2007: ENVIRONMENTAL ENGINEERING SERVICE LEARNING PROJECTS FOR DEVELOPING COMMUNITIES

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Environmental Engineering Service Learning Projects for Developing Communities

Abstract

The senior-level Environmental Engineering Design course has evolved since 1998 to include service learning projects. These projects have been conducted for the University, in association with a local non-profit group (iCAST), in association with Engineers Without Borders (EWB), and through other contacts. Students enrolled in the course are earning a Bachelor's degree in Environmental or Civil Engineering, or a Master's degree in the environmental emphasis of Civil Engineering. An evaluation survey was first developed in 2002 and has since evolved. It currently includes 27 questions that students respond to on a Likert scale from 1 to 5, mostly focused on the abilities that the course imparts relative to the ABET A to K criteria and the four additional learning outcomes from the American Society of Civil Engineers' Body of Knowledge. There are also questions related to the students' perceived differences in various project types. In Fall 2006 this survey was administered for the first time in the Civil Engineering capstone projects course, where students worked on a single non-service learning project. In Fall 2006, the students in the Environmental Design course with service learning projects reported significantly greater improvements in abilities to design based on economic, environmental, social, sustainability, and health and safety constraints; oral communication skills; and the awareness of engineering impacts in a global and societal context, compared to the Civil Engineering course. All respondents in the Environmental design course agreed that "service learning projects are appropriate to include" in the design course; by comparison, only half the students in the Civil engineering design course agreed. The broader benefits of service learning projects are also evidenced in student essays on their design experience. Thus it is concluded that service learning projects provide more emphasis on non-technical aspects of importance in engineering design and a richer learning experience than projects based on real world needs that are executed solely for the educational benefit of the students.

Motivation for Design Courses

Designing solutions to the needs and problems of society is an activity that sets engineers apart from other professions. It requires that an engineer creatively bring to bear technical expertise in mathematics and sciences, under the constraints of regulations, safety, and public approval. Most engineering programs culminate the undergraduate degree experience by a so-called "capstone" design course. The students are required to combine their previous educational and real world experiences in a team setting to solve an engineering problem. The design experience can capture the complexity of real world challenges and prepare the students to enter the workforce with a more realistic concept of expectations.

A variety of different types of projects can be used in capstone courses. They can be based on a high-tech innovative need, almost along the lines of a research project. They can be based on a real-world problem. In these cases, the professor can usually manage uncertainly and project scope to a greater extent. However, in these cases the results of the student work are generally the learning that the students gain – rather than a real world impact. Service learning projects in

a design course offers trade-offs. In some cases the problem may be less technically challenging, but it is often more difficult in terms of real world economic, political, and social complexity. It is more difficult to control the experience and ensure that the data and timing of the activities fall nicely within a one- or two-semester format. However, the potential that the student work will be used by the community in a real way helps justify the frustrations and work load for both the students and project mentors.

Environmental Design Course Description

CVEN 4434 Environmental Engineering Design (EvEng Dsn) has recently incorporated service learning projects. The course is multi-disciplinary, serving students earning a Bachelor's degree in Environmental Engineering (EVEN) or Civil Engineering (CVEN; for students concentrating in environment or water), and Master's degree students in Civil Engineering focusing on environmental engineering and the Developing Communities track. For students earning dual B.S. degrees in EVEN and CVEN, the course counts as the capstone for both majors. For students earning dual B.S. degrees in EVEN and Chemical Engineering (CHEN), the students take EvEng Dsn and the 2-credit capstone in CHEN to fulfill both degree requirements. The course is 1 semester long and is offered only in Fall term. Therefore, some students take the course in the final semester of their B.S. degree while others have another semester or two of coursework remaining.

On the first day of class, students are presented with an overview of each available project (typically 3 to 5 available), and asked to form groups based on projects they are interested in and the skills of the group members. Team composition is important due to differences in the previous coursework of the students. Groups have ranged in size from 3 to 8, but 4 appears to be optimal. In some semesters, more than one team will work on the same project. The total number of students in the class has varied from 10 to 28. The course is run like a consultant-based project for the duration of the semester, where the primary activities in the course include: filling out weekly timesheets; a written and oral proposal in response to the Request for Proposals (RFP) prepared by the client and/or instructor; a written workplan; a written Alternatives Assessment draft (provided to the clients and instructor); and the final written and oral presentation of the Alternatives Assessment and Preliminary Design. Some clients have indicated that the final written reports prepared by the students are of similar quality to that prepared by consultants. In 2004 and 2006, students wrote reflective essays on the service-learning and/or real world aspects of the course. These essays provide good insight into student attitudes about the experience.

A summary of the project types conducted over the years that I have mentored the course are provided in Table 1. Types of projects in the class have included:
- Real current or past projects of environmental consultants. The consultants mentor the project and supply data for the project; the students' output is not intended to be directly used. These projects have included remediation projects for industrial site clean-up and wastewater or drinking water treatment plant upgrades for local municipalities.
- Real projects being considered or done in the past for local municipalities for water or wastewater treatment. These projects are mentored directly by the treatment facility employees

- Service learning projects for the University of Colorado – Boulder. Employees from the University mentored the projects and hoped to use the student results to move projects or potential projects forward.
- Service learning projects conducted in association with international Engineers Without Borders (EWB) projects. Most of these projects have been water/sanitation related.
- Service learning projects conducted in association with a local non-profit facilitating group (iCAST) for businesses and communities interested in sustainability. The community may or may not eventually implement the student recommendations. These projects have been within the state or neighboring states. These projects have included drinking water, wastewater, fly ash reuse, biodiesel waste processing, and dairy waste minimization and treatment. The students may or may not have direct contact with the project clients.
- Service learning projects organized through other avenues for communities or businesses. This includes the Fall 2006 project to design a wastewater treatment system for an impoverished community in Mexico.

Table 1. Summary of project types conducted in different years of the Environmental Engineering Design Course with the number of projects / number of students participating shown

Year	Consultant -mentored		Municipal W/WW	Service Learning						other
				CU	EWB		iCAST		direct	
	mun	Remed			w/ww	other	mun	other		
'99-'00			5/22							1/8
'01-'04	1/3	3/20		2/8	2/10	1/3	3/16	1/4	1/4	
2006								2/9	1/12	

* note: 2005 is not included because the author was on sabbatical

Course Evaluations

An evaluation survey was first developed in Spring 2002 and emailed to former EvEng Dsn students. The response rate to the initial survey from the 1998 and 1999 students was very low, in part due to the lack of contact information for all of those students. In subsequent years, the survey has been modified. It currently includes 27 questions that students respond to on a Likert scale from 1 to 5, mostly focused on the abilities that the course imparts relative to the ABET A to K criteria and the four additional learning outcomes from the American Society of Civil Engineers Body of Knowledge (BOK). There are also questions related to the students' perceived differences in various project types, including support or not for participating in service learning projects for developing communities. In recent years the survey has been administered to students in the final week of the class; this has raised participation. The surveys are voluntary and returned anonymously. The survey was not given in Fall 2005 because the normal course instructor was on sabbatical. In Fall 2006 the survey was administered for the first time in the Civil Engineering capstone (CvEP). Additional surveys have also been given to project clients/mentors and administered for the purpose of contrast with freshman students.

Civil Engineering Course

To contrast the experiences of students working on service learning projects with other types of capstone projects, students in the Fall 2006 Civil Engineering Projects (CvEP) course were asked

to complete the same evaluation survey given to the Environmental Design students. This course is a single semester, 4-credit course and was first developed in Spring 2006. The 23 students in the course were all Civil Engineering students graduating in December 2006. They worked on a single non-service-learning project. The course has a single faculty member who organizes the experience, with contributing faculty from the other sub-discipline areas in CVEN to mentor students. The faculty coordinator receives full teaching credit (3-credits) for the course, while the affiliated faculty members each receive 1-credit toward their teaching load. In addition, there are industry mentors identified in each of the major CVEN sub-discipline areas (structures, geotechnical, water, construction) that assist the students. The project in the fall semester 2006 was to design a new building that is already being constructed on campus.

Student Demographics

Demographics in the two courses are summarized in Table 2. The overall size of the CvEP and EvEng Dsn courses in 2006 was similar, although at some points in the past the EvEng Dsn course has been much smaller. The percent females in the CvEP course was 22%, lower than the 28 to 78% females in a single semester of the EvEng course. The percentage of minority students in the CvEP class (22%) was higher than the range in the EvEng course (5-16%). The versions of the survey through 2004 did not ask that students provide their gender and ethnicity. A total of 54 EvEng and 16 CvEP surveys were returned representing a 58% response rate.

Table 2. Demographics of Students in Senior Design Courses and those who returned the Survey

Course	**Semesters**	**Student Major**	**Total # in course / # Returned Evaluation Surveys**				
			Students	**Female**	**Male**	**Minority**	**Grads**
EvEng Dsn	1999 to 2004	EVEN* CVEN	40 / 24 47+*9* / 21+*9*	21.5 19.5+*4*	18.5 27.5	5 3+*2*	0 9 / 9
EvEng Dsn	Fall 2006	EVEN* CVEN	10 / 9 6+*5* / 6+*3*	3 / 3 1+*4* /1+*2*	7 / 6 5+*1* /5+*1*	2 / 2 2+0 / 2+*0*	0 / 0 5 / 3
CvEP	Fall 2006	CVEN	23 / 16	5 / 4	18 / 11	5 / 5	0 / 0

* If EVEN students were dual majoring with CVEN, students were counted half in each major. If EVEN students were dual majoring with CHEN, the students were fully counted as EVEN.
+ Graduate students in the environmental emphasis of Civil Engineering are counted as CVEN
** Demographic information not provided by one CVEN survey respondent

Results based on Service Learning Essays

In the Environmental Design course in 2004 and 2006, students wrote formal essays at the end of the semester describing the impact of the service learning aspect of their project on the overall design experience. Some of the students did not work on a service learning project, in which case they discussed the impacts of having interactions (or lack of interactions) with a consultant or client. The essays were submitted about a week following an in-class discussion. The discussion enabled students to compare and contrast their project experiences with that of their peers. Using the assignments that were not collected by the students and were therefore available for re-review in spring 2007, a coding analysis of the essays was conducted (2004 n=13; 2006 n=20). Each essay was read and 19 significant themes that occurred in more than one student essay were identified. Then all the essays were re-read to determine and verify the

range of the diverse themes that were present within each essay. The themes that were expressed in the largest number of the student essays are summarized in Table 3. The percentage of students in various groups that discussed the theme in their essay are also indicated. The site visitors are all of the students that visited their community at least once over the course of the semester; note that site visits were optional. The costs associated with the visit were covered by the client, facilitator, and/or a service-learning grant.

Table 3. Most Common Emergent themes from EVEN Student Service Learning Essays

Theme discussed in Student Essay	Total # /% students	% site visitors (n=15)	% service learning projects (n = 26)	% non SL projects (n=7)
Real world experience	30 / 91	97	92	86
Data: poor, rich, assumptions	26 / 79	87	85	57
Communication importance	25 / 76	87	79	71
Serve community	21 / 64	60	65	50
Importance of non-technical aspects	20 / 61	47	58	71
Relationship with real project/community motivating	16 / 48	53	56	29
Disparity of stakeholder goals	15 / 45	53	46	43
Team work with other students	12 / 36	43	42	14
No one right answer to dsn problems	11 / 33	40	37	14

The most common theme to emerge in the student essays is that the students appreciated the real world nature of their design problems, and how this was a unique experience compared to most assignments in other courses. Many students realized that engineers often do not have the data they need to use various design equations. The students gained confidence during the semester in locating information they could use and making assumptions when needed. One student noted: "*Another misconception I've had about the engineering profession is the acquisition and use of data. In all of my classes, we have been 'data rich', or, given all of the information we need to complete our tasks. In this case of [this project] I wasn't so lucky. This process of making good assumptions and then applying them was a radically different approach to problem solving than I was used to. However, I believe that making reliable and accurate assumptions is an essential skill in the professional world and is something that was not emphasized in my education until this project.*"

Another theme was the importance of communication among teammates and with the client(s) and communities about goals and expectations. Students noted the importance of serving the community; for example: "*I think that the way projects will affect the lives of people living near the site is often ignored by engineers, and it should not be*." In addition to the nine themes listed in Table 3, other themes that were less commonly cited (in order of decreasing frequency from 10 to 3 students) were: would have preferred more direct interactions with the community; the experience built confidence; the single semester format was too short to complete the project; the importance of good time management; sustainability; communication across a language barrier was particularly challenging; poverty; cultural exchange; short time of the community visit was limiting; and, outsiders may be unable to recommend what will be best for the community.

Many students found that service learning projects were more motivational than non-SL projects. One student said: "*By traveling to the community we were able to meet various people in the community... By forming these relationships I... really wanted to help them out and design a reliable wastewater treatment system.*" Another SL student noted: "*It seems like for the last few years in engineering all I have been doing is taking numbers and putting them through some formula to get a whole new set of numbers. This time we had people say that this mattered to them....*" A third SL student stated: "*After meeting with [the] mayor I truly felt the significant role we were playing. Our design could be chosen as the wastewater treatment for the town. Yes, I heard that before going to Mexico, but after the meeting with the mayor, it felt real.*"

Students with real community contact had a rich learning experience. For example, of the 8 students who visited their community (Pesqueira) in Mexico and met with the mayor and other locals, the essays included 8 to 10 different themes versus only 5 to 9 themes in the essays of the 4 students on the same project who did not visit Pesqueira (total number not statistically different; $p = 0.17$). There were no statistically significant differences in the individual essay themes of the students who traveled to Pesqueira compared to the students who worked on the same project but did not travel to the community. A reason for this may be that at least 1 person from each of the 3 teams traveled to the community and shared their experiences with the group, the students who did not travel to the community still could contact project support persons in Mexico by email, and one student non-traveler served as a translator for audio tapes from the site visit. In addition there are a small number of students to support statistical tests.

There were 4 themes that were discussed significantly more often ($p \leq 0.05$) in the essays of the students who worked on a service learning (SL) project compared to those who worked on a non-SL project: sustainability, communication against a language barrier (Spanish) was particularly challenging, poverty, and cultural exchange. For example, none of the 7 students working on non-SL projects mentioned sustainability in their essay, compared to 33% of the SL students. The last 3 themes emerged in the students who worked on the Pesqueira project (significantly higher than other SL students). Other themes that were mentioned by the Pesqueira students significantly more than the other SL students who worked on U.S.-based projects were: real world experience, serving the community, and too short to fit the project in a single semester. There was significantly less emphasis on teamwork by the Pesqueira students, perhaps due in part to the fact that the Pesqueira students had so many other important ideas about the SL experience to communicate: an average of 9 theme points by the Pesqueira students vs 7 from the other SL students vs 6 by the non SL students (p values 0.00 and 0.06, respectively). This may also relate to the somewhat generic idea of "non-technical aspects" that the non-SL students emphasized, while the SL students focused their essays on specific aspects (such as communication) but didn't necessarily classify them as "non-technical" and distinct from their various technical challenges. One student noted: "*ABET... decides on the criteria for accrediting engineering programs. Of these eleven criteria, seven involve non-technical skills. This senior design course is the only course I have taken that incorporates all eleven of these criteria*."

Results from Student Evaluations

The College-wide Faculty, Course Questionnaire (FCQ) forms that are administered at the end of every course are generally of minimal use in determining course outcomes and student learning.

The "historical" form contained the same questions from 1999 through spring 2006, with students rating various aspects of the course on a scale of F (0) to A (4.0). The FCQ form was revised in Fall 2006 and contains somewhat more helpful questions that students respond to on a scale from 1 (poor) to 6 (excellent). Table 4 below summarizes the average student ratings in the EvEng and CvEP senior design courses, in addition to the chemical engineering (CHEN) capstone course (2 credits) and the mechanical engineering (MCEN) capstone course (3 credits fall; follow-on course for 4 credits in spring) for comparative purposes.

Table 4. FCQ Results Summary

Senior Design Course	Years	Enrollment	Overall Course Rating	Overall Instructor Rating	Workload *	Intellectual Challenge	How much Learned
old FCQ format: 0 to 4 scale							
EvEng	F99-04	10-25	2.9-4.0	3.0-3.9	5.8-7.6		
CvEP	Sp06	15	2.3	2.2	7.2		
CHEN	Sp04-06	45-46	2.6-3.5	2.6-3.7	5.8-7.0		
MCEN	F04-05	4-35/ section	2.5-3.4 (3.1av)	1.3-3.7 (2.9av)	5.1-6.8		
new FCQ format: 1 – 6 scale							
EVEN	F06	18	5.0	5.4	4.0	5.4	5.2
CVEN	F06	26	4.8	5.1	4.6	5.7	5.1
MCEN	F06	5-35/ section	4.4-5.7	3.7-6.0	3.1-5.3	4.6-5.5	4.4-5.6

* Old FCQ workload relative to credit given: 1 = too light; 5 = ok; 9 = too heavy;
2006 FCQ workload in hrs/week: 1 = 0-3; 2=4-6; 3=7-9; 4=10-12; 5 = 13-15; 6 = 16+

In general, self-reported learning by the students in EvEng and CvEP courses are similar. In the EvEng course, the highest ratings were from 2001 when the 10 students worked on three SL projects: two associated with EWB and one for a local community. There was a very wide range of student ratings for the ~11 different sections of the MCEN course, indicating that the experience could vary widely based on instructor and/or project.

Results from Student Surveys

The survey that was developed to specifically evaluate the capstone design course yields more useful information than the FCQs. When comparing the responses of the Fall 2006 EvEng students versus the CvEP students, the responses were significantly different ($p \leq 0.05$) on 10 of 27 5-point Likert-scale questions, which included primarily ABET-related learning outcomes. The questions with differences in average student responses are summarized in Table 5. The students in the EvEng course generally had a broader and more diverse learning experience compared to the CvEP students. The higher response on the "most design intensive" course question may be a result of differences in the EVEN versus CVEN curriculum. Specifically, the CVEN curriculum has a greater emphasis on integration of design experiences in multiple courses. This is largely due to the historic curriculum model in CVEN that lacked a single capstone course requirement until the curriculum change in Spring 2006. Prior to 2006, students had a minimum of three courses where design was a large portion of the course content, 3

courses with moderate design content, and 6 courses with design having at least a small role in the course. In contrast, the EVEN students are required to take a freshman design course and the senior design course, with some integration of smaller design elements in other required or option-specific coursework. Interestingly, the CvEP students did not report greater learning related to the four questions specific to the American Society of Civil Engineers (ASCE) Body of Knowledge (beyond the ABET A to K criteria), even though these aspects were supposedly emphasized in the CvEP course and not in the EvEng course; the EvEng responses were slightly higher, although not to a statistically significant extent (p 0.14 to 0.54).

Table 5. Contrast in Survey Responses of students in Senior Design Courses

Design Survey Question	EvEng Dsn avg response $\pm$ stdev	CvEP avg response $\pm$ stdev
The course was the most design intensive of my curriculum	4.7 ± 0.6	3.9 ± 1.5
The course improved my ability to design a system to meet desired needs	4.6 ± 0.6	3.9 ± 1.1
within realistic constraints, such as:		
economic	4.6 ± 0.7	2.7 ± 1.5
environmental	4.7 ± 0.6	3.3 ± 1.5
social	4.2 ± 1.2	2.4 ± 1.5
health & safety	4.2 ± 0.9	3.1 ± 1.6
sustainability	4.4 ± 0.8	3.0 ± 1.5
The course improved my oral communication skills	4.3 ± 0.8	3.4 ± 0.9
The importance of non-technical aspects of engineering design were realized in this project	4.4 ± 0.6	3.8 ± 1.0
The course helped to develop my awareness of the impacts of engineering in a global and societal context	4.1 ± 0.9	3.2 ± 1.2

The second portion of the design survey asked 11 questions related to project types; students responded disagree, neutral, or agree to each question. These responses were coded as 1 to 3 to facilitate quantitative comparison. Student responses between the two courses were significantly different on only three questions. All respondents in the Environmental design course agreed that "service learning projects are appropriate to include" in the design course; only half of the CvEP students agreed. When the reverse question was asked, 94% EvEng and 31% of the CvEP students disagreed with the statement "service learning projects are not appropriate for this class." On the question "I think that a project for a developing community would have been frustrating due to potential lack of data", 13% CvEP students agreed and 31% disagreed with the statement compared to 61% and 17% of the EvEng students, respectively. This difference is probably due to the fact that the EvEng students experienced this lack of data themselves or observed it among their peers, while the CvEP students only speculated about this aspect.

Another interesting aspects of the survey are the number of students who would have chosen to work on a project for a developing community if given the opportunity, compared to projects for a municipality or industry; 31% of the CvEP students versus 67% of the EvEng students. The most popular project option for the x CvEP students (50%) was a project for industry. When stated as a choice among projects for the University, a developing community, an industrial

client, or a project with a local consultant, 31% of the CvEP students and 78% of the EvEng students selected a developing community project. The most popular project type for the CvEP students was a project for the University (38%). Although not explicitly stated, it is perhaps implied that developing community projects are more likely to be service learning projects, indicating that it might be appropriate to include a service learning project as an option if multiple project types are provided.

Real World Outcomes of the Service Learning Projects

Although the service learning projects are intended to directly benefit a community, it is difficult to achieve this goal within a single semester and the current course format. The students spend the bulk of their time on the alternatives assessment phase of the project, and do not generate complete plans and specifications for their selected design. In addition, the limited single semester time frame means that students are often forced to make assumptions for the preliminary design that would be better to acquire actual field data prior to the final design. Thus, without strong follow-through in some manner after the end of the semester, it is difficult for the projects to have a significant impact. In many cases, the projects are continued in some manner after the semester. For example, on two of the three EWB-related projects, there was eventual follow-through by the local student or professional chapter that completed implementation of a portion or all of the student design. One of the iCAST projects for a local Native American community resulted in implementation of the student-recommended design, although this took a full three years after the end of the semester. Thus, the student designs may provide further information to clients or other stakeholders that may take time to fully come to fruition.

Summary

SL projects provide a rich learning experience that is particularly beneficial in emphasizing the non-technical aspects of engineering design. The opportunity to travel to the community is important both to enrich the learning experience for the students and also to increase the probability that the student design will meet with the approval of the community. While opportunities to serve developing communities provide additional benefits, this also introduces additional challenges unless close proximity or other forms of contact with the community can be maintained. For these projects, a single semester format is also more restrictive than for the other SL projects. However, across various project types other students also noted that a two-semester experience would have enabled them to do a more complete job. The reflective essays are an important aspect of helping the students to think about and realize the importance of their service to the community. The essays also provided an effective tool to evaluate student learning. The information provided from these essays was more rich and meaningful that the various survey tools that were developed.