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Improving Municipal Infrastructure in Capstone Through a Consulting Firm Model

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Improving Municipal Infrastructure in Capstone Through a Consulting Firm Model

The capstone experience is the culmination of students' academic careers. It must expose students to a world that will soon be extremely familiar for many – the life of a consulting engineer. In order to provide such an experience, programs throughout the country provide a variety of capstones that challenge students. Although some capstones offer opportunities that deliver a "real-world" project, others continue to offer a traditional project that falls under the rubric of "textbook" problems. Although there may be sound, legitimate support for offering a "textbook" capstone, including the magnitude of work involved for instructors, using a real-world project offers tremendous benefit.

In order to ensure that the students' capstone experience is true-to-life, and emulates consulting firms, the transportation capstone program in the Department of Civil and Environmental Engineering (CEE) at Northeastern University (NU) has created a program that benefits the students and the surrounding communities. The 14 week semester emulates a major project in a consulting firm with project requirements, deliverables, and community meetings. The real-world approach has been in place since 2010 and has involved 18 major infrastructure projects in 12 communities in the greater Boston area. The benefits of the program have been far-reaching, for the communities involved as well as for the students.

The anecdotal feedback from all involved has been positive. In order to quantify the benefits of providing a real-world project for students taking the transportation capstone at Northeastern University a survey was performed, in which 87.5% of the recent graduates (e.g., 0.5 years – 2.5 years) thought that the project requirements emulated their non-academic experience. This paper details project identification, team formation, project requirements, deliverables, and survey results.

Introduction

The civil engineering capstone course at Northeastern University (NU) follows other schools' format by offering a project-based course; however, there are two circumstances that make Northeastern more of an exception than the rule – one is student-based and the other is program-based. First, most of the students prior to their final semester when capstone is offered, have had at least 1.5 years of real-world experience working for consulting firms during their cooperative experience. Based on their experience, they have heightened expectations. No longer is a fictitious problem acceptable. This cooperative real-world experience requires instructors to challenge the students in a different way, since many of the students have worked as engineers in a consulting firm.

Second, for the past four years, the transportation capstone students have worked on real-world projects for municipalities in Massachusetts. The projects have required students to think progressively about ways to create systems that have an impact on the community. Based on the designs, some community officials have used the projects to illustrate ideas to local citizens,

some have used the designs for grant applications, and others have incorporated some of the features in their infrastructure system.

Capstone

Although Civil Engineering capstone requirements vary by program throughout the United States, all are required according to ABET there is no common program or approach[1]. Depending on the program and a community's needs, some programs have reached out to community officials to design civil engineering projects. At Villanova, students created storm water designs for on-campus projects[2]. Students at the University of Toledo recently worked on a civil engineering project that covered several sub-disciplines that would encourage tourism and promote economic development[3]. At the University of Hartford, students designed a new roadway that would connect the campus to a popular shopping center[4]. Although all programs offer a capstone, or integrated experience, no other program appears to offer a capstone course every year similar to NU – where four or five real-world projects are designed.

Project Identification

For the last 4 years, one of the three capstone instructors in CEE has contacted local municipalities in an effort to identify community needs that may be addressed through capstone. Well in advance of the spring semester, the instructor sends out requests for projects (RFP) to community officials in Massachusetts. The RFP highlights NU's capstone program and asks them if they have projects that they would like NU to consider for the transportation capstone. Once a project is identified on the global level, a project scope is typically created by the NU instructor. The scope is then reviewed by the municipal official and refined if needed.

Consulting Firms

At the beginning of the spring semester the instructor meets formally with the students to discuss the capstone class, identifies "project teams", and awards projects. During the first class, the instructor discusses the overall objectives and goals for the semester. At the end of the class the students are given their first assignment – they must submit a cover letter and resume to the instructor and provide a brief summary (e.g., a powerpoint "slide") that highlights their experience.

The cover letter highlights their qualifications and requests that they be considered for a project manager position or engineering position in the firm. Since most students have been on three co-op jobs prior to their senior year, they have current resumes that highlight their 1.5 years of experience (many have more because they continue to work with a firm after their co-op end and they are back in school). Their qualification slide highlights their work experience as well as their academic experience, namely course taken.

During the next formal meeting, the students present their qualifications to the class. They also indicate to the class whether or not they want to be considered for a project manager position. Once all of the qualifications are presented and the project managers are identified (either through a vote or the student asking that they no longer be considered), the instructor leaves the

room and the project managers identify students that they would like to have work with their "firm".

Each class, which ranges in size from 16 to 30 students, depending on the graduating demographic, is broken down into several design firms. Each firm varies in size, but typically ranges from four to six students. The internal structure of the company follows that of a large-scale consulting firm, including management and engineers. The instructor serves as the principal-in-charge (PIC) (Figure 1). Each team has a project manager, and several engineers.

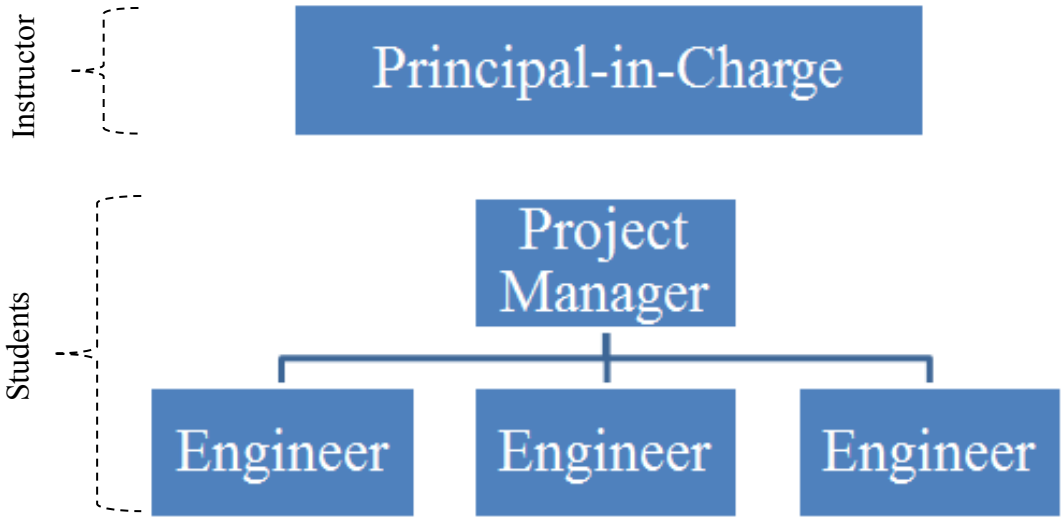

Figure 1 – Capstone Consulting Firm Structure – Four Students

The Civil Engineering capstone class at Northeastern University is 14 weeks long, and is broken up into two manageable sections – pre-spring break and post-spring break. The schedule includes major milestones which include deliverable dates, and community meetings (Figure 2).

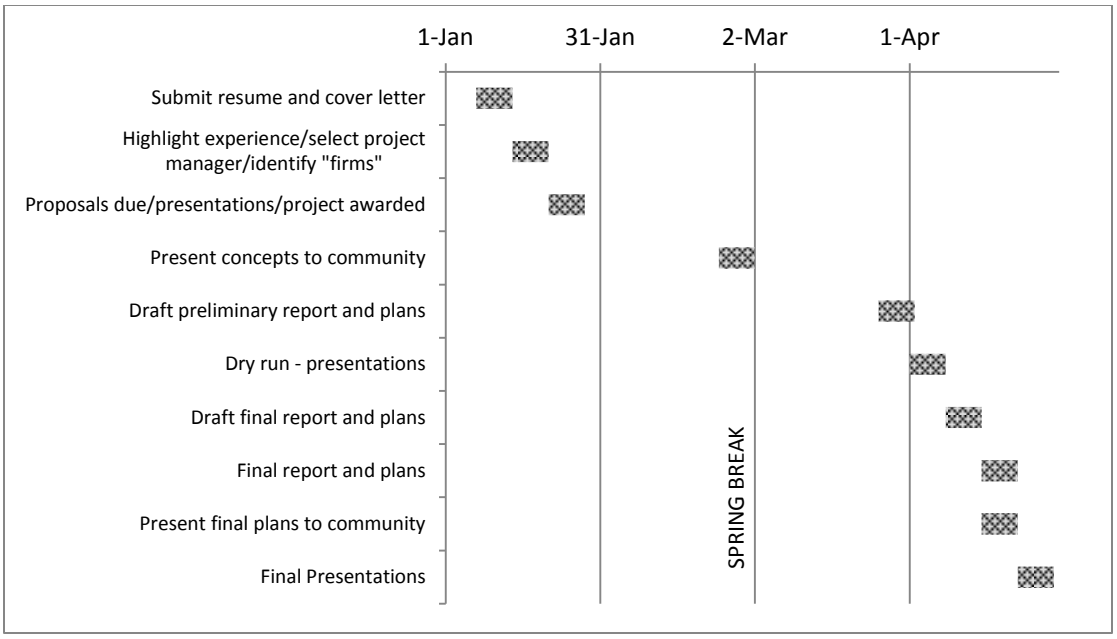

Figure 2 Transportation Capstone Requirements, by Week, Civil and Environmental Engineering (Transportation Concentration) – Northeastern University

Semester Outline – Task-Based

During the second week of the semester, the firms are given project descriptions. The project descriptions are "broad". The "broad" descriptions are deliberate – they afford the students the opportunity to be creative in their approach. The projects are reviewed by the consulting teams. After the review, the students write two proposals. Students typically select projects based on their level of interest in a specific project, their knowledge of the project area, as well as the description.

A formal outline for the proposal is given to the students. The outline includes required material, namely, a letter from the firm, a written description of the firm's approach to solving the on-site challenges, and their qualifications. During one of the formal classes, proposal content is discussed. Students are asked what makes one proposal stand out from another and what material should be included, and what should be "left-out". One component of a successful proposal that is always highlighted is the firm's knowledge of the project area and their creativity in their approach.

As a result, the team must visit the sites (unless there is a geographical constraint), identify on-site constraints, generate at least one short-term, low-cost solution, and discuss design approaches that may be used for implementation. One critical element that may be atypical in a proposal is the short-term, low-cost solution. A short-term low-cost solution is an issue or challenge that can be addressed with the municipality's current resources.

Several objectives are fulfilled when students are required to submit a short-term low-cost solution. First, it requires them to think outside of the classroom by identifying challenges in the real-world. This is no easy task. Students must spend time in the field observing. Second,

students must formulate solutions that can be fulfilled on a limited budget, in the short-term. Engineering solutions can be costly and as a result, may take several years to implement. Identifying a short-term low-cost solution in the proposal requires the students to think on a different level; one that doesn't involve cost, but current resources. Finally, and perhaps most importantly, it highlights and reinforces "giving back". Through this process, students realized (and are reminded) that they cannot just walk or drive through the community in which they live or work – they must "open their eyes", apply their engineering skills, and provide assistance to others at little to no cost.

After their field observations, the consulting firm then develops two proposals – for two of their preferred projects. Similar to the non-academic world, the proposals are due on a certain date and time. No late proposals are accepted. After the proposals are received, each project manager receives an email that invites their firm to make a formal presentation. The invitation states that they will have no more than 15 minutes to present their project ideas, during which time they should highlight their firm's qualification, as well as their project approach.

Their formal presentations are made to their peers and PIC. Each firm presents their qualifications just once; and then proposes on the two projects. The client, if present, will provide his feedback to the PIC who makes the final decision. The project is then awarded to the firm that is best suited for the project. In instances where multiple firms make presentations on the same project, the team that is best qualified for the project is awarded the project. Factors impacting the decision include the firm's articulation of the challenge, their understanding of what is required to address the challenge, and the qualifications of their team.

Once the project is awarded, it is the project manager's responsibility to identify a detailed project scope and relevant project timeline. The PIC provides a timeline for major milestones (e.g., dates and times for mid and end of semester presentations, draft and final reports and plans submissions), the firm must then provide complementary milestone dates for their tasks, including field data collection, project site visits, identification of alternatives, generation of preliminary drawings, and preparation of final drawings and details.

Early on in the semester, the project manager in cooperation with the team, assign work and tasks. The required tasks are usually "grouped" and assigned to individuals based on experience and interest. For example, one team member may be responsible for the design work in AutoCAD, while another one (or two) may be responsible for writing the report. This is not an ideal scenario - it would be beneficial to have each student work on multiple aspects to gain exposure and understanding. Although it is not personally advantageous, it does emulate the real-world environment, where tasks are typically "stove-piped".

At this point in the semester, usually three weeks from the beginning, formal meetings are replaced by weekly project meetings. Each week the team meets with the PIC. During these meetings, updates are provided to the PIC, and next steps are discussed. Not only are these meetings beneficial for the students, from an update and "are we moving in the right direction", but they also provide valuable insight into participation. The PIC interacts with each one of the students, asking questions, and discussing the project. Each person's involvement in the project

is noticeable at this point. It becomes apparent, very quickly, who is doing the work and who isn't.

The projects typically require students to visit the municipality to collect data. Once the data are collected, students start to formulate design ideas and designs that address their findings. Each group must identify at least three alternatives to address their findings, and out of the three alternatives, they must identify a "preferred" alternative.

After the preferred alternative is identified, it is presented to their peers, community officials, and PIC in a formal setting. A formal presentation is followed by a review of the preferred alternative. During the preferred alternative review, the client provides feedback to the design team regarding the preferred alternative, the other options, and insight and anecdotal information regarding the project. At this point, the client may identify an element that they like in one of the non-preferred alternatives, and ask the students to consider including it in the final design. Since nothing is truly finalized, it is very easy for the students to consider revising their preferred design.

The preferred alternative design is typically presented to the client just before spring break (approximately two months after the semester begins). After spring break, the students meet with the instructor to discuss the client's feedback and input, as well as discuss the report. Over the five weeks following spring break, the students then finalize their plans and reports. During this time, several meetings are held with the team and the PIC and one or two formal presentations are made, based on the needs of the class/groups. When the final plans and report are completed, the students work on generating a formal presentation that will be used for their clients and peers.

Approximately two weeks before the students make their presentations to the clients, they have a "dry-run" on campus. The students are making the presentation to their peers; however, they are doing it as if the client were present. Several "ground rules" are established prior to the presentations. Each student must speak, and each group gets 20 minutes for their presentation. The students are critiqued by their peers and instructor for the oral portion as well as the content of the slides. After the presentation to their peers, the students revise their presentation to reflect comments made by their peers and instructor. When the final presentation is polished, students make a presentation to community officials in their municipality.

Project Requirements

The deliverables consists of two parts, a written report and design drawings. Each part carries equal weight in grading, and both are critical for the project.

The written report comprises several chapters, including data collection, existing conditions analysis, future conditions, an objective evaluation matrix, conclusions, and recommendations. The report itself is typically well over 300 pages long, with the main document comprising 100 +/- pages, while the appendix is approximately 200 pages. Depending on the team's structure, a couple or all of the students may be responsible for its completion. The report is typically passed through the group prior to submittal, for a quality assurance/quality control (QA/QC) review.

The design plans are full-size (e.g., 24 x 36") drawings that are at a 90% design level. The remaining 10% of the work primarily includes additional design details, and terrain grading. The plans have the same format that would be required for any large-scale construction project. The number of pages (e.g., sheets) in the plan set range from 30-60, depending on project magnitude.

Capstone Validation Survey

In order to quantify the similarities between the capstone class and the life as a consultant, a survey was created and distributed to recent graduates. The survey asked over two dozen questions to recent graduates from the Transportation sub-discipline of the CEE program that were directed toward addressing the impacts of the capstone program. The students (i.e., now practitioners) from the last three graduating classes were surveyed.

Since most practitioners from the program have at least 1.5 years of experience, and as much as four years, they were considered to have a good perspective on real-world applicability. The students that graduated three years ago have over 4 years of experience (3 since graduation and at least one year of co-op) and the most recent graduates had 1.5 years of experience (0.5 since graduation and at least one year of co-op). Most students have 1.5 years of co-op; however, the first experience happens so early in their academic career that it was not included in their "real-world" experience.

Out of the 63 surveyed, 24 responses were received or approximately 38% of the total. The questions were divided into three major "groups", namely, overall experience, project requirements, and soft-skills developed. The practitioners had five options for responding to the questions – "identical, almost identical, similar, different, and not applicable."

When asked "how well did the capstone experience emulate your real-world experience" with regard to proposal writing, 8.3% responded "identical", 37.5% responded "nearly identical", and 33.3% responded similar (Figure 3). Combining the "identical", "nearly identical", and "similar" responses results in over 79.2 % of the practitioners viewing capstone similar to their real-world, post-graduate experience.

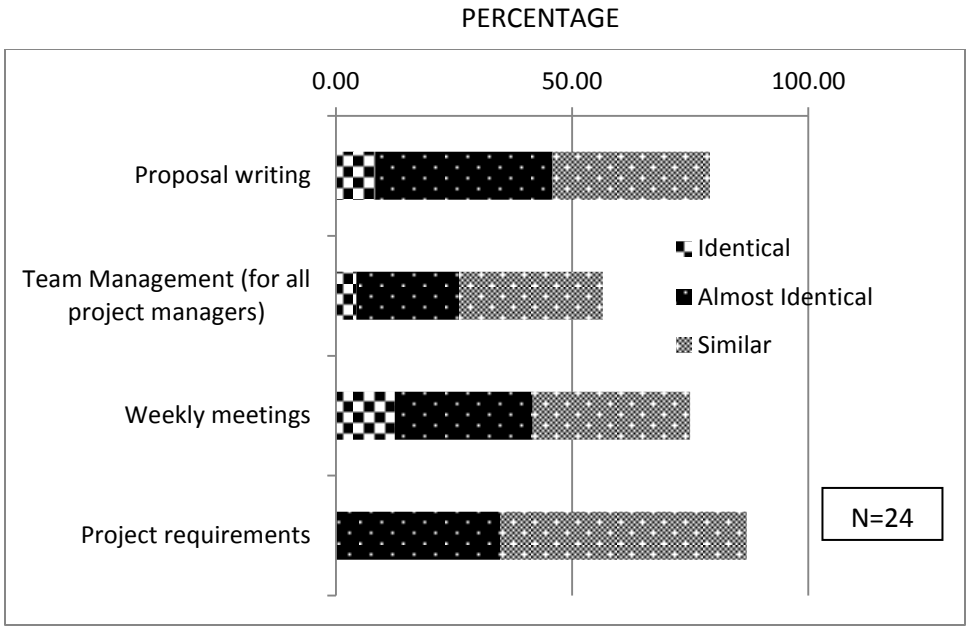

Figure 3 Results from Survey Questions - How Closely did the Capstone Experience Emulate Your Real-World Experience

The results are helpful and informative. Many employees may not have the opportunity to write a proposal under they have several years of experience. Since capstone provides an opportunity to "propose" on a project, it may be providing them with an opportunity earlier in their career due to their familiarity with the process and the final product.

One other question that is informative is their view of the project requirements. Of the responses, 34.8% of the responses were "nearly" identical, and 52.2% of the practitioners thought that the capstone project requirements were "similar". Combining the "nearly identical" and "similar" responses results in 87% of the practitioners viewing the project as emulating their "real-world" experience.

This response provides valuable insight to the program. Only 13% didn't view their experience as "real-world". Since one of the objectives is to provide an experience that is as "real-world" as possible, it is beneficial to know that the class reflects one of the objectives. Due to the structure of the course, a significant amount of time is required to identify projects, gather data, and produce results; therefore it is valuable to know that it is viewed as a real-world project.

Capstone Validation Survey – Part 2

The next major section of the survey focused on project requirements. The section had thirteen questions and students were asked to answer questions in an order that was similar to their experience on the project.

In the beginning of a project, the students collected data, which were then analyzed. Once the data were analyzed, a conceptual plan was developed that highlighted their work. This plan included alternatives to solve the "engineering" challenges identified. Once a concept was approved by the client (e.g., municipality) and the PIC, the students finalized their drawings and

report. At the end of the semester the students present their deigns to their client as well as their peers. The following sections describe the design approach in capstone.

Data Collection

Some data that students need are readily available either from the local municipality or from the state. Even if much of the data are provided by the municipality, the students are required to go out in the field because they have to identify short-term solutions that can be done with limited resources. Students typically spend at least two days out in the field collecting data.

Based on the survey results close to 80% (20.8% "identical", 16.7% "nearly identical", 41.7% "similar") of the practitioners thought that this aspect of the project emulated their non-academic experience (Figure 4).

Data Analysis

Once the data are collected, students analyze them. This is an opportunity for students to support their proposal observations with "facts". Based on the survey results 87.5% (25 % "identical", 29.27% "nearly identical", and 33.3% "similar") of the practitioners thought that this aspect of the project emulated their non-academic experience (Figure 4).

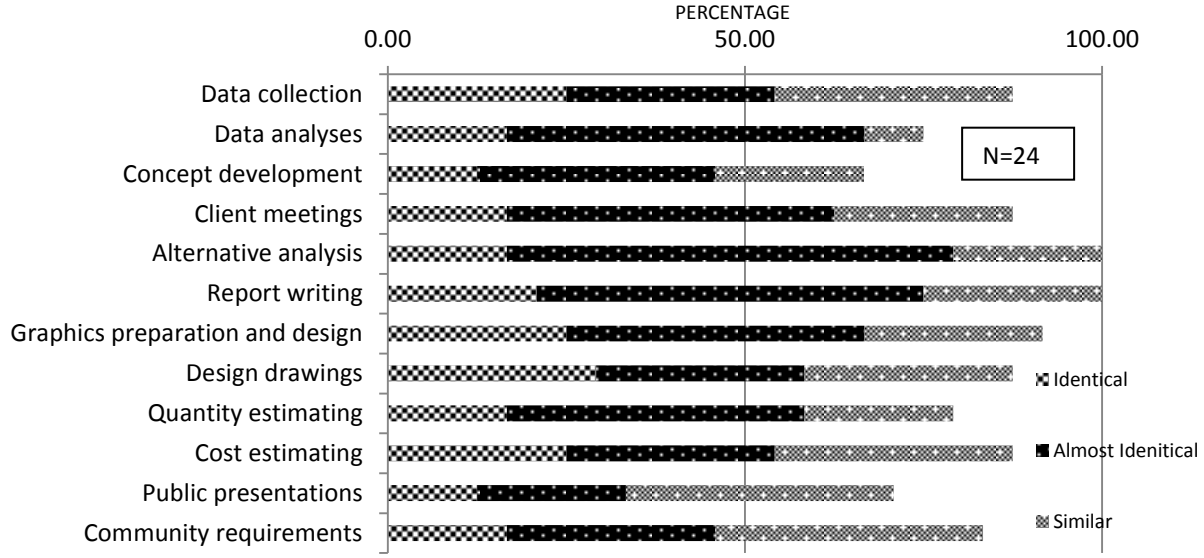

Figure 4 Results from Survey Questions - How Closely did the Capstone Experience Emulate Your Real-World Experience – Project Requirements

Alternatives Analysis

In the alternative analysis section, students generate ideas and evaluate engineering solutions for their project. At this point, ideas are generated on both the macro and micro level. Once generated, the alternatives are ranked, based on the students' project objectives and goals.

Once all of the concepts are generated, students must identify the "preferred" alternative for each location/section. The preferred alternative is identified through an objective matrix, comprising quantifiable metrics. Based on their objectives identified at project outset, the values that meet or exceed their objectives are tallied, and the one with the greatest number is identified as the "preferred" alternative.

Based on the survey results (Figure 4) 87.5% (25% - "similar", 45.8% "nearly identical", and 16.7 % "identical") of the practitioners thought that this aspect of the project emulated their non-academic experience.

Conclusions

To ensure that the capstone is effective in providing a culminating experience, instructors can provide an effective real-world experience that follows a design firm's structure and process. The responsibilities of the project team must mimic a design firm to ensure that the students are well-prepared for the next stage in their life and career. Northeastern University's transportation capstone program has used real-world projects to expose students to large-scale engineering projects. This approach has been successful from a program, student, design, and community perspective for the last four years.

Based on a survey administered after capstone, and when the students had been working full-time for at least 6 months (in addition to their 1.5 years of cooperative experience) a majority of students (i.e., 87%) thought that the capstone experience was similar to their real-world engineering experience. Based on these results, as well as the well-received community support, NU will continue to offer capstone in a similar manner to promote learning, understanding, and community involvement.

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