Challenges and Rewards on On-Campus Projects in Capstone Design

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Abstract
This paper discusses the Environmental Engineering capstone design course for Civil and Environmental Engineering undergraduates at the University of Colorado. Over the past four years, the course has successfully introduced a variety of service learning projects as options among the three to four projects available each year. Clients for these projects have included the University of Colorado and various communities. The structure for the course is briefly described, followed by a description of student feedback on their learning experiences and mentor satisfaction. The benefits and drawbacks of working on projects for the University are described and contrasted with projects for communities, industrial clients, and municipalities. Although each project provides a unique experience and perspective, the greatest benefit of University projects is the accessibility and frequency of contact between mentors and students. Although political and stakeholder buy-in may be difficult to achieve from all parties in order to implement student designs, the benefits of these projects make it worth pursuing future projects with the University.

Background
A significant design experience in the senior year caps off most undergraduate engineering curriculum. Per the Accreditation Board for Engineering and Technology (ABET) the requirements for design are: "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, … ethical, health and safety, social, and political."[1] Content related to a number of other ABET criteria for engineering curricula can also be incorporated within a capstone design course, including abilities to work on multi-disciplinary teams, communicate effectively, and engage in lifelong learning.

At the University of Colorado (CU), the course CVEN 4434 Environmental Engineering Design fulfills the capstone design requirement for students in two different ABET-accredited B.S. degrees: environmental engineering (EVEN) and Civil Engineering (CVEN). EVEN is a cross-departmental degree, incorporating chemical, civil, and mechanical engineering courses. Within CVEN, the course is required for students self-selected into a special water/environmental track and optional for other general CVEN students. Starting in 2003, the course was officially cross-listed as a 5000-level course and M.S. students, particularly those without a traditional engineering bachelor's degree, have begun to enroll in the course. The course is structured around group projects where a team of students tackles a single design project for an entire semester. The projects in this course have included traditional municipal water and wastewater problems, remediation projects for local clients, and service learning projects for various communities.

In the past two years projects serving the University of Colorado have been added. Campus-based projects have the potential to provide an ideal learning experience and provide a true service to the University. The various projects in the course appear to emphasize different aspects of the overall design process, and feedback from students in the course has been gathered to assess these differences. The content of this paper is based on the seven years that I have taught this course, with basic course data summarized in Table 1.

Table 1. Summary of the CU Environmental Engineering Design Course

Year Course Element	1998	1999	2000	2001	2002	2003	2004
Number of students in the class	28	20	11	10	18	25	15
*CVEN undergraduates**	*26*	*17*	*10*	*6*	*6*	*6.5*	*2.5*
*EVEN undergraduates**	*0*	*2*	*1*	*4*	*12*	*14.5*	*8.5*
Graduate students; other engrs	*2*	*1*	*0*	*0*	*0*	*4*	*4*
Number of different projects available	1	3	3	3	3	4	5**
Project clients: U = university; M = municipality; I = industrial; C = community	1 M	2 M 1 I	3 M	3 C	1 I 2 C	2 U 1 I 1 C	2 M 2 I ** U
Number of mentor surveys returned	NS	NS	NS	NS	2	5	4
Number of student surveys returned ***	1	6	5	7	8	10	14
Average FCQ course rating (scale 1-4)	2.18	3.41	3.09	4.00	3.83	3.48	NA

NS = not surveyed; NA = not available
* Students earning a dual BS degree in both EVEN and CVEN were counted as 0.5 toward each degree count; this includes 3 students in 2003 and 1 student in 2004.
** includes Biodiesel project that was worked on for only the first 2 weeks of the semester
*** Survey distributed in spring 2002 (1 survey returned from unknown year), January 2003, and December 2004.

Project Summary

Projects for the course have been selected based on contacts with local consulting engineers, professors, and non-profit organizations. These contacts have built up over the years. All projects now address current, real needs of a client. Early service learning projects were conducted in association with Engineers Without Borders (EWB). A key partner over the past 3 years is the non-profit International Center for Appropriate and Sustainable Technology (ICAST). Ravi Malhotra from this group has served as a facilitator for communication between the student design teams and project representatives. ICAST also works with other Universities and courses to serve the needs of communities both locally and abroad. ICAST makes contact with communities and determines where help from a student design team might be appropriate. In 2004 ICAST also helped assure commitment from partner groups by requiring that they pay to bring students to the site and pay any costs associated with analyses needed to support the design effort (such as analysis of water quality samples, etc.); costs are limited to $1000. Each of the projects over the past three years are listed in Table 2, including the basic engineering need, location, mentors, the total number of students that worked on the project, and the number of student post-course surveys returned. Mentors who were sent a written survey in December 2004 are underlined; those who returned evaluations are indicated in italics.

Table 2. Summary of 2002 to 2004 Projects

Project Client Project need, location	Project Mentors	# of students/ survey responses
Community		
Water/sanitation, Nicaragua	EWB professional, in-country volunteers (2)	7/2
Wastewater, Colorado	*Facilitator*, Community representatives (2)	4/1
Wastewater, New Mexico	*Facilitator*, Community rep, IHS rep	8/4
Industry		
Site Remediation 1, CO	*Consultant A*, Consultant B	7/5
Site Remediation 2, WY	*Consultant A*, Consultant B	9/3
Site Remediation 3, Canada	*Consultant C*	4/4
Power plant, CO	*Facilitator*, Operator	4/3
Municipality		
Water utility, California	*Consultant D*	3/3
Wastewater utility, CO	*Facilitator*, Operator	4/4
University of Colorado		
(Biodiesel)	Student leader	(3)
Solid waste composting	*CU staff A*, CU staff B	3/1
Solid waste processing	*CU staff A*, *CU staff C*	5/2

Course Structure

At the beginning of the semester, the students form into teams and select one of the three to five available projects. Teams are typically include three to four students. More than one team may work on the same project. Each project description is written in the form of a Request for Proposal (RFP) by the client and/or the course instructor. Team formation is critical to ensure that a diversity of skills are available. This is important since the EVEN and CVEN students have different course preparation prior to the capstone design course. A more complete description of the course elements is provided in a previous ASEE conference paper[2].

Students begin the semester by responding to the RFP. If possible, clients (typically representatives from local consulting firms, the University, and ICAST) are part of the audience when the students present their proposals. The students create a work plan to outline their anticipated tasks and time management throughout the semester. Given that many weeks go by between due dates for the deliverables, time management by the students is critical. Weekly timesheets are submitted by each student. Typically, individual meetings between each team and the instructor occur on a weekly basis to ensure that progress is being made. Meetings with other project mentors and clients vary considerably.

About two months into the semester, an Alternatives Assessment written report is submitted by each team. These are provided in a professional format that is distributed to clients for their feedback. Due to the busy nature of most consultants and plant operators, only minimal client feedback has typically been provided to the students on their Alternatives Assessment report. Over the last month of the semester, the students revise their alternatives assessment and conduct a more detailed preliminary design of the selected treatment/remediation approach. This includes more specific calculations, AutoCAD drawings, a refined cost estimate, and a discussion of implementation. Final presentations of the alternatives assessment and preliminary design are made to clients about one week before the final written report is due. This enables the students to get feedback on practical issues and address them in the final report. The final written submission is typically a 100-150 page report, including hand calculations in the appendices and supporting information. The students provide a copy of their final report to clients.

Outcome Evaluation Tools

A variety of methods have been used to evaluate the course itself and the benefits of different project types. Because FCQs and the departmental ABET survey are completely anonymous, differentiation between different project types is not possible; thus results from these evaluations are not included in this paper. The evaluation tools allow the students to reflect on their experience and provide feedback. Additional evaluations were completed by project mentors. Each evaluation method used to draw conclusions about the course is briefly described below.

Service Learning Papers. For the first time in Fall 2004, students were asked to reflect on their service learning experience in a full class discussion (2 hours) followed by 3 to 8 page written essays. Based on numerous references on educational pedagogy[3,4], this reflective component is essential to achieving real learning from the service experience. The students were asked to identify all of the various groups and stakeholders involved with their project and how each group might benefit from the project. They were asked to identify a particular experience or set of events surrounding their project that were non-technical in nature which they found particularly challenging, and discuss whether these issues would be likely to be encountered in similar settings or unique to this particular community/problem. The students also discussed the level to which non-technical aspects influenced their selected technical/engineering solution.

Exit Interviews. At the end of the semester after all of the deliverables have been submitted, the professor holds 15-30 minute individual interviews with each student. These have been conducted all seven years of the course, following the method of the previous instructor, Professor JoAnn Silverstein. The questions require students to reflect on their individual learning experience and what they felt was most beneficial to them. It also helps the professor determine what worked and didn't work, and to develop strategies to improve the learning experience in future semesters. However, since the interview isn't anonymous and grades are generally not yet completed, some students may be less than honest if they have negative feelings or comments.

Graduating Student Surveys. Students graduating with an EVEN degree are asked to complete an Exit Survey. It asks them to reflect on their entire B.S. degree experience. Completing the survey is optional. Although the survey contains no questions specifically related to the capstone design course, feedback on various questions may shed some light on the broader impact of the course within the curriculum as a whole. Given the timing of when students take CVEN 4434 relative to graduation, surveys from the Fall 2003 design class were gathered. This included 9 surveys from a potential pool of 16.

Student Surveys. A survey was developed to evaluate potential differences in self-reported learning due to different project types. Two versions of the survey have been used. The first survey included 21 questions and was created to evaluate the benefits of projects serving developing communities[2]. The survey was distributed in January 2002 by email to all of the students who took the class from 1998 to 2001; response rates from the earliest years were predictably low given that many of the email addresses were incorrect and general interest may have been low. In January 2003 the same survey was sent to the Fall 2002 students. The second survey distributed in December 2004 contained additional questions on the level of mentor involvement with the students, service learning, and projects with the University of Colorado (a total of 31 questions). This survey was emailed to the Fall 2003 students and given out in-class to the Fall 2004 students. The advantages of surveying students a longer period of time after they have taken the class is the retrospective they have and a real appreciation for what was most beneficial as they are starting their careers as practicing engineers. However, the response rate from these former students is generally much lower. To avoid double counting feedback from a single individual since the surveys may be returned anonymously, groups that were previously surveyed (2002 and prior) were not re-contacted to fill out the second survey.

Mentor Evaluations. In December 2004, a 25 question survey was sent to individuals that were significantly responsible for mentoring student design projects in Fall 2002 through 2004. The goal was to evaluate the motivation, satisfaction, and level of involvement of the project mentors. In some cases, a single project had more than a single involved mentor (as discussed previously in Table 2). In addition, a single individual sometimes mentored more than a single project. Responses were received from six of nine mentors (as of January 3, 2005), representing 10 of the 12 design projects over the past three years.

Professor Impressions. I have developed impressions from teaching the course over the past 7 years that are not adequately captured in the various formal surveys that have been distributed. These impressions are based on informal discussions with current students, former students, mentors, and other faculty. I have included these ideas where relevant in the results section.

Results: Mentor Motivation and Satisfaction

There were notable differences in the motivation of the mentors. Because the surveys were returned by the key person(s) sponsoring and serving as a client for each project, these differences are important. Results are summarized in Table 3 below. The main motivation for the University representatives was to use the outcome from the student work. For the consultants and the facilitator, enhancing student learning was the highest motivation. The expectation of the greatest real "service" to the clients was held by the University and the lowest by the consultants. The outcomes of the student work were also the most useful to the University.

Table 3. Average mentor response on scale of 1 [low, disagree] to 5 [high, agree]

Question:	University (2 people, 2 projects)	Consultant (3 people, 3 projects)	Facilitator (1 person, 4 projects)
I sponsored a student project primarily to help:			
beneficially use the outcomes from the student work	5	3	4
enhance student learning	3	4.3	5

identify good employees in the future	2	3	1
The outcomes from the student work were useful	4.7	3.7	3.25
I believe that the time I invested in helping the students and working with the project was well spent	4.7	4.3	5
My expectations for the outcomes from the student project were met.	4.3	4	4.25

Results: Interactions between Mentors and Students

A clear advantage of the University projects was the frequency of contact between the project mentors and the students (shown below in Table 4). Each project has the opportunity for mentor/student meetings and contact as frequently as desired or arranged by either party. The most frequent contact by all communication modes combined was reported by the University mentors (representing 2 projects), followed by the consultants (representing 4 projects), and the least by the non-profit facilitator (representing 4 different projects). Given the easy proximity to the University mentors, since students can simply walk across campus, it is not surprising that a large margin of difference existed for the in-person meetings. The fact that phone conversations and email did not close this gap could be due to the comfort level that is fostered by in-person meetings. There was a wide disparity between mentors – total contacts by all modes with the consultant mentors ranged from 6 to 27 over the semester.

The contact frequency reported by the mentors and students differed somewhat. Students reported their frequency of contact with any project mentor (excluding the course instructor), and as such this may have included more than one person. For example, two separate University mentors interacted with students from one project, thus making total contact time with both mentors combined (based on the mentor surveys) of 13 emails, 12 phone conversations, and 16 in-person meetings over the semester. Also, each team typically designated a single student to be the main point-of-contact with the project mentors. Therefore, one student per team may have had significantly more interaction with the mentors. Furthermore, the number of students included in the average varies based on the project type (3, 9, and 11 students for University, Consultant, and Facilitator, respectively). Overall, there was agreement with the mentor surveys that the most contact from all modes combined was with the University projects followed by the consultants, then the facilitator. The total time invested as reported by the mentors was the highest from the facilitator (40 hrs/semester), versus a similar time commitment by the University employees and the consulting engineers (17-20 hrs/semester).

Table 4. Frequency of Student/Mentor Interactions

Mentor	Frequency of contact between students and mentors, # of times/semester					
	Average Mentor Reported per project			Average Student Reported		
	Email	Phone	In-Person	Email	Phone	In-Person
University	5	2.5	8	13	3.3	6.7
Consultant	7	3.3	2.7	6.9	3.5	4.2
Facilitator	5	1.5	2.5	5.4	1.0	1.7

* Using 112 days/semester

From discussions with the both the students and mentors, more frequent contact is a key to providing both parties with a successful project. From the student perspective, there is a greater sense that the clients really care about the outcome of the student work when they interact more frequently. Students also have a better sense of direction and less frustration with uncertainties.

During exit interviews with the 25 students in Fall 2003, 18 mentioned something pertaining to client interaction. Nine students indicated that more contact with the client would have been helpful. Seven students noted positive interactions with the client and good motivation. Four students indicated that the level of client involvement was sufficient. It is interesting that of the students working on projects for the University, half noted that more interaction with their mentors/clients would have been helpful, versus only 29% of the students that worked on the other projects. Given that the students working on the University projects already had the most frequent client contact, it appears that the students realized how helpful it was and therefore desired even more. In contrast, the students working without significant client interaction got by without it and perhaps did not realize what they were missing.

From the mentor perspective, they have a greater likelihood of receiving a final project that meets their needs when they are able to communicate with the students more frequently. One consultant noted: "If I did this again, I would want to schedule some time to meet with the students after they had received... the RFP... but BEFORE they wrote up their proposal. ...perhaps it might be best to get the mentors to commit to four "mandatory" meetings.... There was nothing precluding our group from arranging these, but it's too easy to default to e-mail rather than getting together." Another mentor noted: "My observation has been that students are sending an email and waiting for a reply – which is sometimes not sufficient to get the desired response – phone calls and follow-ups are necessary."

Results: Other Advantages of University Projects

A number of leaders at CU recognize the limitations of a course experience in providing a complete design over a single semester. The University projects may also have greater appeal to students with majors outside of engineering, including environmental studies and business, providing a true multi-disciplinary experience. Among 4 of the 6 mentors responding to the survey, there was an average response of 4.9 (on a scale of 1 to 5, highest agreement) to the statement "I feel that the team might have been strengthened if non-engineering students with skills in planning, economics, environmental policy, etc. were included." The two dissenters were consulting engineers who scored this statement as a 2. In contrast, the average of all 52 student responses (on a scale of 1 to 5, highest agreement) was only 2.9, and from the 3 students who worked on University projects this score was even lower at 1.7.

The close proximity of students to the project location is an advantage of University projects. Other projects may also be located close enough to allow a site visit, such as the remediation, municipal, and community projects in Colorado. On the question "I think that the ability to tour existing facilities and the locally relevant area would be a significant advantage over projects where this is not possible", the average mentor rating was 4.2 (on a scale of 1 to 5, strongly agree) and the average student rating was 2.65 (on a scale of 1 disagree to 3 strongly agree; only 3 students of 49 respondents disagreed with this statement).

Two other questions were targeted specifically to University projects on the second version of the course survey. Of 24 respondents, 10 strongly agreed/agreed with the statement "I think that an advantage of a project with CU would be a familiarity with local stakeholders"; 12 strongly agreed/agreed with the statement "I think that an advantage of a project with CU would be a possibility to really benefit the University."

Results: Drawbacks of University Projects

After the highly successful experiences in 2003 working with the University on two design projects, I looked forward to the Biodiesel project in 2004. However, early difficulties frustrated the three students working on the project and led us to disband the group. The key difficulty may have been the impetus for the project. It is important to have the proper stakeholders at the University engaged before the project begins. In this case, a student-run organization, CU Biodiesel, wanted the students to design an on-campus system to process waste oil from dormitory and on-campus food services into Biodiesel fuel to run University buses. However, facility siting is the purview of the Boulder Campus Planning Commission. In addition, the Fire Marshall had significant concerns. In a meeting with the student team he communicated an attitude that the students could not complete a project of sufficient quality for real implementation and that he did not want to waste his time meeting with the students for a project that was merely a learning exercise. In meetings with other University stakeholders over the first few weeks of the semester, the students were met with similar negativity which was discouraging. As a result, of the three students on the team, one dropped the course and the other two students joined the other project teams. One student still commented on this experience in her service learning paper, noting: "Originally I thought the most challenging aspect of the project would be designing the facility, but this was not the case. It became clear to me that the major challenge in designing a biodiesel facility for the university would lie in the bureaucracy of the project... [and working with] several different group with conflicting interests."

Similar difficulty getting buy-in from all parties was also encountered by students in Fall 2003. One team was investigating a site location and design of an intermediate processing facility (IPF) for recyclables on campus. In their effort to survey various stakeholders, one official from the Planning, Design & Construction unit on campus responded "I worry that working outside the established framework of basic campus planning principles will produce inaccurate and unusable results." He refused to participate in the survey, even as he noted that "extensive discussions with users and other campus stakeholders" were needed, and this was precisely what the students were trying to achieve with the survey as a first step. The students found this feedback very discouraging. However, the strong support of two campus mentors for each of the CU projects still led to successful projects. Although the projects (food waste composting and IPF relocation) have yet to be implemented, the mentors felt the efforts were worthwhile. Some of the student work was presented at campus-level Environmental Round-Table meetings.

On the 11 survey questions pertaining to the benefits and significance of the course, the average of the three responses from the students who worked on the University projects were significantly lower than the 48 students working on non-CU projects for three questions: "the course improved my communication skills", "the course inspired me to learn more on my own potentially including graduate school", and "I feel that my team might have been strengthened if non-engineering students were included" (based on a t-test differences are significant at 87, 95, and 80% confidence, respectively).

Results: Service Learning Projects

The goals of working on service learning projects are two-fold. First, the students will receive a very complete learning experience by working on a project with a true client and stakeholder involvement. Second, the outcome from the students will provide a real service. The students each typically devote around 150 hours per semester on their project, and having a real value to this work is both motivational to the students and can benefit clients. However, given the single semester duration of the course it is difficult to conduct an entire project to the point that it can be implemented. In addition, politics and other constraints often dictate the ultimate fate of a project. The slow nature of University politics and committees make it difficult to fit a complete experience within a single semester; but this difficulty is common to most Civil/Environmental Engineering projects. For example, students worked with a local Colorado community where residents were each on individual sewage disposal systems (septic tanks and leach fields); their goal was to find an alternative for better wastewater management. The county health department was the real driver for the project, while many residents in the community were unconvinced that their wastewater was contaminating local groundwater and surface water. The community voted in November of the year following the student project whether to support a centralized wastewater treatment plant; it lost by one vote. The following year, the community voted to support a plan. This project went through two different full engineering studies and designs by paid engineering consultants over a 4 year period prior to receiving this approval. Therefore, it is not uncommon that long periods of time may be needed to build community consensus around a project.

Mentors and students both rated their opinion on the inclusion of service learning projects in the design course; results are shown in Table 5. The mentors exhibited strong agreement that service learning projects are appropriate for the class. The two students who felt that service learning projects are not appropriate worked on a project for an industrial client and municipal project with a local consultant in 2004.

Table 5. Survey responses on service learning projects

Survey Question	Rating	# of responses	
		Mentors	Students
I think that service learning projects are appropriate to include in the class.	Strongly agree/agree - 5	5	19
	neutral/no response	1	3
	Disagree - 1	0	2
I think that service learning projects are not appropriate for this class	Strongly agree/agree - 5	0	2
	neutral/no response	2	4
	Disagree - 1	4	18

Results: Final Overall Comments

On 8 of 11 questions pertaining to the course, the average positive response (on a scale of 1 to 5) was higher from CVEN students than EVEN students. These differences were most significant for “my satisfaction level with my design experience in the course” and “my ability to function on teams was improved/valuable in the course”. This may be due to curriculum differences in the majors that result in broader preparation for CVEN students in important topics (AutoCAD, economics) versus more teamwork already built-in to the EVEN curriculum.

From the graduating senior surveys administered to EVEN students, 4 of the 9 respondents worked on projects serving the University of Colorado. For the "skills of an environmental engineer" students rated their ability to "design pollution control or treatment systems or environmental monitoring or remediation plans" as 3.3 vs 3.8 (on a scale of 1 to 5 = very high ability) for students who worked on CU vs non-CU projects. For their program experience, students rated their design experience ability as 3.5 vs 4.4 for students who worked on CU vs non-CU projects. This may be somewhat due to the nature of the specific projects. Based on exit interviews, the University projects were viewed by students as somewhat less technical in nature. In addition, 3 of the 9 students (but none who worked on the University projects) listed the design course under "What was the best course you took? Why?"

Conclusions

Using real projects in the design class provides a valuable opportunity for the students to see the importance of both technical and non-technical aspects to project success. Universities are like small cities, and offer a variety of potential projects for civil and environmental engineering. Although politics and conflicting goals may exist between various entities on campus, this is also true of most other engineering design problems. The University setting may simply provide the best place for students to learn about and appreciate these different perspectives. The proximity to sites and relevant stakeholders is a significant advantage of working on a project with the University. Although challenges exist in fully implementing student designs from a one-semester course, I certainly plan to work with the University on design projects in the future.

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