

**AC 2010-539: AN INNOVATIVE SENIOR CAPSTONE DESIGN COURSE
INTEGRATING EXTERNAL INTERNSHIPS, IN-CLASS MEETINGS, AND
OUTCOME ASSESSMENT**

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An Innovative Senior Capstone Design Course Integrating External Internships, In-Class Meetings, and Outcome Assessment

Abstract

Responding to an increasing need for civil engineering students to obtain real-world experience, a senior design course for civil engineers was modified to integrate external internships. Students attend class twice a week and work outside the classroom in an appropriate civil engineering design office supervised by licensed Professional Engineers once a week.

Students are assigned in groups of up to three to local engineering firms or agencies in their discipline of choice (geotechnical, structural, transportation, or environmental engineering). The firms work with faculty to identify a project that the students can work on side-by-side with professionals. The students work in the company a minimum of three hours per week. They are required to continue their work during the rest of the week, both in-class with the supervision of a faculty member (who is also a licensed Professional Engineer) and in group meetings on their own time. Four presentations are integrated throughout the course and attended by faculty in the appropriate discipline. In addition, bi-weekly “client meetings” are held with faculty to monitor the progress of the students and give advice regarding the project.

Outcome assessment assignments are incorporated in the class and quantitative rubrics (using two or three performance indicators, depending on the outcome) are evaluated by faculty at appropriate points in the course. Other forms of feedback include student and employer surveys at the end of the experience.

The internships have been a great success at almost no expense to the university. Students have been absorbing concepts quickly and the placement companies have enjoyed the interaction with the students. This paper will describe in detail the course objectives, course outline, placement strategies, assessment procedures, and the successes and failures of the method with local engineering firms and agencies of varying size.

Introduction

Engineering capstone courses are excellent tools for preparing traditionally-educated engineers for the real world of design. As a result, a plethora of schools use such courses and knowledge in the area is vast. For example, as of 1997 there were approximately 100 papers related to engineering design courses ¹ and at the time of this writing, at least 150 papers were published.

Several of these previous studies focus on student design projects involving real-world projects. Some argue that using real-world projects provides students exposure to working with challenging clients and imperfect design information ². Students need this experience with real world problems to become effective civil engineers ³.

This paper presents a synopsis of previous studies on engineering design courses in the next section, particularly those including industry collaboration. Next, the case study methodology is discussed in detail, including the new course’s integration with the Civil Engineering Body of

Knowledge for the 21st Century⁴. The last sections present the findings of the instructors' experiences with the course.

Previous Work

Overall lessons from past capstone courses

Previous work examining the learning in engineering capstone courses has focused on team-based learning, problem-based learning, and impacts of the learning environment. Yost and Lane (2007) argue that effective team-based learning in capstone courses require that teams be heterogeneous and have shared goals, meaningful activities, timely internal feedback, and external comparisons and feedback⁵. Thus, for faculty to facilitate an effective team-based learning experience, they must be very deliberate in the planning of team projects, milestones, activities, and feedback methods and timing.

Quinn et al. (2008) focused on problem-based learning approaches in a structural engineering capstone course as a way to integrate knowledge from previous classes with those newly learned from independent thinking. This study found that a problem-based learning format required significantly more time due to the additional feedback for students and that team-building exercise could strengthen communication between student teams and the instructor⁶. Others have investigated the application of problem-based learning into an entire civil engineering curriculum at the University of Colorado, finding promising evidence for future pursuit⁷.

Two key studies examined the impact of the learning environment, one examining changes in the classroom workspace, the other, learning changes from lecture to team projects. Grulke et al. (2001) found that students in a professional and technologically-equipped workspace performed significantly better on technical content and communication than students asked to complete their project in available space in campus engineering buildings⁸. Dinsmore et al. (2008) focused on how changing the student learning environment from traditional classroom lectures to a student team project changes declarative, procedural, or principled knowledge. In this context, declarative knowledge includes understanding engineering terms such as benefit-cost analysis, procedural knowledge applies to understanding processes such as pavement design, and principled knowledge is being able to explain the concepts behind the design. This study examined an engineering design course using student teams guided by faculty. While this course did improve declarative knowledge more than traditional lecture courses, the course change did not foster any improvements in student's procedural or principled knowledge. These authors noted that the lack of improvement in principled knowledge is particularly distressing as it may disadvantage students entering industry⁹.

The results from these previous studies indicate that team- and problem-based learning environments can improve declarative knowledge but require more faculty time. Further, changing the learning environment to a more-professional setting can also improve communication and help students connect key concepts of their principled knowledge. Thus, many senior design courses have investigated collaboration with local industry to sponsor team- and problem-based student design projects.

Lessons from capstone industry projects

Schools such as the University of Wisconsin Platteville ¹⁰, Rowan University ¹¹, University of Oklahoma ¹², University of Kentucky ⁵, Jackson State University ¹³, Lake Superior State University ^{2; 14}, Florida State University ¹⁵, and University of Arizona ¹⁶ use capstone projects involving industry participation (Table 1). This list is not comprehensive, but rather a synopsis of schools having published best practices on the topic. Because of these previous endeavors, there is a wealth of knowledge about challenges and best practices for these types of senior design courses. These studies include capstone courses that include industry-supervised work, international projects, and multidisciplinary projects.

The University of Kentucky's capstone course includes projects in coordination with local industry. During this project, students learned more about the true management of a project, how to work with clients and senior engineers, and how the design process fits within the larger framework of the business world and the local community. While scheduling and coordination were noted as significant challenges, the largest challenge to this program was selecting projects that were the correct scope and timing for each semester's students ⁵.

Other studies have focused on the benefit of local industry feedback. In particular, industry partners in engineering design courses can help evaluate student competency gaps by assisting in senior design courses ^{13; 17; 18}. One method of identifying these gaps is through before and after surveys focused on identifying the technical skills required of new graduates ¹³. The authors state that, "the capstone course experience provides a pivotal opportunity for employers, educators, and students to share opinions concerning the strengths and opportunities for improvement in the program."

At least two schools use international senior design projects to expose students to the global impact and reality of engineering design. Both the Rose-Hulman Institute of Technology ¹⁹ and Florida State ¹⁵ have an international senior design project coordinating with Engineers Without Borders. International experience can benefit students by introducing students to international design codes and by providing experience in the global work force and with local industry partners ¹⁹. Challenges can include student adaptation to new learning and cultural environments, access to local design codes ¹⁹, keeping regular team communication, and finding industry partners with adequate time ¹⁵. Best practices include providing students with more than two weeks to decide on participation, requiring regular web-camera (or similar) communication with international team members, and expanding teams to include multi-disciplinary components ¹⁵.

Several other studies have focused on the impact of multi-disciplinary design courses, where multidisciplinary is considered involving more than one engineering department. A multi-disciplinary engineering senior design project exists at Lake Superior State University, where local industry helps select appropriate projects ^{2; 14}. The students complete their two-semester design course while working in a dedicated room structured similar to an office setting. The authors noted that the key challenges included forming teams, grading students individually, and coordinating the projects. This method also requires available space to provide students with a dedicated, professional senior design room.

The University of Arizona offers a multi-disciplinary, industry-sponsored, senior design course. Because this course integrates students from across disciplinary boundaries, equitably assigning qualified students to preferred projects became a challenging task as noted by others. To reduce the time required to make the teams, instructors developed software to match student qualifications, abilities (GPA), and desires with the existing pool of projects, creating equally matched teams. The software allowed instructors to save a significant amount of time, albeit their involvement is still critical to ensure a quality final team selection ¹⁶.

Despite differing disciplines, program sizes, and course designs, this review of industry-sponsored engineering design courses reveals several key themes. Including industry in student engineering design courses requires more faculty time to coordinate projects and poses challenges to identifying appropriate projects. However, industry feedback provides a significant value to both students and departments.

Table 1: Reviewed Industry-Sponsored Senior Engineering Design Courses

School	Semesters	Annual Enrollment	Engineering Emphasis	Student Group Size	Sponsor Support
University of Wisconsin Platteville	1	70	Mechanical	4-5	Mentoring, Funding Encouraged
Rowan University	2	15	Civil	4-5	Project Idea and Mentoring
University of Oklahoma	1	95	Elec. / Computer	4	Project Idea, Mentoring, and Funding
University of Kentucky	1	NR	Civil	4-6	Project Idea and Mentoring
Jackson State University	1	50	Industrial	1	Mentoring, Dept. Feedback
Lake Superior State University	2	75	Multidisciplinary	4-8	Funding and Mentoring
Florida State University	2	NR	Mechanical	3	Funding
University of Arizona	2	300	Multidisciplinary	3-6	Project Idea, Mentoring, and Funding
NR = Not Reported					

Methodology

The internship class at Southern Illinois University Edwardsville developed as a direct expression of the needs of local employers, through discussions at the bi-annual Industrial and Professional Advisory Committee (IPAC) meetings. In these meetings it was clear that students would benefit from a required onsite engineering experience that was supervised by practicing engineers.

Previously, the senior design class (CE 493) had been a catch-all for university and ABET assessment needs. Southern Illinois University Edwardsville is known and nationally ranked for its “senior assignment.” The civil engineering capstone design class was used to not only provide engineering students with a capstone design experience but also to satisfy the university requirement of a culminating senior experience that could be used to assess the performance of seniors regarding the departmental and university objectives.

In 2000, with the introduction through ABET of the revised engineering accreditation criteria, the course became an ideal source of assessment for almost all of the departmental outcomes. Outcome assignments, wherein departmental expectations for student performance were evaluated on a student-by-student basis, were added to the course. These assignments were

originally given to every student each semester, but the frequency was eventually lessened to assess each outcome only every three years based on recommendations from ABET²⁰.

Thus, there was a challenge in introducing significant industry involvement in a course that had frequent assignments and rigorous assessment requirements. It became clear to the coordinating faculty that a hands-off internship would not satisfy our needs for ABET assessment. There would need to be direct faculty involvement in the course, with faculty still providing some supervision in order to help coordinate a still-intense assessment schedule.

Civil Engineering Body of Knowledge

At about the same time as the decision to introduce an internship experience in CE 493, the Civil Engineering Body of Knowledge for the 21st Century (BOK) was published. In the vision for the “Model Civil Engineering” student, it is recommended that students “seek relevant work experience.” Students at Southern Illinois University Edwardsville have traditionally had great success finding outside experience. Prior to 2008, at least 90 percent of students regularly had employment in a civil engineering related field before graduation. However, the economic downturn hit the St. Louis area fairly hard, and beginning in the fall semester of 2008, only 50 to 75 percent of students were finding outside employment as engineering interns on their own. Integrating internships within CE 493 provided a means for every student to have an onsite engineering experience with a practicing engineer.

In addition to encouraging students to obtain professional experience prior to graduation, the BOK also sets rubric expectations for students and practitioners at various education levels. In particular, the CE 493 class, as the culminating experience of civil engineering students at the Bachelor’s level, is an ideal place to not only assess whether students have met the expectations of the BOK but also one of the last chances that the university has to make sure that all students are educated to the proper foundational level.

To ensure adequate student knowledge levels, employer surveys reveal if elements of the education are lacking. For example, the department is presently evaluating the ABET outcome “knowledge of math through differential equations”, also known as the “Mathematics” foundational outcome in the BOK. Because of the importance of this outcome, discussions with supervising employers are now underway to determine exactly what calculus should be emphasized at the undergraduate level and how it might best be demonstrated within the context of professional practice.

Project Guidelines for Industry-Sponsored Senior Design Course

Students in the class are all seniors in the final semester and thus have considerable academic experience. In order to avoid unevenly matched teams, faculty divide students into groups of from one to three based on their interest (environmental, geotechnical, structural, or transportation engineering), knowledge of past student performance, and anticipated projects, as suggested by others¹⁵. An appropriate group is sent to work at the jobsite or office three hours per week while the university is in session. Although other schools require 100 hours of industry-sponsored work¹³, this program required 36 hours of industry-supervised work and 30 hours of faculty-supported work to account for assessment tasks, as discussed previously.

It is not required that the students be paid. The onsite experience they get partially counts towards their requirements for completing the course CE 493 Senior Design. The following four guidelines encompass the expectations for the internship portion of the course.

1. **Appropriate project selected:** This is coordinated with a contact person at least a month before the start of the semester (mid-July for fall and early December for spring) to identify an appropriate project. Projects need to have a significant deliverable at the end of the 15-week semester so that the students can write a report on their work and make a presentation at the university.
2. **Administration:** During at least 30 minutes of the three hours in the office each week, a supervising engineer (PE or SE) needs to be available to answer the students' questions. A name and contact information are necessary so the faculty can keep in touch as needed.
3. **Workspace:** Students need to be provided workspace (desk, conference table, etc) for their weekly three hour office attendance.
4. **Reference material:** Students need to have access to necessary design references and other pertinent information for the project while in the office.

In addition to the three hours per week the students are in an office, they are required to attend class and keep the faculty informed of their progress. During class periods, different topics are lectured on. A team-building exercise is included to help foster open communication within groups and with the instructor as recommended by ⁶. Students are also required to turn in bi-weekly progress memos and run mock client meetings with instructors. Although most students are members of student chapters, one course requirement is to attend a professional meeting, meet local professional engineers, and write a memo about the experience. Because student learning occurs largely outside of the classroom ²¹, these meetings introduce students to topics presented from an industry perspective. Additionally, students often identify job leads and boost the Department's visibility.

The requirements for memos and mock client meetings provide students with timely feedback on their project progress. Some argue that requiring students to turn in memos reporting their progress can reduce the amount of work left until the deadline ²². The mock client meetings reinforce the deadline expectations, provide an opportunity for students to present their progress and discuss key challenges, and receive instant feedback on their progress and plans.

All of the faculty working with the students are licensed PE's or SE's and are able to help them with some of the engineering questions that arise while they are out of the office. Also, the University has some resources that might not be readily available in some office locations (e.g., research laboratories, instrumentation, and finite element programs) that can be used to further investigate questions that arise.

Some companies have identified excellent student projects, yet there were proprietary or confidentiality concerns. To address these challenges, presentations and reports were authored for "faculty eyes only." Otherwise, presentations are open and reports may be used for accreditation purposes.

Before the change to industry-sponsored design projects, projects were developed by the instructors. They usually included components of real world projects that were future endeavors. However, to make the projects interdisciplinary – covering environmental, geotechnical, structural, and transportation engineering aspects, they often were weak in at least one area. Occasionally external clients would talk to the class, or local design companies would consider the findings in their future design. The new format provides students the opportunity to work on current projects, experience common changes that take place in the design process, and possibly see the constructed products of their design in the near future. The final projects were an interesting mix (Table 2).

Table 2. Projects under the New Format

Engineering Discipline	Projects
Environmental	Sewer line to replace septic systems, Site remediation, Troubleshooting operational issues at a wastewater treatment plant
Structural	Historical building load analysis, New structures
Transportation	Interstate intersection, Road intersection, New gas pipeline

Outcome Assignments

Integrating the requirements of ABET assessment, the BOK, and the onsite internship experience was made fairly straightforward but the already in-place outcome assessment assignments. The assessment schedule is now on a three-year rotation and the outcomes assessed in CE 493 at present are shown in Table 3. Outcomes b, h, m, and n are the only departmental outcomes that are not explicitly assessed in CE 493.

Assessing a particular outcome in a given semester is done using an “outcome assignment” that is designed to evaluate the students with respect to a given rubric. For example, for spring 2009, the class was asked to analyze part of a project using a procedure that could be done using calculus. In the case of students in the structural engineering section, they were asked to determine the deflections in one of the beams of their project using integration and were also asked to propose a testing procedure that could be used to verify the member’s yield strength. Once the assignments were turned in, the faculty evaluated them using a rubric with three outcome indicators that had been designed to measure whether the students exceeded, met, or did not meet, departmental expectations. These assignments continued with the change to the industry sponsored project format.

Table 3: Outcomes assessment schedule in CE 493

Course	Semester Primary Program Outcomes Assessed																
	(a) math, science, and eng (b) design/conduct experiments (c) design a system, comp or process (d) function on teams (e) solve engineering problems (f) prof & ethical responsibility (g) communicate effectively (h) broad education (i) lifelong learning								(j) contemporary issues (k) techniques, skills, eng tools (l) proficiency in math (m) proficiency in four areas (n) experiments in more than one area (o) perform civil eng design (p) prof practice issues (q) work experience								
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
CE 493-eng design	S09		S12	S09	S13	S10	S13		S10	S11	S14	S09			S12	S11	S11/S14

Survey Results

To assess the impact of the change to industry sponsored projects, instructors used surveys of students and employers. The student survey was conducted two semesters before, fall 2008 and spring 2009, and one semester after, fall 2009. Student enrollment was 27, 18, and 13, respectively. The employer survey was conducted after the first semester of the new project format, fall 2009. There were nine employers (four who had groups of two students and five who had single students). The response rate was 100% for all surveys.

Student Surveys

The student survey was administered the last class of the semester during the two semesters before (fall 2008 and spring 2009) and one semester after (fall 2009) the course format change. One of the first questions asked students to rate the statement “This course has increased my interest in Civil Engineering.” Figure 1 shows the responses, where the grey bars are the “before” case and the black bars are the “after” case. These findings indicate a strong shift towards self-reported student interest in their major and future career.

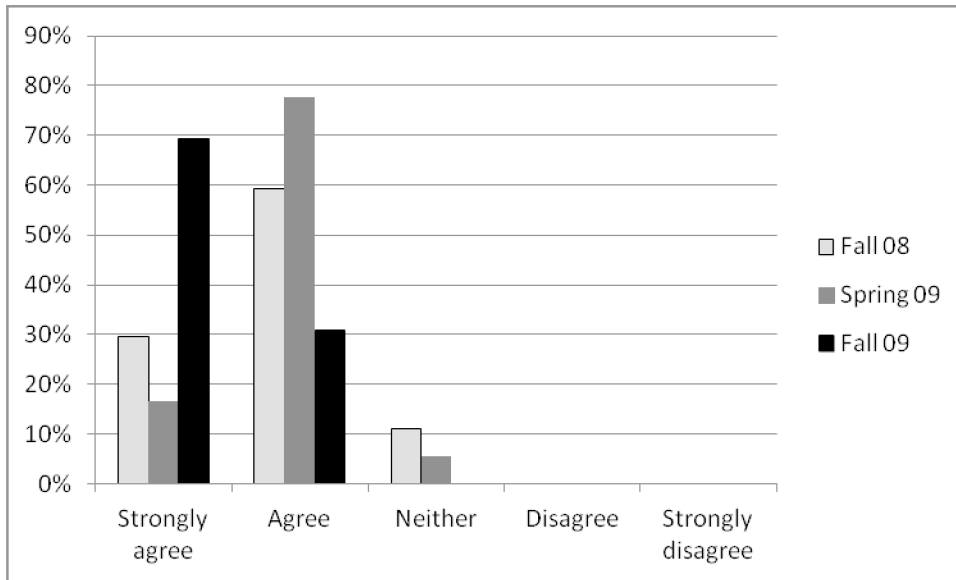


Figure 1: Responses to "This course has increased my interest in Civil Engineering"

Next, students were asked to rate the statement "I have learned something about Civil Engineering as a result of this course." Figure 2 shows the findings. Similar to Figure 1, the grey shaded bars indicate responses from semesters before the curriculum change and the black bars indicate responses from the semester after the change to industry-sponsored projects. The responses to this question also suggest a shift towards students acknowledging their learning as valuable and significant.

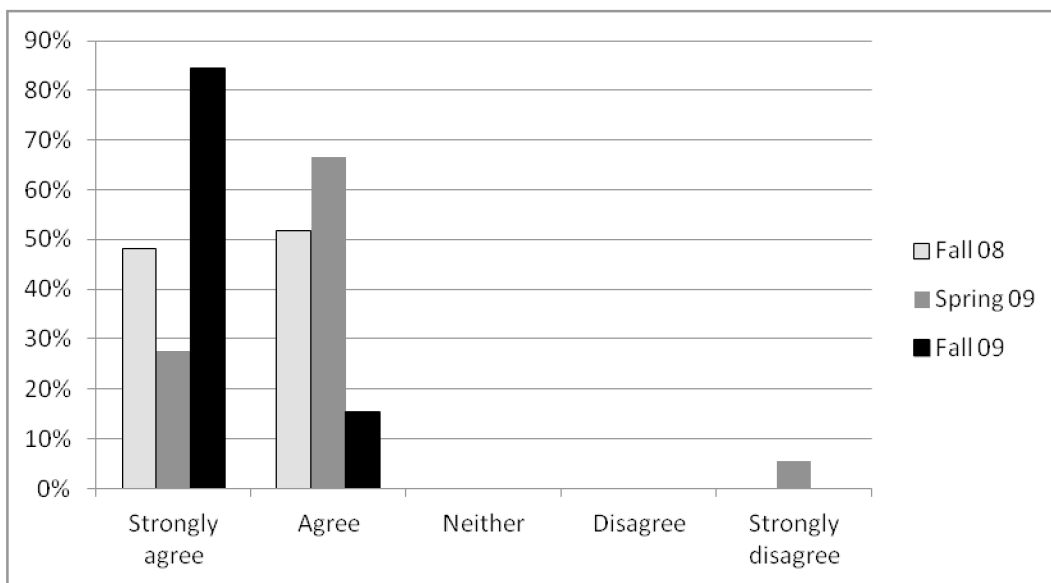


Figure 2: Response to "I have learned something about Civil Engineering as a result of this course"

Figure 3 displays the responses to the statement “I improved my abilities to identify and address problems using civil engineering techniques,” where the bar colors are the same as the previous two figures. Again, the responses indicate a shift towards students strongly agreeing.

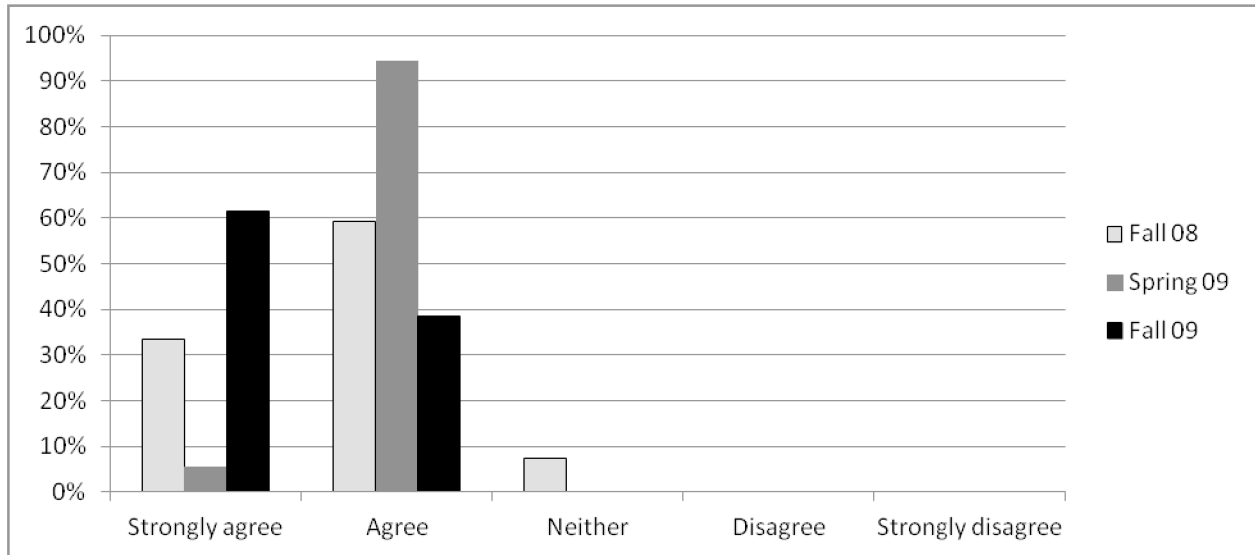


Figure 3: Response to "I improved my abilities to identify and address problems using civil engineering techniques"

Because strong communication skills are important in the engineering profession, fostering written and verbal communication skills has always been a key component in CE 493. Aside from the mock client meetings, little was changed in the instructor-led portions of the course between the new and old formats. Surprisingly, the survey responses indicate a significant shift towards students reporting improvement in their communication (Figure 4). In addition, the faculty and members of the Department’s external advisory panel noticed an improvement in the final presentations of the students over previous students.

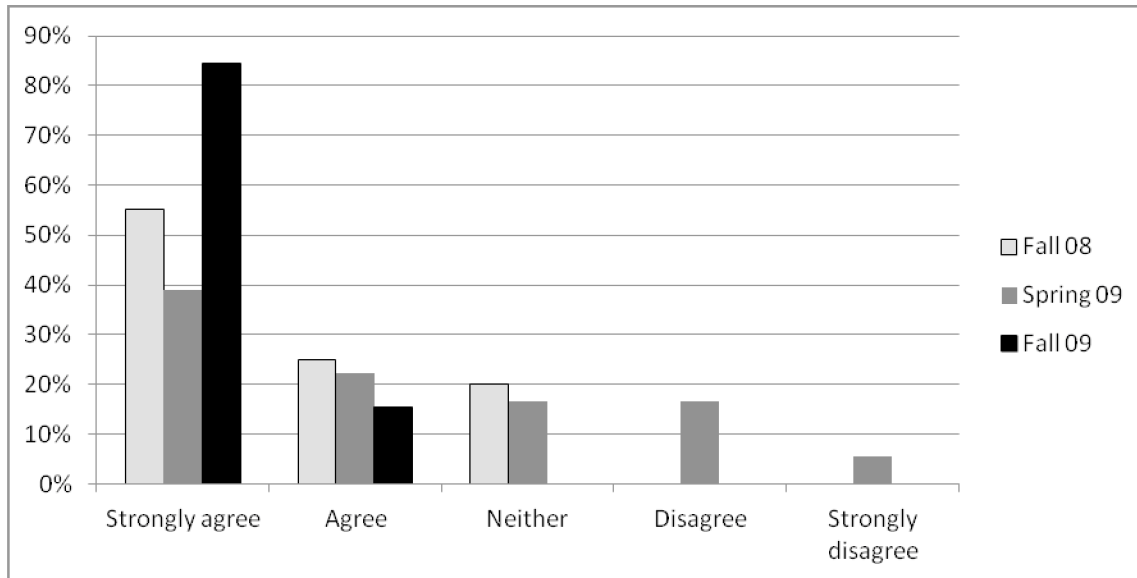


Figure 4: Response to "I improved my written and oral communication skills as a result of this course

Other portions of the survey included questions such as “I am more aware of ways that civil engineering relates to other fields and ‘real life’ as a result of this course,” “The course broadened my perspectives on intellectual, social, and /or ethical issues,” and “I improved my independent and objective reasoning skills as a result of this course.” The responses similarly shifted to higher ratings, with 100% of after students agreeing and strongly agreeing while from 10 to 39% of before students chose neutral or disagree. None of the responses differed significantly before and after the course format change for two survey questions – “Overall, this course has been effective at making me a better civil engineer” and “I now have a more clear idea of the roles civil engineers play in the public and private sectors.” However, afterwards all students chose agree or strongly agree while previously from 5 to 17% of students chose neutral. The lack of significant change for the former question indicates that students have consistently found value in their capstone design experience. A question incorporating a scale indicating degree of betterment may have shown a shift in attitudes. The lack of significant change for the latter question is likely a result of the faculty’s historic effort to incorporate practical design aspects and professional expectations in the course.

Employer Survey

The industry partners during CE 493 played a significant part in the success of the program and their feedback was solicited at the end of the semester via a survey form. The survey polled respondents on the effectiveness of the course format, the performance of the students, and the skills they would like to see from new hires. Figure 5 shows the findings about the course format. The organization and schedule were highly rated by respondents, likely due to careful project selection and clear communication between faculty and the industry partners. Although

several smaller engineering firms were initially concerned with the workload required to host students, the findings of the survey rate the workload as manageable. The last column in Figure 5 indicates that respondents were undecided whether the program was mutually beneficial to employers. Those respondents rating the workload the highest or rating the program not beneficial to their company commented that they considered participation as a way to give back to the Department and were not concerned if the program was not always mutually beneficial to their company.

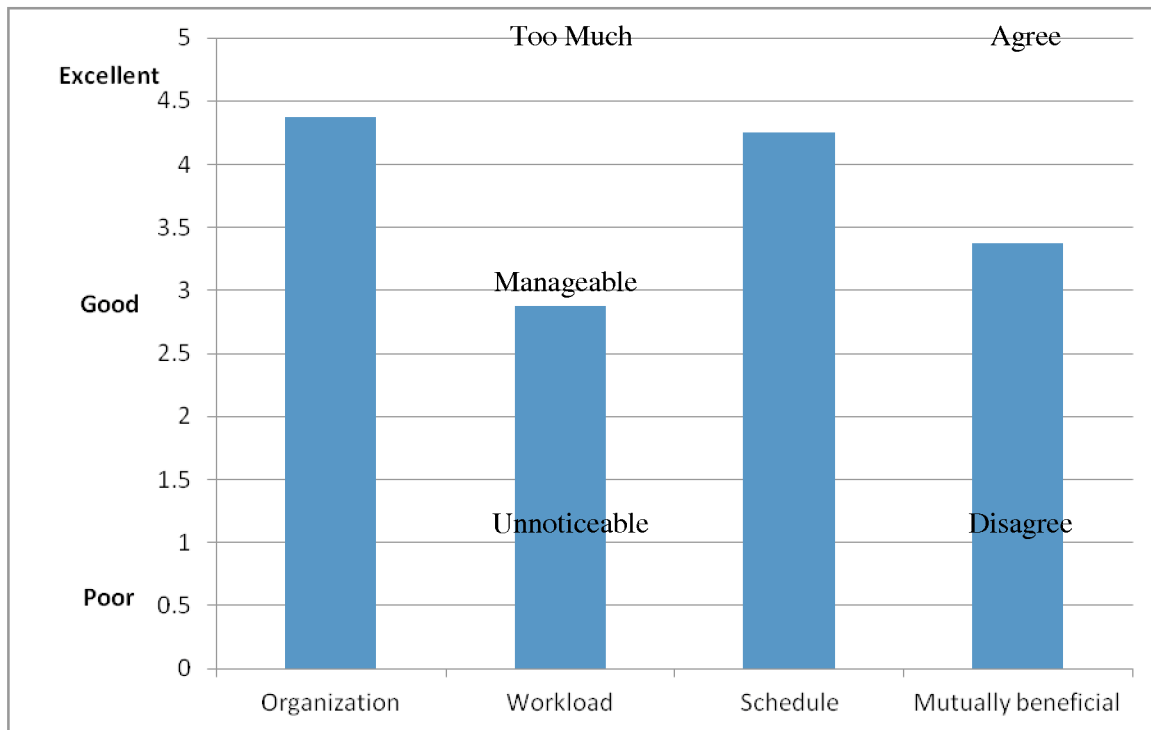


Figure 5: Industry Feedback on Course Format

Industry partners were also asked to rate the students’ performance throughout the semester. Figure 6 shows the findings, illustrating that students performed professionally and were assigned appropriately to host companies. Students were also rated well on their work ethic and preparation but rated lower on their ability to arrive on time. Although the instructor stressed the importance of arriving on time and thoroughly preparing for meetings in addition to acting professionally in office settings, feedback indicates that these topics require emphasis throughout the semester to achieve higher ratings.

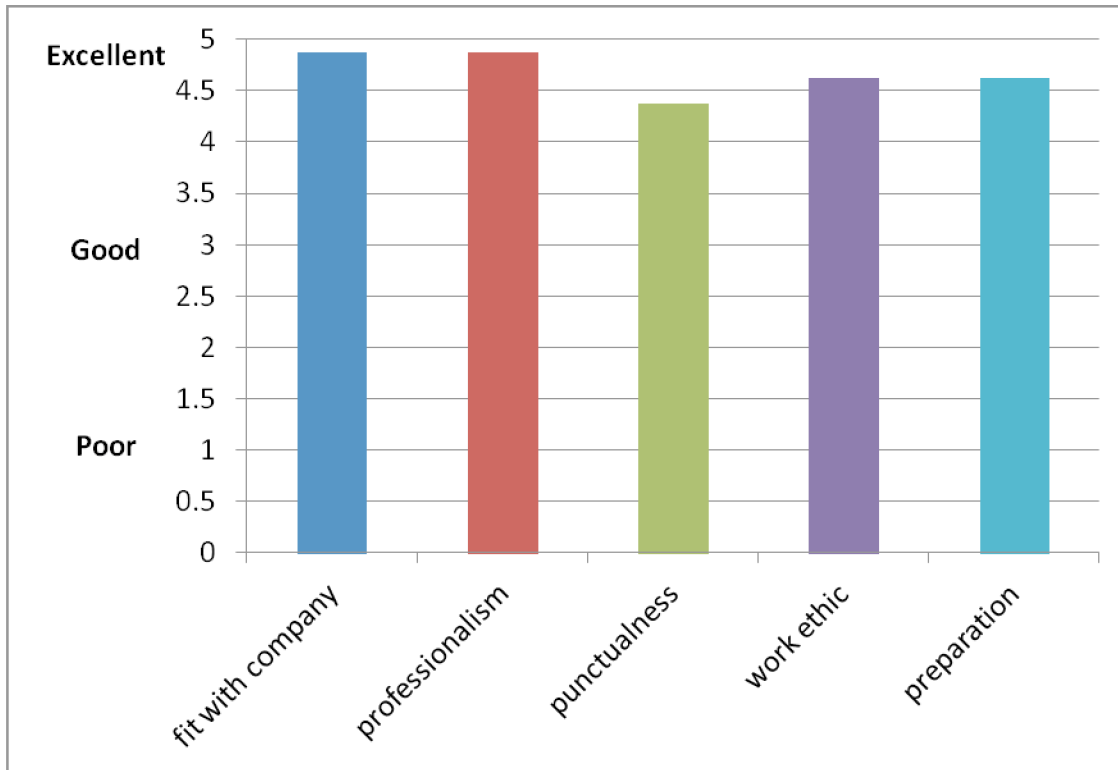


Figure 6: Industry Feedback on Student Performance

Next, the industry partners were asked for suggestions for improving the internship program. The feedback was very positive and the only change recommended was to provide feedback about how well each company is mentoring students. In particular, some industry partners seek more information on managing the new generation of students now graduating from universities.

The last section of the industry partner survey focused on the value of specific skills for entry-level engineers. This portion of the survey was motivated by previous work¹³, and the findings are presented in Figure 7. Overall, employers considered the ability to solve problems and show up on time to be the two most valuable qualities of new engineers. Further analysis of skills rated less than 3.5 revealed that those skills were discipline specific. For example, only civil engineers in the structural discipline were concerned with calculus competency of their entry-level employees.

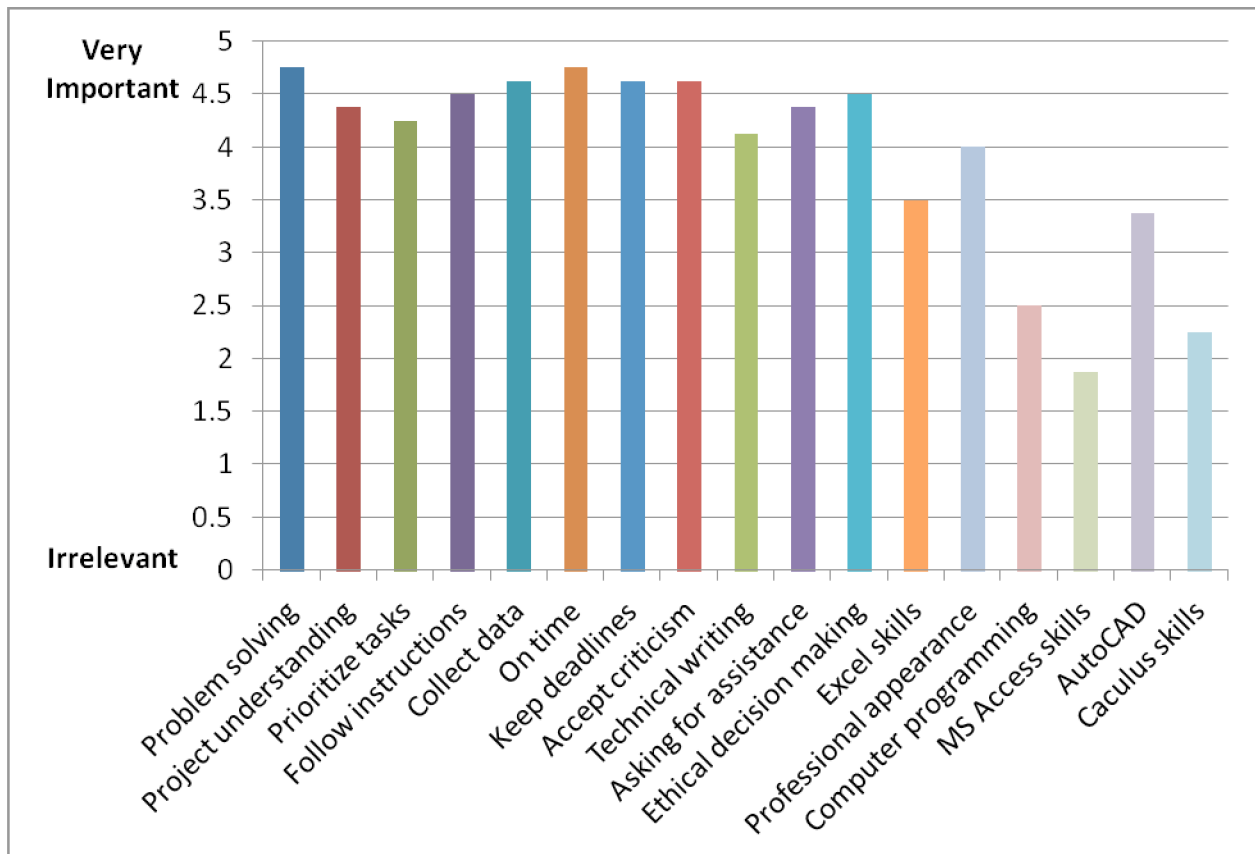


Figure 7: Industry feedback on important job skills

Lessons Learned

The primary successes of this senior design course format were student motivation and learning speed. Compared to previous semesters, qualitative observations indicated that the students’ motivation towards projects had significantly increased. Further, the students seemed to absorb knowledge at an accelerated rate.

Two key challenges with the course included student professionalism and value of sustainability. Although rare, some industry partners noted that students did not always recognize professionalism. For example, a student wrote to his supervising engineer as if it were a text message to a friend, neglecting all capitalization and punctuation. Second, due to the variety of projects students complete, it is more difficult to ensure that students consider sustainable solutions rather than simply conventional solutions. These challenges have guided the instructor to increase emphasis on professionalism in the course and to consider sustainability prior to selecting projects for subsequent semesters.

Conclusions

While the sample sizes are small, including industry sponsored projects into the civil engineering senior design course at Southern Illinois University Edwardsville appears to provide significant value to graduating seniors and local industry. Students reported increases in their interest in

their discipline, learning within civil engineering, communication skills, and ability to solve problems. The faculty and members of the Department's external advisory panel also noticed an improvement in oral communication skills during the students' final presentations. Because the industry participants reported that problem-solving ability was among the top qualities they seek in new hires, using industry sponsored projects provides clear value to students. In addition, in a tight job market, the internship provided the students with valuable work experience.

Industry participants evaluating the program provided positive feedback on the course's organization, indicating that the project guidelines were adequate. Selecting appropriate and similarly challenging projects in terms of scope and discipline and assigning students proved challenging yet manageable. For the initial term, these tasks were made easier by the small class size (13 students) and the interest in participating by members of the Department's external advisory panel. While the partner companies suggested receiving more feedback on their performance in mentoring students, such measures are easily implemented, likely by an exit interview held by the employer.

The faculty workload was not significantly different under the new format. Given the variety of projects, there could be concern of a lack of faculty expertise to assist students. However, the industry partners provided the majority of the assistance that the students required.

Future research should continue this work by identifying the causes for the observed trends and reviewing trends in ABET outcomes in this course and other senior-level courses typically taken at the same time. In addition, more data is required regarding which job skills are viewed as most important (Figure 7) so the results can be stratified by sub-discipline.

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