcomes supporting student design skills include:

- Use of real-world design projects: 1) best reflects complicated design constraints, 2) better engages the engineering community, and 3) provides a robust learning experience.
- Use of real-world design projects requires partnerships with practicing engineers and jurisdictional agencies to provide base drawings, studies, surveys, and data.

Table 2 – Capstone mapping to AACU Value Rubrics and ABET Student Outcomes 1 and 5

I. Association of American Colleges & Universities (AACU): Selected Value Rubrics	
Outcome Criteria	Capstone course, deliverable mapping
1. Inquiry and Analysis	Capstone II, Drainage Design
2. Critical Thinking	Capstone II, Geotechnical Design
3. Written Communication	Capstone I, Alternative Bridge Submittal
4. Quantitative Literacy	Capstone II, Bridge Design
5. Intercultural Know./ Competence	Capstone I, Concept Report
6. Ethical Reasoning	Capstone I, Wetlands Permit Application
II. ABET Outcome 2: an ability to apply engineering design to produce solutions that meet specified needs with consideration of:	
1. public health,	Capstone II, typical section: design for peds & bikes
2. public safety,	Capstone II horiz./vertical design: road/ramp/intersection
3. and public welfare,	Capstone II final submittal: adherence to design standards
4. as well as global,	Capstone II, Const. materials US vs. international imports
5. cultural,	Capstone I, 30% design: ROW impacts, sensitive sites
6. social,	Capstone I, Concept Report: residential land use impacts
7. environmental,	Capstone I, Wetlands Permit: wetlands and water quality
8. and economic factors.	Capstone II, Final design: project cost, team hr. submittals
III. ABET Outcome 5: an ability to function effectively on a team whose members together provide:	
1. leadership,	Team Org Chart/CATME peer evals
2. create collaborative/inclusive envir.,	University leadership 1-7 rubric criteria
3. establish goals,	Final expert panel presentation
4. plan tasks,	Project construction schedule
5. and meet objectives.	Graded final design rubric

- Interchange design projects provide an effective intradisciplinary capstone assignment including 1) transportation planning, 2) traffic engineering, 3) roadway geometric design, 4) environmental engineering, 5) structural design, 6) geotechnical design, 7) storm water drainage design, and 8) construction engineering.
- Students inherently dislike solving open-ended, ill structured real world design problems.
- Engagement of the professional engineering community in capstone design curriculum enriches the student learning environment and improves quality of student deliverables.

- CATME is an effective online web-based tool useful in creating well-functioning student teams and beneficial in facilitating productive peer evaluation data and dialogue.

Conclusions

In summary, students learned how to synthesize realistic design standards, apply a process to meet desired needs and develop design drawings, specifications, cost estimates, and project schedules with realistic constraints such as environmental, social, political, ethical, health and safety, constructability, and sustainability. The capstone project required students to work in teams, apply their knowledge and skills to solve a complex real-world problem, in preparation to transition from the familiar college learning environment to realistic open-ended and ill-structured challenges of professional practice. Lastly, it challenged students to consider a broader range of technical and non-technical evaluation inputs, benefiting from experience of professional engineers who provided mentoring and valuable technical perspective based on their engineering experience in performing similar projects across the local area, and beyond.

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