Session 1725

A Capstone Design Approach in Civil Engineering

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Abstract

Assessing student outcomes from the civil engineering program at Oregon Institute of Technology (OIT) identified several areas of concern. Ineffective team skills, limited multi-disciplinary design experience and inadequate integration of technical communications with the engineering curriculum were specifically targeted for improvement. To strengthen student outcomes in these areas, technical communications faculty and civil engineering faculty at OIT developed a new senior project curriculum.

Senior civil engineering students must now complete a three-term, full academic year, senior project sequence that integrates engineering design with communication skill development. The class functions as a civil engineering consulting firm with civil engineering faculty leading design teams in geotechnical engineering, transportation and traffic engineering, environmental engineering, structural engineering and planning. Two communications faculty are also part of the firm and provide in-house expertise in technical communications.

The firm is required to respond to a formal request for proposal (RFP), develop a conceptual plan within the proposal, and prepare and present a professional proposal to secure the project. The RFP identifies a real project within the local community and is multi-disciplinary in nature. Upon proposal acceptance, specific design teams are formed in which students complete the project design as specified in the firm's proposal. Effective communication both intra-team and inter-team is essential to ensure a professional cohesive design by the firm. Final designs are submitted in written reports, including all plans and specifications, and presented orally to a diverse audience of professionals, peers and faculty. Technical communications faculty assist students in preparing proposals, written reports and presentations, and guide the process of internal documentation procedures such as daily logs and weekly progress reports. Workshops on professional ethics, group dynamics and peer reviews are also incorporated in the class. Local professionals and other faculty participate as clients, consultants and experts.

Surveys given to students at the end of the project reflect a moderate improvement in student outcomes based on this class. Students appear reluctant to leave the organized structure of the classroom for the open ended problems presented by the design projects. Alumni, however, who have completed the sequence, have given strong endorsements. Local professionals and Industrial Advisory Committee members have expressed satisfaction with the approach and objectives of the class.

Introduction

Oregon Institute of Technology (OIT) is a public institution focused on undergraduate education with limited graduate offerings. The main campus is located in southern Oregon on the high desert, eastern Cascades region, approximately 300 miles south of Portland, Oregon and 350 miles northeast of San Francisco, California. Programs are also offered at a Portland campus and in Seattle, Washington.

The civil engineering degree program is the only engineering program currently offered at OIT and is limited to the Klamath Falls campus. The department also offers a degree in geomatics and maintains a student population of about 130-150 students, with 100-120 majoring in civil engineering. Other engineering-related programs include computer software engineering technology, computer engineering technology, electronic engineering technology, mechanical engineering technology, manufacturing engineering technology and environmental science. While teaching is the focus of the school mission, two research departments are active; these are the GeoHeat Center and the Oregon Renewable Energy Center.

Course Development

Ongoing assessment of student outcomes for the civil engineering graduates utilizing the ABET 2000 criteria identified several areas that could be improved[1]. Particularly helpful assessment tools included feedback from the Industrial Advisory Committee for the Civil Engineering & Geomatics department, employers, and graduates, as well as classroom assessment tools for current students. Analyses of results suggested these three target objectives for curriculum improvement:

- Increased multi-disciplinary design experience
- Improved development of team skills
- Integration of technical communication with engineering curriculum

In the interest of strengthening student outcomes in these areas, several courses within the existing curriculum were targeted[5,6]. The senior engineering design coursework, however, offered the only effective mechanism for incorporating significant multi-disciplinary design experience[5,8].

Until 2000, the civil engineering (BCE) program required 12 term credits, generally 3 courses at the senior level. These courses focused on specific design areas such as structural engineering, hydrology and environmental engineering, traffic engineering, or construction management. While individually challenging and containing some excellent design approaches, the courses failed to offer an integrated or holistic, multi-disciplinary approach to design reflecting the actual design challenges faced by today's practicing civil engineers, nor to aid in the development of the student from design learning to performing design work[1,2,5].

Faculty decided to reformat the senior design experience entirely. A year-long capstone sequence was envisioned, featuring a multi-disciplinary design challenge that incorporates technical communications and group dynamic components, a focus similar to efforts at other instutions[7,8,9]. The result is a required three-term sequence, commencing in the fall, incorporating 9 of the required 12 senior level design credits, and 6 credits of communication work[7].

Course Premise

The premise of the capstone design sequence is that the students are junior engineers in a civil engineering consulting firm[1,8]. Faculty act as project engineers and one faculty (rotating) is the chief executive officer (CEO) for the firm for the year. Communication faculty are part of the firm's management as well. To the extent possible, references are to "the firm" and "the project" rather than "the class" or "the assignment." A typical organization chart is shown in Figure 1.

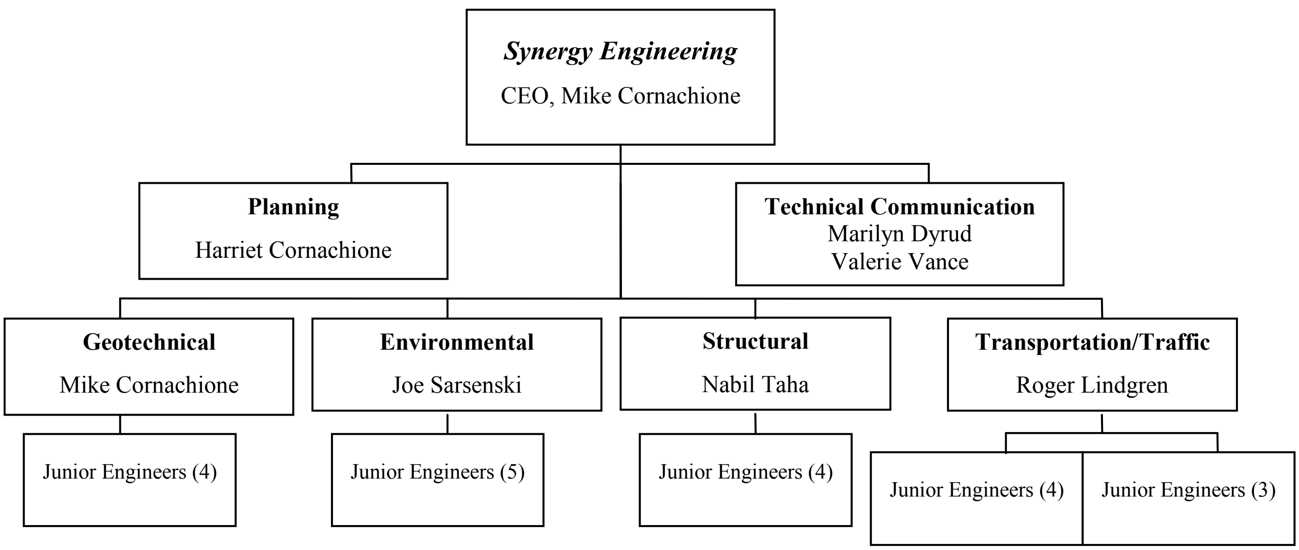

Figure 1. Organization Chart

Each fall, the firm receives a request for proposal (RFP) to which they must respond by the end of the term with the following components:

- a conceptual plan addressing all the RFP components
- a formal proposal, incorporating the conceptual plan
- an oral presentation of the proposal

Each RFP is formulated around a real, local engineering project, with participation encouraged from local engineering consultants and government agencies[7,8]. Typical projects have included development of two different sites, including subdivisions and commercial structures. This third year the project is the design of an airport.

During the winter term the firm performs the engineering design for the project, which generally incorporates site investigation, geotechnical investigation, infrastructure development (roads, sidewalks, water, sewer, other utilities), wastewater treatment plant, runway development, master plan development and the design of at least one structure, incorporating appropriate building codes and considering seismic loads. The construction plans and specifications, along with a final report developed by each design team are completed during the spring term and presented to the client, along with various invited guests.

Corporate Workings

The senior design experience begins with the introduction of the company organizational chart, followed by the introduction of the RFP. The immediate objective of the company is to develop the best conceptual plan possible for the project. A "competition" is set up, with the junior engineers assigned to teams by senior engineers. These initial planning teams are grouped to provide "evenly" distributed attributes such as leadership, technical ability, and communication expertise by faculty using an informal process, rather than a formal team formation strategy such as "MBTI" indicators[3]. Typically, close friends or known study partners are split during this phase of the course. These planning teams are charged with developing the following:

- a conceptual design plan which addresses the RFP components
- a firm name and logo
- a poster presentation for their plan

Formal company meetings are scheduled twice weekly and attendance is expected as in the workplace. That is, while it is recognized that events may supercede the company meeting, employees are expected to notify their project manager/engineer if such a situation arises, just as they would in the workplace.

During the fifth week the firm holds the internal poster session competition for the proposed project. Junior engineers, project engineers and management, as well as invited guests vote for the design plan, and the firm name and logo that will be carried forward for the remainder of the sequence. Interestingly, both students and faculty have reached consensus independently on the best design choice.

This first quarter also serves as a model for the remainder of the project in terms of documentation and procedure. Recordkeeping standards are established and an opportunity to develop team communication techniques, such as meetings, e-mail, or phone protocols, is provided. Peer reviews provide junior engineers with an opportunity to evaluate and recognize more and less effective team behaviors, as well as provide a way to communicate these both to "management" and professionally to their peers[4,10]. Design teams are required to submit weekly progress reports and all junior engineers must maintain a daily project log[6].

Just prior to the poster session, specialized design teams required for the project (usually geotechnical, structural, transportation and environmental) are identified. Junior engineers can request their top three placement choices through a company form they submit to management. Through this form they must document their background to justify their design team placement requests[3,4]. At the conclusion of the poster session, the top plan and top firm name and logo are announced, based on an immediate tally of evaluations, and the design teams are formulated.

The last five weeks of the fall term are devoted to making any necessary design changes or enhancements to the conceptual plan for the project. The plan is then drafted and a written proposal and presentation prepared. Individual project logs continue, documenting design team and responsibility changes, and weekly progress reports continue but are now addressed directly to the design team project engineer, rather than to a conceptual plan file. Project engineers attempt to loosely guide teams during this time, encouraging team work focused on clearly addressing all aspects of the RFP related to their design team's specialty, and integrating, as needed, with other design teams to develop a cohesive company proposal. A planning team is responsible for developing protocol for information sharing, especially design work for infrastructure, and for the proposal compilation. Introductory and summary material, as well as transmittal and presentation formatting, is also the responsibility of the planning team.

The remaining two terms, approximately 20 weeks, are devoted to the development of the detailed engineering designs for each sub-discipline involved in the project. Company meetings during these weeks typically focus on various communication issues. The role of the progress reports in ensuring timely completion of required tasks, as well as identifying potential scheduling conflicts (i.e., when road design changes cause changes in the completion dates of water/sewer design) is stressed. Client driven communiqués are brought in. Workshops on group dynamics and professional ethics[6,8] are conducted.

Individual design team meetings are held with the project engineers, generally weekly and outside scheduled class time. Engineering design specific to each discipline (geotechnical, structural, etc.) is performed by the junior engineers and presented for review and critique during these meetings. The project engineers (faculty) generally attempt to allow the junior engineers leeway in developing their design, providing technical guidance only as needed. Project engineers may provide management intervention in the event of non-performance issues and when inter-team progress threatens the overall project schedule.

During company meetings, expectations and methods for individual project activity documentation (project logs) and team project activity documentation (weekly progress reports) is communicated. Guidelines are provided for the various written reports. Draft reports are required and critiqued both by communication faculty and by technical faculty (management). Company meetings and individual design team meetings are used to discuss documentation, which is treated as the critical component it must be. Guest lecturers on specific engineering topics and junior engineer technical topic presentations also occupy some of the bi-weekly company meeting time (class time). Finally, company meetings are used to provide direction regarding poster session development and presentation guidelines to ensure clarity and invoke an expectation of quality of the final products.

The project culminates with formal reports and presentations from each design team, as well as appropriate plans and construction specifications. A final company-wide presentation of the designed project is held for the client. Local engineering consultants, city or county officials and engineers, as well as other students, faculty and administrators are invited to attend the final presentation. A timeline summarizing the major events of the project is shown in Table 1.

Table 1. Timeline of Major Events

	Term	Week
Receive the RFP	1	1
Site visit and meet client	1	1
Conceptual plan competition	1	5
Design teams formed	1	6
Oral and written proposal	1	10
Design begins	2	1
Oral and written interim report	2	10
Final design begins	3	1
Draft report	3	7
Oral and written final report	3	10

Enrichment Opportunities

The structure of the firm has also allowed opportunities for enrichment activities. Workshops on such topics as team building, conflict resolution and engineering ethics have been developed for the firm by communication faculty. Other project classes at OIT have also contributed to the final project. Business management students prepared a marketing study for one of the subdivisions designed by the firm. Freshman civil engineering students are required to perform a small component of design as directed by junior engineers in specific design teams. This links the freshman students with the process and graphically represents the expectations of the civil engineering program to first year students.

Assessment

While faculty from both the Civil Engineering & Geomatics and the Communication departments have made substantial and willing contributions to the success of "the firm," there have been some rough areas along the path to success of this capstone design sequence. One of the first things recognized by faculty is that team skills of faculty needed to be developed and honed, and indeed could at times mirror their students' challenges regarding team work. Compromise does not always come readily to academicians! Diverse professional experiences and differing pedagogical approaches must be resolved, though, for a course such as this to be successful.

Offering this sequence required catalog and curricular changes that had to be approved at the institutional level. Fears and concerns, therefore, of faculty outside the participating departments had to be addressed. Once the acceptance was gleaned from the institution, marketing the new approach to the students presented some unforeseen dilemmas.

Not least of the growth pains of the emerging capstone sequence is the fact that there is substantially more preparation time involved, and it is more intense and demanding to teach a successful collaborative course than one taught traditionally by a single professor. The importance of clear and continuous communication, as well as flexibility, mutual trust and respect has certainly been demonstrated for the participating faculty.

A major goal of the capstone project was to address a major curriculum weakness and enhance students' ability to work on multi-disciplinary teams. The faculty also felt that the capstone project, with a strong component of communications skills, would strengthen most of the a-k student outcomes. At the completion of the project, students were asked to evaluate their experience in relation to specified outcomes. Students ranked each outcome form 1-5, with 5 being the highest score, and were given the opportunity to provide additional comments. The average score for each of the outcomes for the first two years of the project are detailed in Table 2.

Table 2. Student Assessment of Capstone Project

	2001/2002	2002/2003
An ability to apply knowledge of mathematics, science, and engineering	3.83	3.89
An ability to design and conduct experiments, as well as to analyze and interpret data	3.83	4.00
An ability to design a system, component, or process to meet desired needs	3.89	4.17
An ability to function on multi-disciplinary teams	4.05	3.67
An ability to identify, formulate, and solve engineering problems	4.28	4.00
An understanding of professional and ethical responsibility	3.83	3.61
An ability to communicate effectively	3.94	3.83
The broad education necessary to understand the impact of engineering solutions in a global and societal context	3.83	3.17
A recognition of the need for and an ability to engage in life-long learning	4.17	3.65
A knowledge of contemporary issues	3.22	2.41
An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	3.56	4.06

Results of the first two years of student perceptions of the class show moderate to strong approval in most of the outcomes. Interestingly, the ability to function on multi-disciplinary teams did not score as well as faculty had expected. This likely stems from the fact that teams did have problems communicating and had to learn techniques to assist in group communication skills. Student perception, therefore, was that they did not function well in multi-disciplinary teams because they encountered problems. The faculty also thought that the very nature of the projects, which were land development projects, brought forth the impact of engineering in a societal context and contemporary issues of zoning, land use, population densities, quality of living, and community growth. Students, however, did not see the connection. This, in turn, challenges the faculty to link the connection in future years.

Conclusion

The cost to faculty of the capstone design sequence has included time, energy, adaptation to change, as well as development of compromises of individual desires or goals. The cost to students has included time, stress of challenge (planning, creativity, critical thinking) and, for a limited few, extra communication-related coursework.

The benefits do, however, far outweigh these costs, in the achievement of the following:

- Strengthened program in civil engineering
- Met objectives for an ABET capstone sequence
- Provided a multi-disciplinary experience for students
- Enhanced team-skills experience for students
- Initiated technical communication in an experiential setting
- Challenged professorial development

In summary, after three years of continued assessment in this capstone design sequence for civil engineering students, it has become an integral part of the curriculum and forms a strong bridge for students to cross into the real workplace. With continued assessment, this capstone curriculum will continue to evolve into an enriched senior experience providing both the faculty and students with an enhanced understanding of team-based, multi-disciplinary project work.

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