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Civil Engineering Capstone Design: Team Formation, Preparation, and Performance*

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The following paper describes our experiences working with student design teams in a new two-quarter capstone course in civil engineering. Each student completes a survey that defines his or her academic coursework, industrial experience, status with respect to Engineer-In-Training (EIT) certification, current grade point average, and experience with computer-aided design software. The course instructors use this information to subdivide the class into six-person teams, ensuring that each team has a comparable degree of background and experience. The teams are multi-disciplinary in that each member is assigned a specific civil engineering role that relates to his or her elective coursework and industrial experience. After forming teams, the students complete a three-part, month-long lesson on communication. The lesson includes presentations and activities that focus on team building, active listening, communication styles, and assertiveness. These lessons are described in the paper. The intent of the lessons is to prepare the students to successfully interact and work together over the six-month course sequence. The approach to forming and preparing student teams has proven successful, as evidenced by peer evaluations and by project assessments completed by faculty members and local engineering professionals.

Keywords: capstone design; civil engineering; communication styles; multi-disciplinary; design team

1. Introduction

Five years ago we revamped our civil engineering capstone design sequence by changing it from an individual study course into a directed study offering [1, 2]. In the new course, students work in six-person teams to complete an integrated design for a private sector development or public works project. We consider the teams multi-disciplinary since each team member represents a specific civil engineering specialty discipline during the research and design phases of the project. During the first term of the course, the student teams research the project and prepare a written Statement of Qualifications in response to a specific Request for Qualifications. During the second term, the student teams prepare a written Design Report with a full set of calculations and design drawings. At the end of each term, the students present their submittals to an interview panel consisting of faculty members and practitioners.

In redesigning the capstone design experience to be more team focused, we recognized the need to provide the students with additional training and practice in teamwork and communication. Alumni and employers had historically assessed student abilities in the aforementioned non-technical areas as low, when compared with technical abilities such as problem solving, designing, interpreting data, and conducting experiments. In order to prepare our students for success, we therefore developed a three-part, month-long lesson on interpersonal communication. The lesson includes group activities and presentations that focus on team building, active listening, communication styles, and assertiveness. The students complete all activities while working in their design teams. The primary objective of the lesson is to prepare the students to successfully interact and work together over the six-month long capstone design sequence.

In this paper, we present the new capstone design course. We then discuss the procedure followed to form the multi-disciplinary student design teams. In addition, we describe the three-part communication lesson and the learning outcomes associated with this lesson. We close the paper by summarizing course assessment and evaluation techniques along with results.

2. Course background

2.1 Rationale

The culminating design experience for civil engineering undergraduates at our university was once realized through a course entitled 'Senior Project.' Individual students or multi-student teams would work independently (outside the traditional classroom setting), with periodic guidance from a faculty advisor of their choosing. This system worked well during the first several years of our program's existence. However, by 2005 our graduating senior class had grown significantly to nearly 150 students. Thus, small issues that had always been associated with the Senior Project course had grown into full-

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fledged problems requiring immediate attention. Specifically:

- It had become increasingly more difficult for faculty and students to come up with novel projects.
- Projects often focused more on analysis than design.
- Projects often focused on only one of the four civil engineering emphasis areas taught within our curriculum (i.e. geotechnical, structural, transportation, and water resources engineering).
- The technical work undertaken often failed to account for the many non-technical issues that frequently control real-world designs.
- Project report and assessment standards varied considerably from one faculty member to another.
- Average grades in 'Senior Project' were nearly a full grade point higher than those awarded in the program's other senior-level technical elective courses.
- Students frequently failed to complete their projects by the end of their final term in residence, which delayed graduation dates.
- Several faculty members were spending considerable time on senior project advising, which was keeping them out of the classroom and limiting their ability to pursue other professional development activities.

To address these growing problems and to provide a more realistic team-driven design experience for our students, the faculty members decided to switch to a structured course format for 'Senior Project.' Other civil engineering programs had demonstrated prior success in developing structured capstone design courses for their students [3–6]. More recently, authors have discussed their experiences with civil engineering capstone design courses [7, 8].

In developing the focus of the new course, the faculty members decided to combine an integrated design exercise with elements of the program's existing course on 'professional practice.' This course had been taught as a senior-level elective for the past ten years and had proven to be popular with the students. Over a third of our graduating seniors filled the course each year. Other civil engineering programs have developed similar courses [9]. In our course, local professionals presented lessons and exercises on various topics including ethics, professional licensure, leadership, communication, and project management. Course content focused on topics emphasized in two textbooks on project management [10, 11].

The faculty members felt it essential to incorporate a professional practice component into the new senior design course, given the past success and popularity of our professional practice course, the opportunity to further involve local practitioners in our capstone design offering, and the desire to more fully address some of the non-technical outcomes associated with the program's mission. Others [6, 7, 12] have discussed the value of working with practicing civil engineering professionals in the classroom. In addition, several authors have proposed means for incorporating non-technical outcomes into a capstone experience [13, 14].

2.2 Course outcomes and activities

We designed the new course to ensure that each senior had an opportunity to (1) participate as a member of a team in an integrated culminating design experience, (2) work on a team while assuming the role of 'expert' within a particular civil engineering specialty discipline, (3) acquire and practice many of the professional skills that are used on a daily basis by design engineers, and (4) demonstrate minimum technical proficiency in geotechnical, structural, transportation, and water resources engineering. We specified outcomes for the capstone course that corresponded with program outcomes and performance metrics developed by our constituents. These outcomes and performance metrics were based on the current ABET accreditation criteria and the Civil Engineering Program Criteria that were defined for the 2008 evaluation cycle. We defined performance metrics as specific skills that we expected our students to have by the time of graduation. Table 1 lists performance metrics that were given particular emphasis in the new course offering.

2.2.1 Activities outside the classroom

The new course includes activities that are undertaken outside and inside the classroom. The primary outside-of-class activity involves work on a private sector development or public works project that would benefit one of our local communities. The project is selected before the course begins with assistance from local consulting engineers and public works personnel. The project must include elements of geotechnical, structural, transportation, and water resources engineering, which represent the civil engineering specialty disciplines taught within our program. In addition, an adequate set of field data must be available.

During the first term of the course, the students prepare a written Statement of Qualifications (SOQ) in response to a specific Request for Qualifications (RFQ). During the second term, the students prepare a written Design Report that includes a full set of calculations and design drawings. Each term, the students present their ideas orally during a

Table 1. Program outcomes and performance metrics emphasized in the development of the capstone course curriculum

Outcome	Performance Metrics
Graduates have an ability to design a civil engineering system, component, or process to meet desired needs within realistic constraints.	Demonstrate an ability to interpret current civil engineering standards and incorporate them into design. Demonstrate an ability to design a civil engineering system, component, or process. Demonstrate an ability to recognize and incorporate multiple design constraints. Demonstrate an ability to produce civil engineering design drawings.
Graduates have an ability to function on multi-disciplinary civil engineering teams.	Demonstrate an ability to describe the interpersonal and communication problems that hinder effective teamwork. Demonstrate an ability to evaluate different communication styles. Demonstrate an ability to apply active listening techniques. Demonstrate an ability to function effectively on a design team comprised of individuals representing two or more civil engineering emphasis areas.
Graduates have an understanding of professional and ethical responsibility.	Demonstrate knowledge of the American Society of Civil Engineers (ASCE) Code of Ethics. Demonstrate an ability to apply ethical codes and evaluate ethics cases that may arise in civil engineering practice. Demonstrate an ability to assess the impact of engineering designs and decisions on public safety and the environment. Demonstrate an ability to identify and explain important aspects of project management, scheduling, contracts, risk management, and professional liability. Demonstrate an ability to explain the reasons for seeking professional licensure after graduation.
Graduates have an ability to communicate effectively.	Demonstrate an ability to write effective essays and technical reports. Demonstrate an ability to compose and deliver an effective oral presentation. Demonstrate an ability to prepare a Statement of Qualifications (SOQ) for a civil engineering project.
Graduates have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.	Demonstrate an ability to develop community consensus building techniques for a civil engineering project. Demonstrate knowledge of important environmental regulations relevant to civil engineering design.
Graduates have an ability to use the techniques, skills, and modern engineering tools necessary for civil engineering practice.	Demonstrate an ability to operate civil engineering drafting software.

formal 50-minute interview. Report and interview performance are assessed by a three-person panel consisting of a faculty member and two senior-level practitioners, all of whom are licensed Professional Engineers. Project scores, including the written and oral components, are valued at 40 percent of the course grade each term. A student's peer review score, which can range between zero and one, is applied as a direct multiplier to the project score. The peer review scoring process is described later in this paper.

To date, we have offered the new capstone design course five times. The five projects included: the design of a commercial office complex with associated parking and municipal roadway improvements; the design of a two-lane emergency access bridge over a protected creek; the design of a residential housing development with associated municipal drainage and roadway improvements; the design of a high school football stadium, track, and parking lot with associated roundabout improvement; and the design of a freeway interchange. To illustrate the scope of work for a typical design project, we describe one of the projects in more detail below.

The 2008 project involved the design of a high-density, multi-family residential development for a local municipality in dire need of additional low- to medium-income housing. Each student team was required to create a specific design proposal that addressed each of the issues enumerated in Table 2. In developing the project scope, we worked closely with local design professionals already involved with this project. We learned through multiple offerings of the course to spend considerable time developing the project scope so that the students had adequate time to complete their projects.

Each student team was provided with an identical set of data, including architectural drawings, information on the local and regional geologic setting, a site-specific soils engineering report, traffic studies, rainfall intensity-duration-frequency curves, stream flow data, and AutoCAD files that defined the site and regional topography and the location of all existing utilities. We required that all design solutions conform to all applicable local codes and standards. The students spent considerable time during the first term of the course researching these codes and standards as well as the needs of all project stakeholders.

Table 2. Principal scope items associated with the 2008 design project

Area	Principal Scope Items
General	Site design including an improvement plan showing the location of all dwellings, retaining walls, roads, parking areas, open spaces, and key drainage features.
Geotechnical & Structural	Foundation design for dwellings. Material and compaction specifications for all fill and pavement sections. Lateral support system or retaining wall design (critical section only). Structural design for the vertical and lateral load resisting systems.
Transportation & Traffic	Geometric alignment and pavement cross-section design of all intra-parcel roads. Striping plan and recommended signage. Recommendations for street improvements that are consistent with both the General Plan Circulation Element and the Traffic Impact Analysis performed for this development.
Water Resources & Utilities	Recommendations for preventing surface erosion and maintaining the quality of storm water discharge. Intra-parcel storm water management system design and detailing. Storm drain design to verify the adequacy of an existing culvert.
Other	Environmental compliance and permitting. Project advocacy in the context of community review.

Each student team was required to present their design recommendations in a comprehensive written report and a 20-minute presentation, which was followed by a 20-minute question and answer session and a 10-minute debriefing. The written report included a summary of the proposed design, which was supported by high quality engineering drawings and well-documented engineering calculations. The report also included a discussion of the team's overall approach to completing the work, recommendations for conducting the required public review, and suggestions for how best to obtain all necessary approvals and permits.

2.2.2 Activities inside the classroom

The new capstone course includes seminar-style presentations on such professional issues as assertiveness and interpersonal communication, advocacy and consensus building, qualifications based selection, leadership and motivation, project management, delegation, contracts, professional liability insurance, risk management, avoiding litigation, environmental permitting, professional ethics, professional licensure, construction estimating, and miscellaneous contemporary issues. These topics were lifted from the curriculum of the professional practice course described previously. Mostly local senior-level civil engineering professionals give the presentations. All students attend these presentations together in a lecture environment.

The course also provides formal instruction in four different civil engineering specialty areas, namely geotechnics, structures, transportation, and water resources. Technical modules within these areas focus on quantitative considerations important for the design project and serve to reinforce some of the knowledge areas that typically appear in the breadth session of the National Council of Examiners for Engineering and Surveying (NCEES) Principles and Practice of Engineering Exam. These modules focus on such quantitative considerations as bearing capacity of shallow foundations, axial capacity of deep foundations, consolidation settlement, reinforced concrete spread footing design, reinforced concrete stem wall design, masonry design, timber design, seismic analysis and design, geometric highway design, pavement design, storm water collection and management, culvert design, closed channel flow, and pumps. We worked closely with our Industrial Advisory Board and local practitioners to develop this list of topics. The students attend these modules in their design teams in a laboratory environment.

For these in-class activities, we assess student abilities on a weekly basis by assigning written reflection exercises during the seminars and problem sets during the technical modules. Student performance on these assignments constitutes 30 percent of the course grade. We also assess student abilities through final examinations, which are given at the end of each term. The exams are approximately two hours long and include non-technical and technical parts. The exams consist of true-false, multiple-choice, short-answer, analysis, and design questions and constitute the remaining 30 percent of the course grade.

2.3 Course delivery

Delivery occurs via a two meeting per week schedule. We use a lecture-lab format that is valued at 3 quarter units per term (6 quarter units for the two-term sequence). Non-technical topics are discussed in a 110-minute Tuesday evening lecture session, and technical topics are presented in a 170-minute

Thursday evening design laboratory. The first half of the laboratory is devoted to a review of the evening's analysis/design packet, and the last half of the lab session is spent on team-based problem solving of a formal assignment.

The entire class (as many as 180 students) attends a common Tuesday evening lecture session. However, there are four separate Thursday evening lab sessions, which permit closer instructor-student interaction during the associated analysis and design activities. On any given evening, one-quarter of the class will be dealing with geotechnics, one-quarter of the class will be focusing on structures, one-quarter of the class will be studying transportation design, and one-quarter of the class will be working with water resources. Each week, the instructors switch homerooms so that every student receives identical instruction by the end of a four-week rotation.

2.4 Course instructional team

An instructional team of three to five faculty members and up to thirty senior-level practitioners leads each offering of the senior design course. The practitioners play an essential role in the delivery of the course, acting as section instructors, guest speakers, interview panel members, and project advisors. All members of the instructional team are licensed Professional Engineers or appropriately certified non-engineering practitioners. Each team member has one or more of the following roles:

Course Coordinator (1). The Course Coordinator is solely responsible for the content and administration of the course. The Course Coordinator is responsible for moderating the Tuesday evening seminars and ruling on all requests for special consideration with respect to any administrative matter (including absences from class, due dates of assignments, date and time of exams, grades, etc.).

Section Instructors (4~6). The Section Instructors are responsible for leading the technical breakout sessions scheduled for the Thursday evening analysis/design labs. Sections have been team taught in the past. A particular Section Instructor will appear once in each section during each scheduled 4-week rotation. The Section Instructors are faculty members or practitioners with technical expertise in each of the following four emphasis areas: (1) geotechnical analysis and foundation design, (2) structural analysis and design, (3) traffic/transportation engineering and highway/pavement design, and (4) water resources and water supply/distribution.

Guest Speakers (12~16). Each Guest Speaker is responsible for preparing and delivering one of the Tuesday evening non-technical seminars. The speakers are senior-level practitioners who are well versed in the seminar topic and have personal experience with case histories that support the theoretical aspects of the seminar.

Interview Panel Members (12). The Interview Panel Members are responsible for reviewing the student-authored written SOQs and Design Reports and evaluating those same student teams during two 50-minute interviews (one each term). Interviews simultaneously take place in four separate venues, with each panel consisting of one faculty member, one senior-level consulting engineer, and one senior-level professional from a local public works agency. We require the Interview Panel Members to be registered Professional Engineers with relevant design experience.

Project Advisors (2). The Project Advisors hold senior-level positions within the consulting firm or public works department that is sponsoring the SOQ/Design Project. These individuals are extremely familiar with the nuances of the specific project being undertaken by the students and serve as the primary external contact point for project-related questions. We require the advisors to be registered Professional Engineers.

In 2009, the instructional team consisted of 2 tenured/tenure-track faculty members, 2 part-time lecturers, and 30 senior-level practitioners, making the capstone course offering a true faculty-industry collaboration. While adhering to the criteria listed above, we recruit senior-level professionals from local firms, local professional organizations, and our civil engineering alumni network. We periodically rotate new members through the course to enhance diversity and to allow interested professionals the opportunity to participate. We actively recruit female professionals. Each year, our goal is to recruit an instructional team as diverse as our civil engineering student body, if not more.

To date, the local professional community has supported the new senior design course enthusiastically and without reservation. In fact, there is a list of highly respected practitioners waiting for an opportunity to participate. In the eyes of many of the students enrolled, the involvement of so many design professionals as speakers and project reviewers is what validates the course and makes it such a great bridge between theory and practice.

3. Presentation and discussion

3.1 Emphasis on teams

Many team-oriented and project-based capstone design courses will include introductory course material that focuses on the design process and the design project [15]. These topics are addressed during the first term of the subject capstone course. However, based on feedback from faculty members, alumni, and our Industrial Advisory Board, we focused more on team building during the introductory course lessons. The students work together in their design teams for approximately six months; therefore, we felt it was important to provide the teams with the best opportunity for success. We attempted to achieve this goal by paying careful attention to team formation and by providing specific course content on team building and interpersonal communication.

3.2 Team formation

In the new course, essentially all student work (except for exams) is completed as a member of a team. Therefore, considerable thought is given to selecting team rosters. The students complete a survey during the first class meeting that defines (1) their academic coursework, (2) their industrial experience, (3) their status with respect to Engineer-In-Training (EIT) certification, (4) their current grade point average (GPA), and (5) their experience with computer-aided design software. The course instructors use this information to subdivide the class into six-person teams, ensuring that each team has a comparable degree of technical breadth and depth, practical experience, professional preparation, and academic preparation. With regard to academic preparation, the instructors attempt to ensure that each team has a comparable average GPA and a comparable level of computer-aided design experience. Table 3 summarizes student participation in the capstone course during the past five years.

Each member of a given team is assigned a specific role that relates to his or her elective coursework and industrial experience. On their surveys, the students report the top two civil engineering emphasis areas that they are interested in pursuing after graduation. Emphasis area choices include geotechnics, structures, transportation, water resources, or general (which indicates interest and experience in several different areas of civil engineering design). Since the design project includes elements of geotechnics, structures, transportation, and water resources, we ensure that at least one team member assumes a role in each of these specialty areas. The final two team slots are filled with generalists who are able to assist in all different elements of the project. Every effort is made to assign a role corresponding to the student's first choice. Indeed, during the past five years, approximately 80 to 85 percent of our students were assigned first choice roles.

Table 3. Student and team participation in the capstone design course

	Course Offering				
Variable	**2006**	**2007**	**2008**	**2009**	**2010**
Number of Students	138	146	173	160	174
Number of Teams	23	25	29	27	29

Based on enrollment numbers from the past five years, approximately 20 to 25 percent of our civil engineering seniors are female. Once the course instructors have assigned the student design teams using the criteria described above, a final check is made to ensure gender balance. The instructors modify the team assignments so that no female students are grouped alone with five other males.

3.3 Team preparation

Once the teams are formed, the students participate in a month-long series of lessons designed to prepare them for working with one another during the two-term course sequence. The lessons focus on three topics, as described in the following sections. Each topic is delivered in a lecture-type setting with the entire class present and working together in teams. The lessons serve to complement teamwork discussions that are covered in required laboratory courses taken as prerequisites for the capstone design course.

3.3.1 Team building

The first lesson includes a two- to three-hour team building exercise. During the first part of this exercise, the students participate in an icebreaker activity. In recent years, we used the 'Coat of Arms' exercise, where students express important aspects of themselves with drawings or short phrases [16]. During the activity, the students prepare a personal coat of arms, or emblem, and explain it to their teammates. The emblem is divided into quadrants (with prompts), as shown on Fig. 1. Each student prepares their emblem using drawings or short phrases to represent answers to the four prompts. The students then share their emblems with their teammates. The activity takes about 30 minutes with most of this time left open for the student team members to meet one another in a relaxed, low-threat atmosphere. Before the activity begins, one of the course instructors shares his or her coat of arms with the class.

During the second half of the team building exercise, the students develop team identities. The teams are tasked with selecting a team name, preparing a team logo, and choosing a team motto. The course instructors provide the teams with pencils, colored marking pens, and poster board so that they

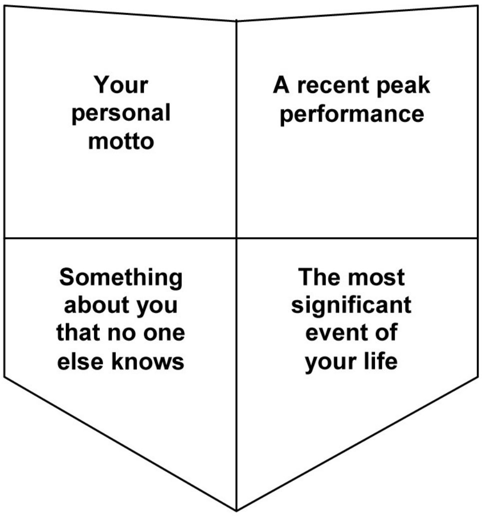

Fig. 1. The ‘Coat of Arms’ and prompts used during the team icebreaker activity.

can prepare their logos. The teams take approximately 90 minutes to complete this task.

For the final 30 minutes of this lesson, the students present their team names, logos, and mottos to the class during short one- to two-minute presentations. The team captain, who is selected by the team during this exercise, leads each presentation. Each team is photographed with their logo after their presentation is complete. At the very end of the lesson, the course instructors present two or three prizes to those teams judged to display the most spirit during the activity. The prizes are gift certificates to local coffee houses or restaurants (where the teams are encouraged to schedule their first design meeting).

Each year, we create a PowerPoint presentation showing the group photographs, names, mottos, and logos for all of the design teams. We show this presentation at the beginning of the next lesson to

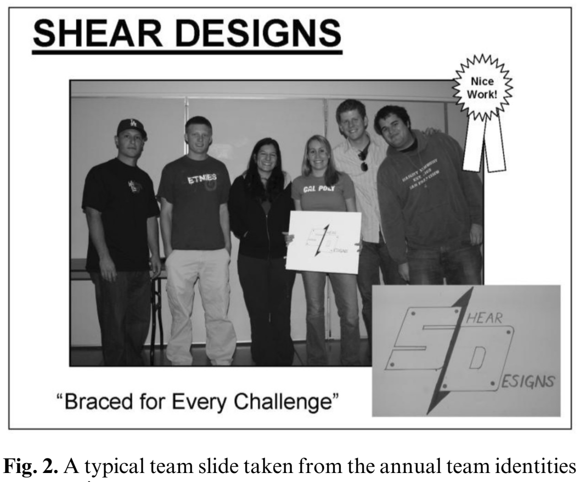

Fig. 2. A typical team slide taken from the annual team identities presentation.

recognize student efforts. The presentation is always well received and serves as an icebreaker for the second lesson on interpersonal communication. Shown on Fig. 2 is a slide taken from a recent team identities presentation. The ‘Shear Design’ team eventually created a digital version of their logo, which they incorporated into an eye-catching header for their written reports and presentations.

3.3.2 Interpersonal communication

The second lesson includes a two-hour interactive presentation and discussion that focuses on interpersonal communication. The course instructors lead this presentation, covering the following topics in some detail:

- Modes of interpersonal communication
- Active listening
- Non-verbal communication
- Effective meetings

The instructors rely on their personal experience and various references in developing the content for the above discussion topics. They also discuss important communication tips and advice emphasized in the text by Culp and Smith [11].

During this lesson, the instructors include reflection exercises for the students to work on with their teammates. A typical exercise will introduce the students to an active listening case history where they analyze a conversation and comment on the listening techniques being used by the different participants. Another exercise (typically assigned after class) requires the students to use best practices when planning and conducting future team meetings. Each team is required to submit an agenda and meeting minutes for several meetings held throughout the term. We review and assess these submittals and, when necessary, provide the teams with advice on improving performance.

Overall, students are strongly encouraged to utilize the tools introduced during the interpersonal communication lesson throughout the two-quarter capstone design sequence. Several problems are included on the course final examinations to assess student abilities in the above topic areas.

3.3.3 Communication styles and assertiveness

The third lesson covers communication styles and assertiveness and is taught by an organizational coach with considerable expertise in this area. The organizational coach we employ for this activity has taught numerous business courses on campus. In addition, she has served as a management consultant to several local engineering firms.

One way to become a better communicator and team member is to understand that people have distinct, preferred, and predictable ways of communicating. Other instructors have incorporated personality assessment exercises into their capstone design courses to help improve team communication and performance [3, 17]. We decided to use a similar method whereby the students assess their own 'communication styles,' which are based primarily on the degree to which the individual is assertive and outgoing [18, 19].

Farley and Donaldson [18] identify four predominant communication styles with the following names: 'medic' (amiable, harmony seeker), 'cheerleader' (expressive, excitement seeker), 'computer' (analytical, detail seeker), and 'steamroller' (driver, results seeker). Each style has different strengths and blind spots, but no style is considered 'better' than another. A person's predominant style is determined by completing a self-assessment survey, which takes about fifteen minutes. The chart on Fig. 3 lists the important characteristics of the four possible communication styles. Table 4 summarizes the distribution of student communication styles observed during each offering of the capstone course. The results show that most of our students demonstrate a preferred communication style corresponding to that of a 'computer.' Overall, the results are remarkably similar for the four years we implemented this exercise in the

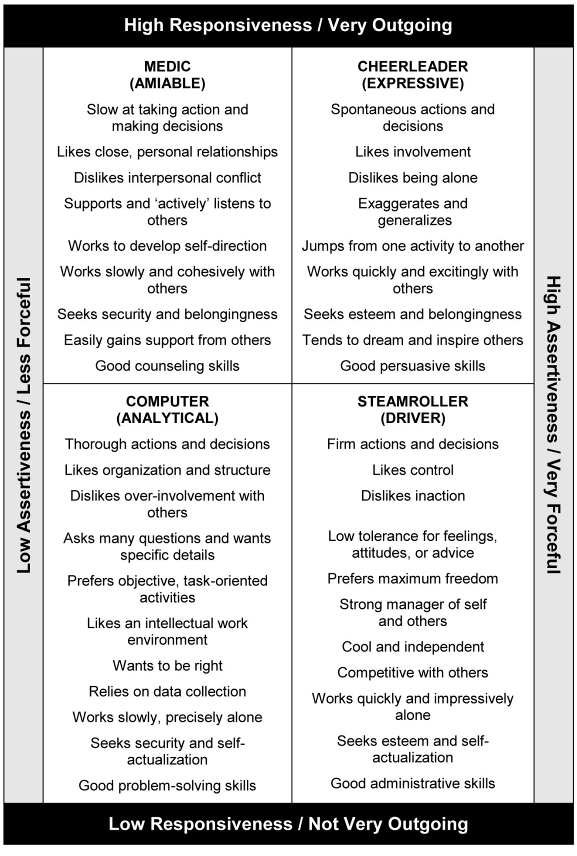

Fig. 3. Characteristics of Farley and Donaldson's four communication styles (adapted from Hunsaker and Alessandra [19]).

Table 4. Distribution of communication style for our senior design students

	Percentage of Enrolled Students			
Year	**Cheerleader**	**Medic**	**Computer**	**Steamroller**
2006	11%	20%	58%	11%
2007	12%	17%	54%	17%
2008	10%	17%	56%	17%
2009	13%	22%	56%	9%
2010	—	—	—	—
All	12%	19%	56%	13%

course. It is noted that this lesson was not incorporated into the 2010 course offering due to scheduling difficulties and instructor preference.

Prior to the third lesson, students complete the communication style survey so that they know and understand their preferred communication style. During the lesson, the organizational coach discusses assertiveness and the characteristics of the four different communication styles. The students then examine and discuss case histories as a class, in their design teams, and with other students having the same communication style. The in-class activities allow the students to work together to better understand that people have predictable and preferred patterns of behaving and communicating. The students are given tips and practice exercises on how to communicate with persons having communication styles that are different from their own. We assess the students' abilities relative to this topic by including reflection questions on the course final examinations.

3.4 Team performance and assessment

Direct and indirect measures of student learning are taken on a regular basis as part of our program's continuous improvement efforts. The capstone course incorporates many opportunities for assessing student learning at a critical point (just prior to graduation) using a consistent methodology [2]. Indeed, the data collected in the new course during the past five years have contributed significantly to the program's self-evaluation process. In the course, analysis and design assignments, reflection exercises, written project reports, oral project presentations, exam problems, and student/evaluator surveys are used to assess student learning relative to more than forty program-specific outcomes and performance metrics. Scoring rubrics and multiple reviewers are used to assess student work whenever possible. Metric goals established by the faculty members define acceptable levels of student achievement. A unique and important aspect of the course is that engineering professionals (from outside the Civil Engineering Program) assess the abilities of all of our graduates relative to numerous technical and non-technical outcomes.

For example, a twelve-person interview panel consisting of eight practitioners and four faculty members is responsible for assessing student projects and presentations at the end of each term. As noted, student teams prepare a written Statement of Qualifications (SOQ) during the first term of the course. One of the assessment categories for this portion of the design project focuses specifically on teamwork and performance. The scoring rubric for this category is shown in Table 5. Note that the scoring rubrics we developed for the written and oral components of the SOQ and Design Project are each three pages long. Thus, in the interest of space, the complete rubrics are not reproduced in this paper.

Summarized in Table 6 are average team performance scores for the past five years, assuming the rubric defined in Table 5. The data suggest steady improvement in team performance. This result seems reasonable since the program has focused more on teamwork and team building issues during the past five years and since the instructors of the capstone course have worked to continuously refine and improve the team building and interpersonal communication lesson plans. It is important to note that we carefully screen the team performance scores to identify any teams experiencing communication problems or personality conflicts during the first term in which they work with one another. After conducting this evaluation, we work with struggling teams to try to resolve problems and/or conflicts so that the teams are prepared to begin the second term of the course on a positive note. It is during the second term when the principal design work for the capstone project takes place.

Using well-defined scoring rubrics, the panel members also grade team performance on the Design Report for categories related to project understanding, design approach, design drawings, design calculations, and presentation effectiveness. Average scores for the past five years are shown in Table 7. Average scores in all categories exceeded our metric goal of 70 percent, indicating that the students had acceptable design skills at the time of graduation. However, the lower scores related to the students' ability to prepare engineering drawings suggested room for improvement. These relatively low scores were confirmed through individual post-course surveys completed by the reviewers and students, as well as through data collected in other courses. These results led the Civil Engineering Program to make curricular improvements in this particular subject area, including a complete revamping of the sophomore-level CAD course sequence in 2009. We believe the relatively high scores shown in Table 7 are further evidence of effective teamwork between students: the design teams are submitting high quality products on schedule.

Our faculty and practitioner panel members also complete a survey at the end of the second term of the capstone course where they rate overall student performance for twenty-five different program outcomes, including those related specifically to team

Table 5. The 'team performance' category of the Statement of Qualifications scoring rubric

Area	Score	Qualifying Characteristics
Demonstrated Competence and Qualifications *Evaluate the group's ability to function effectively as a team:*		
	100%	Intra-team communication appears to be outstanding. The various individuals appear to share a common goal, and the group already appears to be a unified team. Leadership, team organization, and individual roles and responsibilities are well defined. Critical path issues are well understood. This is a very strong team (top 25%) that is prepared to hit the ground running on the design project.
	75%	Most team members appear to be qualified and know their individual roles and/or responsibilities. However, some team issues (such as leadership, organization, project management structure, critical path scheduling, and/or team member interaction) may not have received sufficient attention. Intra-team communication is solid but not outstanding. Resumes may not follow a consistent format.
	50%	There is little evidence that this team has the cohesiveness, organization, technical qualifications, and/or understanding required to succeed on this project. There is evidence of poor intra-team communication. This is a weaker team (bottom 25%) that would be doing considerable learning on our dime if this were a real-world situation.

Table 6. Summary of average team performance scores (out of 100) for the SOQ projects

Category Description	2006 Scores	2007 Scores	2008 Scores	2009 Scores	2010 Scores
Ability to Function Effectively as a Team	72	71	74	80	80

Table 7. Summary of average design report scores (out of 100) for civil engineering senior design team project reports

Category Description	2006 Scores	2007 Scores	2008 Scores	2009 Scores	2010 Scores	Average
Project Understanding	73	76	80	79	86	79
Design Approach	78	76	77	79	81	78
Design Summary and Engineering Drawings	80	75	73	76	77	76
Design Calculations	82	85	82	85	86	84
Presentation and Overall Impact	75	77	74	78	79	77

Table 8. Assessment of student communication performance by practitioner and faculty interview panel members[1]

	2007		2008		2009		2010	
Question (see below)	Score (out of 5)	Percent Acceptable	Score (out of 5)	Percent Acceptable	Score (out of 5)	Percent Acceptable	Score (out of 5)	Percent Acceptable
1	3.4	80	2.9	73	3.4	82	3.1	89
2	2.9	60	2.7	82	2.9	73	3.4	100
3	4.4	100	3.9	91	4.1	100	4.3	100
4	3.5	90	3.1	73	3.3	73	3.3	89
5	3.7	100	3.5	91	3.7	100	3.8	100
6	3.7	100	3.3	82	3.4	91	3.4	89
7	3.9	100	3.2	73	3.5	100	4.0	100

QUESTION: Based on your evaluation of the design teams, please rate the ability of the students to . . .

1. Write a cover letter to introduce their project report.
2. Organize and write a technical report that summarizes their design solution.
3. Compose an electronic presentation using MS PowerPoint.
4. Understand their audience in preparing their written report and oral presentation.
5. Present their findings and design solutions orally.
6. Listen with understanding and answer questions.
7. Work as a team to complete the design project.

[1] A 5-point survey scale is used for the above assessment tool where 1=Poor, 2=Fair, 3=Good, 4=Very Good, and 5=Excellent. The average score for each question is noted in the table using the 5-point scale. 'Percent Acceptable' refers to those survey answers that were recorded as 'Good' or better.

performance and communication. Their assessments are based directly upon their observations of the students during the two-term course sequence. Summarized in Table 8 are results for the survey questions most closely linked to communication skills. We consider these scores relatively high, in comparison to other categories, indicating excellent performance by our students. Our panel members have consistently ranked our students' ability to work as a team and prepare oral presentations as the highest performance categories on this survey. We note that our panel members have scored our students' performance as unsatisfactory in other categories. For example, in 2010, the panel rated the students' ability to assess the impact that their design solutions will have on the environment, to evaluate the reasonableness of their design solutions relative to constructability, and to develop recommendations for conducting the required public review for the project as 45, 55, and 36 percent acceptable, respectively. Average scores for the survey questions were 2.5, 2.5, and 2.2, respectively. We use assessment results like these to make improvements to the capstone course and the program curriculum. We note that panel assessments of the categories listed in Table 8 have never been this low.

At the end of each term, the students prepare peer evaluations for their teammates following a previously developed approach [20]. The evaluation survey includes questions related to the following categories: respect shown for teammates, attendance at meetings, preparation for meetings, communication effectiveness, and acceptance of assigned tasks. In addition, each student prepares a short reflection essay in response to the following prompt: 'Describe the biggest challenge that your team faced in preparing your term report. Explain how your team dealt with (and hopefully overcame) this hurdle.'

Based on the way the survey is formatted, a student's peer evaluation score can fall between 0 and 100 percent. The score, as a decimal, is used as a

Table 9. Distribution of peer evaluation scores for 2006–2010

Peer Evaluation Scores				
(90–100%)	(80–89%)	(70–79%)	(60–69%)	(< 60%)
86%	10%	2%	1%	1%

direct multiplier on the term project score when assessing a student's grade for the term. Collective scores for the past five years are summarized in Table 9. These scores are overwhelming positive. It is noted that we carefully review the peer evaluation scores and the short reflection essays on team performance after the first term of the capstone course. For teams struggling with communication and teamwork, we provide extra counseling to get them back on track prior to the second term of the course.

Each year, we ask our graduating seniors to rate their own abilities and attitudes for over 50 different categories related to their course work within the civil engineering degree program and the senior design course. We use a 5-point survey scale with 1=Poor, 2=Fair, 3=Good, 4=Very Good, and 5=Excellent. The survey is administered during the last two weeks of the second term of senior design. Survey results related specifically to teams and interpersonal communication are summarized in Table 10. These results show that our students appear comfortable in their interpersonal communication skills at this point in their career. Historically, survey results for select other non-technical and technical categories have been considerably lower than the results reported in Table 10. Examples include the students' ability to apply chemistry concepts to civil engineering problems, prepare engineering design drawings, and apply probability and statistics concepts to civil engineering problems. The students appear capable of honestly assessing their own abilities, relatively speaking. Evidence is found in Table 10. In 2010, the graduating seniors demonstrated less confidence in their ability to identify different communication styles. During this year, the seminar on communication styles and assertiveness was not given, but the seminar material was made available as a supplemental reading assignment.

Finally, we also evaluate team performance and the achievement of communication-related outcomes using exam questions and reflection exercises. Historically, the results of these assessments have been positive. These results, when combined with the results presented in Tables 6 through 10, help to confirm that we are meeting (and exceeding) our performance goals for all team-related outcomes and metrics in the capstone course.

4. Conclusions

Nearly 800 students completed the new capstone design course in civil engineering since 2006. During this time, over 130 student design teams worked on five different design projects. Faculty member and practitioner assessments of design team performance are excellent, when compared with other learning outcomes addressed in the capstone course. In addition, student peer evaluations are overwhelmingly positive, and graduating senior surveys indicate that the students value the upfront team building activities and interpersonal communication lessons included in the course curriculum.

We believe the changes made to the original 'Senior Project' course have benefited the civil engineering program in many different ways. All of our students are guaranteed a culminating design experience where a real-life, integrated design problem is solved in a team environment. Assessments of our students' design skills have been consistently high since the inception of the new course, which is encouraging since the evaluation panels have consisted entirely of design professionals with rigorous standards. In 2005, we observed a 26 percent on-time completion rate during the final 'Senior Project' course offering. Since offering the new capstone senior design course, we have observed a 100-percent on-time completion rate (no one has failed the course) and an average final course grade ranging between 2.8 and 3.3 (using a 4.0-point scale). The average grade awarded in all senior-level technical electives during the same period has been approximately 3.0. As evident, the new capstone course is helping us to eliminate many of the problems associated with the old 'Senior Project' course.

Alumni and employers had historically assessed our students' teamwork and communication abilities as low, when compared with technical abilities such as problem solving, designing, interpreting data, and conducting experiments. Although we do not have direct measures of team performance prior to the format change initiated in 2006, assess-

Table 10. Graduating senior survey results for self-assessment of communication skills

	Percentage of Students Self-Reporting their Abilities as 'Good' or Better				
Survey Category	**2007**	**2008**	**2009**	**2010**	**Average**
Identify different communication styles	93	92	93	88	92
Understand communication problems	96	94	92	91	93
Listen effectively	97	96	94	96	96
Function on multi-disciplinary team	98	94	92	96	95

ment results for the new senior design course indicate that our students' teamwork and communication skills are very good. Changes in student performance (for the good) appear to have coincided with the development of the new course and the focus placed on teamwork and interpersonal communication. Our students' abilities in these areas now rate as high, if not higher, than abilities in the technical areas.

Some decisions regarding the format of new course were made due to the sheer size of the program. As noted, student enrollments in Senior Design varied between 138 and 174 during the past five years. To manage this number of students, we formed relatively large student teams (of six students each) and required each team to provide design recommendations for the same project and work scope. We also made the decision to present the weekly non-technical seminars to the entire class. This decision was driven by the limited amount of time that working professionals could devote to the course during a given week. Other engineering programs, especially those with larger enrollments, could easily implement a similar senior design course. Physical facility requirements include one large lecture hall for the non-technical seminars and four medium-sized classrooms for the technical breakout sessions, which should be available at most universities. Overall, we believe the key to success is the ability of the program to recruit a network of enthusiastic professional engineers who are willing to mentor senior students throughout the course and term projects.

Three different faculty members have served as course coordinators for the capstone design sequence during the past five years, including the authors (four times) and another faculty member (one time). Despite the different coordinators, student design team performance continues to improve. We feel the course is sustainable in its current form. Course notes and teaching modules have been refined to the point where a new instructor can quickly step-in and lead the course without requiring a significant amount of course preparation or jeopardizing course quality.

Due to the assignment of three different course coordinators, the capstone course offerings between 2006 and 2010 did not follow an identical format. For example, in 2010, the course coordinator spent additional time during the first term focusing on traditional design process issues and important aspects of actual design project. As noted, this coordinator did not include the learning module on communication styles (but the information was made available to the students as a supplemental reading assignment). It is interesting to note that the peer evaluation scores for the 2010 course were very slightly lower than the average scores reported in Table 9. However, as noted in Table 6, the students' 'Project Understanding' and 'Design Approach' scores were higher in 2010 than in previous years. Given the limited number of course offerings to date, one should exercise care when interpreting these results. Perhaps a trade-off should be considered when addressing design versus communication issues in the course curriculum. Regardless, assessment results from the past five years show acceptable student performance for all of the design, teamwork, and communication related outcomes, despite the fact that different coordinators customized the capstone course in different ways.

Finally, we feel one of the most valuable additions to the new course has been the lesson on communication styles and assertiveness, which is led by a non-engineering professional with considerable business training. Based on student evaluations, this is one of the more popular non-technical modules of the course. We intend to ensure that this module is not omitted from future course offerings. Knowledge gained through this module has helped to improve interpersonal communication between design team members, as evident in our assessment results. During the next offering of the course, our plan is collect communication style data upfront for each student. This will allow us to form the design teams while 'balancing' them with respect to communication style, in addition to past academic performance, work experience, CAD experience, EIT certification, and emphasis area preference. Our intent is to begin to investigate the effect, if any that communication style diversity has on design team performance, similar to work done by others [21].

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