

AC 2007-799: ENGINEERING FOR THE DEVELOPING WORLD COURSE GIVES STUDENTS INTERNATIONAL EXPERIENCE

Angela Bielefeldt, University of Colorado at Boulder

Dr. Bielefeldt is an Associate Professor in the Department of Civil, Environmental, & Architectural Engineering at the University of Colorado at Boulder. She is also the Director for the Environmental Engineering (EVEN) Program that administers the multi-disciplinary, ABET-accredited B.S. degree in EVEN. She is also one of the faculty involved with the Engineering for Developing Communities (EDC) program at the graduate and undergraduate level.

Bernard Amadei, University of Colorado at Boulder

Dr. Amadei is Professor of Civil Engineering at the University of Colorado at Boulder. His current interests cover the topics of sustainability, green construction, and international development. Prof. Amadei started a new program in Engineering for Developing Communities. Its overall mission is to educate globally responsible engineering students and professionals who can offer sustainable and appropriate solutions to the endemic problems faced by developing communities worldwide. Dr Amadei is also the Founding President of Engineers Without Borders – USA and the co-founder of the Engineers Without Borders-International network.

Robyn Sandekian, University of Colorado at Boulder

Robyn Sandekian has degrees in Aerospace Engineering from the University of Colorado. She is currently the coordinator for the Engineering for Developing Communities Program, and also the Service Learning Program coordinator for the College of Engineering and Applied Science at the University of Colorado - Boulder. She has co-taught courses on appropriate and sustainable technology.

Engineering for the Developing World Course gives Students International Experience

Abstract

A new course, Engineering for the Developing World (EDW), has been taught since fall 2005. The course goals include: (i) introduce students to open ended problems at the community level; (ii) help students develop the skills to solve those problems and provide holistic engineering solutions that are sustainable and appropriate to the community being served; (iii) help students develop cultural and social awareness; (iv) help students work in interdisciplinary teams; (v) give students the opportunity to reflect on the importance of their community service; (vi) give students a professional work ethic, and (vii) help students gain a better understanding of the importance of engineering in society and in community development. Two different models for the course have been used: in year one, a single team of three students worked on two different projects for a community in Rwanda over two semesters, earning six credits that could be applied as technical electives in their respective majors. In year two, twelve students in three teams worked on a wastewater treatment/reuse design for a community in Sonora, Mexico. In this format, students earned 3 to 4 credits for the course, which counted as the capstone design experience in their curricula. The students self-selected this international project from among three project options (the other two were service learning projects within the state) in the capstone Environmental Engineering design class. Student evaluations of the EDW course are presented and contrasted against feedback from students who worked on other service learning projects or a traditional civil engineering project.

Motivation for Capstone Design Experiences

Design experience is an important part of the engineering curriculum. The ABET 2005-2006 accreditation criteria for engineering programs¹ indicate this importance via criterion c:

“Engineering programs must demonstrate that graduates have (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.”

The list of specific constraints noted by ABET has grown over time. Capstone design courses also have the ability to teach a variety of the other ABET-specified skills and abilities, many of which are difficult to incorporate into traditional engineering courses. Examples include multidisciplinary teamwork (criterion d), an ability to engage in life-long learning (criterion i), and others².

Professional engineering societies have added other criteria to the so-called “body of knowledge” related to their field, many of which are optimally taught in a capstone design course context. For example, the American Society of Civil Engineers (ASCE) Body Of Knowledge (BOK) outcomes were expanded to include an understanding of project management, business and public policy, and leadership principles and attitudes³. These elements are readily incorporated into a capstone design experience where the student team is a simulated consulting firm working on a real project for a real client.

The National Academy of Engineering (NAE) “Engineer of 2020” report⁴ notes the importance of developing “more ecologically sustainable practices as we seek to achieve economic prosperity. Sustainable practices must proceed apace in industrialized countries and developing countries alike.” Further, the report recognizes that technologies used in industrialized countries may not be appropriate world-wide, stating: “The engineer of 2020 will have to understand how to adapt solutions, in an ethical way, to the constraints of developing countries.”⁴ The report also emphasizes the complexity engineers face will continue to increase and requires consideration of cultural, societal, political, and economic constraints and impacts. Many times this type of complexity is lost and designs focus on largely technological constraints.

Senior design courses are the epitome of project/problem-based learning (PBL), which have been shown to be a more effective pedagogy for learning than traditional lecture/exam based methods.⁵ Most capstone projects follow a “just-in-time” learning model, allowing students to be quite self-sufficient in locating and teaching themselves the information they need, with a variety of professors and professional mentors to provide assistance as needed. The courses compared in this study all incorporated significant “just-in-time” learning, with varying levels of outside direction supplementing this base.

Unique Goals for Engineering for Developing World (EDW) Course

The new course development has been supported by a grant from the National Collegiate Inventors and Innovators Alliance (NCIIA) and the Engineering Excellence Fund at the University of Colorado at Boulder. The course was specifically geared to meet the ABET criterion of student understanding of the impact of engineering in a global and societal context (criterion h), as well as the NCIIA goals of addressing such issues as poverty, disease, and environmental degradation through affordable design, technologies that solve critical problems and meet basic human needs (such as food, water, shelter, health, safety, and education), and pedagogical approaches that encourage awareness of and interest in these global issues. The idea is somewhat similar to Ruwanpura⁶ in having an international design project in capstone Civil Engineering courses.

The course objectives are to:

- Introduce students to open ended problems at the community level,
- Help students develop the skills to solve those problems and provide holistic engineering solutions that are sustainable and appropriate to the community being served,
- Help students develop cultural and social awareness,
- Help students work in interdisciplinary teams,
- Give students the opportunity to reflect on the importance of their community service
- Give students a professional work ethic, and
- Help students gain a better understanding of the importance of engineering in society and in developing community development.

While some of these objectives (such as interdisciplinary teamwork) are common to most capstone design courses, many of these objectives are unique.

Full Year EDW Course

In year one (2005-2006), a single team of three students (one majoring in Civil, one in Mechanical, and one in Aerospace engineering) worked on two different projects for the Muramba and Mugonero communities in Rwanda over two semesters, earning six credits that could be applied as technical electives in their respective majors. The project was part of an on-going project of the Engineers Without Borders – USA chapter at the University of Colorado at Boulder (EWB-CU). All three students in the EDW course had been previously involved with EWB-CU and two had traveled to Rwanda before enrolling in the course. The two projects included rainwater collection and treatment and solar powered lighting. The course itself was fairly structured with required meetings, readings, discussions with experts from the development field, etc. These meetings occurred weekly during the first semester. The second semester was significantly more self-directed by the students. These three students spent 20 days with the partner communities in January 2006 along with three other students from the EWB-CU student team, and the same six students visited the two communities again in June.

Produced deliverables included:

- an interview plan to learn about the broader needs of the communities
- design of an expanded rainwater catchment system
- design of solar powered lighting systems for a school, a medical clinic, and a hospital

Various reports written as part of the project included:

- A Project Management Summary -- December 2005
- A January 2006 Implementation Trip report
- A Project Management Summary -- May 2006
- A draft technical design document and user's guide of the "Bring Your Own Water" (BYOW) hybrid water purification system
- A Solar Lighting System User's Guide
- A final report in June 2006

In the fall semester, each student also gave two technical presentations.

The Rwanda group had an interpreter/assistant, but the majority of the people that the EWB-CU group worked with spoke a reasonable amount of English. The user guide documentation that the students created was translated into French (by a paid translator), rather than the native language of Kinyarwanda.

Despite initial plans per the course syllabus, the students did not write a reflective paper on their service learning experience. However, some indication of the benefits of the course was evident in the student comments in the course survey administered in fall 2006:

“The most important thing I learned, that was unique in this EDW course, was how to actually implement a small scale engineering solution in the field. There is really no other way to learn about the nuts and bolts of implementing a solution in a real community without actually doing it. I learned valuable lessons about engineering/construction logistics in a foreign country as well as communicating on engineering and construction concepts with a team of local

technicians. Another extremely valuable aspect of this course was the fact that we took the project from the beginning, through design, prototyping, and testing, all the way to implementation. This was by far the most rewarding and thought provoking class in my undergraduate career.”

“That course was an excellent capstone to the work we had done in Rwanda over the past few years, and was the most successful year we had with the project. The course partially substituted for my Aerospace Engineering senior design courses and was one of the most valuable courses I had. This is primarily due to the small class size and the collaborative and discussion based nature of the course.”

“The importance of non-engineering knowledge was enormous. There are far more factors than just engineering that need to be addressed in a community or in a project. I learned a lot in the experience of searching for knowledge. I enjoyed the visits and meetings with people involved with development organizations; their questions and experience I think taught us the most.”

Single Semester EDW Course

In fall 2006, twelve students in three teams worked on a wastewater treatment/reuse design for a community in Sonora, Mexico. In this format, students earned 3 to 4 credits for the EDW course, which counted as the required capstone design course for the Civil (CVEN) or Environmental Engineering (EVEN) B.S. degrees. The students self-selected this international project from among three total project options (the other two were service learning projects within the state) in a capstone Environmental Engineering design class. 75% of the women and 75% of the minorities in the class chose to work on the international project. These students were undergraduates majoring in Civil Engineering (CVEN), Environmental Engineering (EVEN, including one student enrolled in a dual degree program with Chemical Engineering), and graduate students in Civil Engineering. Only 33% of the students who selected the EDW project had previously worked on an EWB project (in contrast to the 100% of the 2005/2006 EDW students). Eight students and the professor traveled to the community for four days in October to meet with community leaders and gather data to improve their understanding of the scope of the problem. It is planned that a small number of students will continue to work on the project in spring 2007, earning independent study credit and visiting the community again to present suggested designs and gather information on wastewater quantity and characteristics during the population surge in the community.

This course followed a very open structure, where the students self-directed their time and attention to achieve basic project goals that were outlined in the Request for Proposals (RFP). Each year, an RFP is developed for each project by project stakeholders and the course professor. The course included 4 key deliverables, which were the primary inputs into their grades: an initial proposal (written and oral presentation; 16%), an initial written workplan (4%), written alternatives assessment (draft; 25%), and final alternatives assessment and preliminary design (written and oral presentation; 45%). How the students achieved the deliverables over the course of the semester was largely self-determined. In addition, all of the students were required to write a reflection on their service learning experience near the end of the semester. This, along with timesheets and other minor aspects, comprised the final 10% of their grade. Grades

on the team deliverables were altered for individual students, as needed, based on their efforts and contributions as rated by all team members.

Based on exit interviews, the written course survey, and the service learning papers, the following themes were evident:

- language barrier: since only two of the students who visited the community were fluent in Spanish (four others knew some Spanish), less information was gathered from the site assessment than might otherwise have been possible; the understanding differed among the students based on which community members they had the opportunity to talk to during the visit, how much they understood, and what was translated from tapes of various meetings by a third student fluent in Spanish upon return to the U.S. In addition, much of the written information that we were supplied and email contact was frequently in Spanish. This required translation, and may have added another point for potential misunderstandings.

- service learning projects interjected significant real world challenges that would not likely be present in other types of projects

- service learning projects were more motivational than working on a learning “exercise”

Service Learning Projects in Capstone Design

Students enrolled in Environmental Engineering Design course in previous years have worked on international service learning projects for communities in Belize and Nicaragua. However, these students did not have the opportunity to travel abroad and visit the communities as part of their projects. Students in the Environmental Engineering Design course have also worked on service learning (SL) projects in the U.S. (so-called domestic SL projects), including a wastewater treatment upgrade for a Native American community and water, wastewater, and waste projects for small rural towns in the San Luis Valley in Colorado. These so-called “developing community” (DC) projects also serve graduate students focusing their studies on environmental engineering for developing communities (EDC). Other projects historically included in the Environmental Engineering design course include service learning (SL) projects for the University of Colorado, projects with local small businesses, and projects conducted in association with local environmental engineering consultants. Of the 72 surveys of students from the Environmental Engineering Design course, 75% (54) agreed/strongly agreed with the statement: “the ability to tour existing facilities and the locally relevant area would be a significant advantage over projects where this was not possible.” Of the 6 students who worked on the international projects during 2001 and 2002 but did not travel to the community, 50% (3) agreed/strongly agreed, 2 were neutral, and 1 disagreed with the statement.

Comparison of Student Evaluations

An initial survey was developed to evaluate the Environmental Engineering Design course in 2002⁷, and the survey has been modified over time to reflect more aspects of the course. A total of 72 students and former students have completed the survey. This survey includes questions targeted to evaluate the ABET Criterion 3 (a) – (k) outcomes. It also has questions asking students to contrast different project types. A few additional questions are specifically relevant to the EDW experience. The three students who took EDW in 2005/2006 academic year received and returned the survey via email in fall 2006. A slightly modified survey was also

administered to students in the required capstone Civil Engineering Senior Projects course during the last week of class in fall 2006. In the Civil Engineering course, all the students worked on the same project: a design for a new University Arts Complex building. In addition to a single professor coordinating the course, there were also area-coordinator professors to represent each sub-discipline (structures, geotechnical, construction, and water resources) and a series of professional mentors. Demographics for each of the courses and the overall response rate for the survey are noted in Table 1.

Table 1. Demographics of Students Surveyed in Different Capstone Design Courses

Course Project Types	Students Surveyed in Each Course				Total # of surveys returned
	Total # students	# EVEN seniors	# CVEN seniors	% women	
EDW 2005/2006 international for DC	3	0	1	0	3
Env Engrg Design, fall 2006					
EDW	12	4	4	50	9
domestic service learning (SL)	9	6	2	22	8
Env Engrg Design, 2001-2004					
international for DC, 2001-02	13	5	8	46	6
domestic SL, 2002-2004	32	21.5*	7.5*	28	18
other, 2001-2004	23	13	5	48	14
Civil Eng Project Design, F 2006	23	0	23	22	16
other					

* Some students were dual majoring in CVEN and EVEN, in which case they were counted as “half” in each major

ABET criteria comparisons

For all of the questions related to the ABET Criterion 3 (a) – (k) on the survey, there were not significant differences (t-test $p > 0.05$) in the responses of the students from the 2006 Environmental Engineering design class who worked on the EDW project vs. the other service learning projects. Based on a comparison of the students’ survey responses from each of the four different courses (EDW 2005/2006, EDW fall 2006, Environmental Engineering Design fall 2006, and Civil Engineering Project Design course fall 2006), there were not significant differences in student responses to the following ABET criteria: a (ability to apply knowledge of math, science, and engineering), b (ability to analyze and interpret data), d (ability to function on multi-disciplinary teams), f (understanding of professional and ethical responsibility), and k (ability to use techniques, skills, and modern engineering tools necessary for engineering practice). Questions with significant differences evident between students in different courses are highlighted in Figures 1 and 2. Figure 1 contrasts differences in the design-related experience in the course. Responses to the first question (the course was the most design intensive in my curriculum) indicated that the single-semester EVEN course model, regardless of project type (EDW or other) was the most intensive experience. Responses to the second question (the course improved my ability to design a process to meet desired needs within realistic constraints) were similar for the EDW and EVEN courses, and somewhat lower for the Civil Engineering course. The third question was “constraints important in the project included...” Based on the range of responses to the third question, it is evident that the Civil Engineering project emphasized a

much narrower range of design constraints than the Environmental Engineering and EDW projects. Figure 2 contrasts student responses in other ABET criteria.

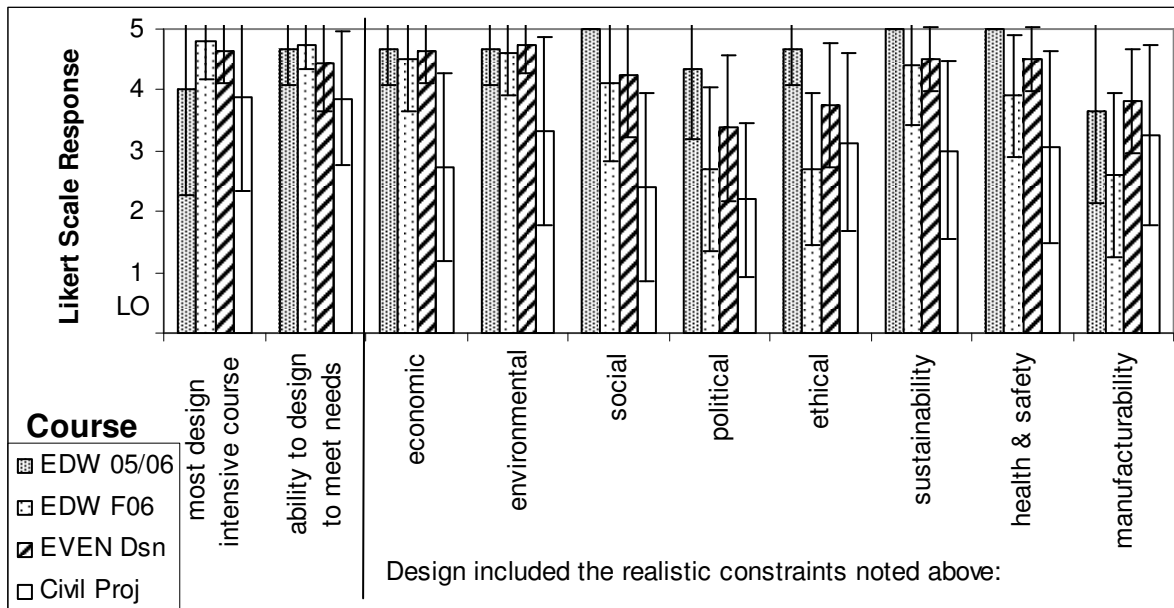


Figure 1. Contrast in the average student responses to ABET-related design questions. Students rated their agreement/satisfaction with each aspect on a scale from 1 [disagree; low] to 5 [strongly agree; high]. Error bars represent the standard deviation (if no error bar is visible, all responses were identical).

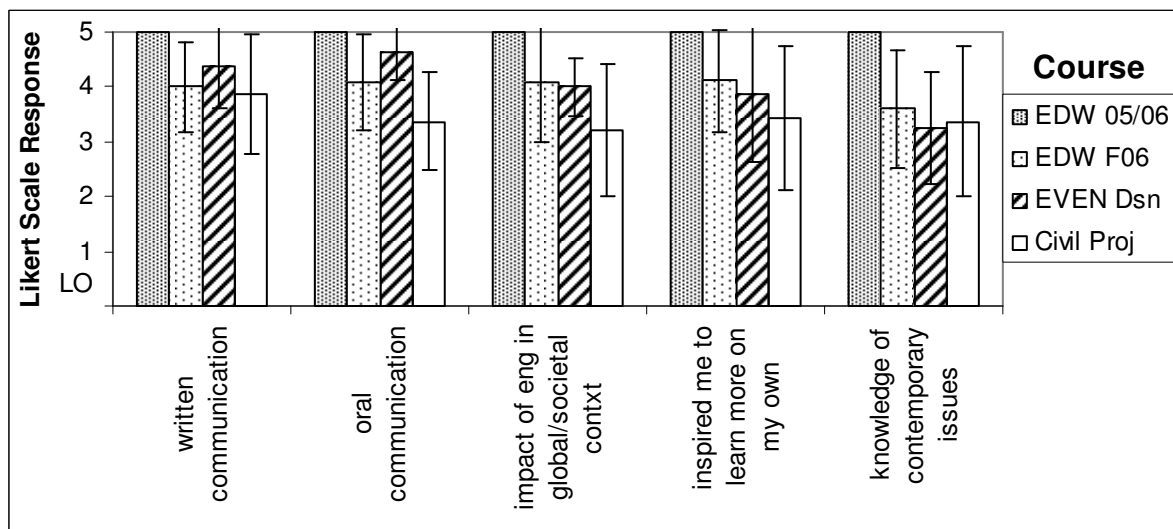


Figure 2. Contrast in the average student responses from different courses on questions related to how much they gained in ABET-related skills and criteria. Students rated their agreement/satisfaction with each aspect on a scale from 1 [disagree; low] to 5 [strongly agree; high]. Error bars represent the standard deviation (the lack of error bars from the EDW 05/06 course indicates that the 3 responses were identical).

Averaging all of the ABET-related question responses indicated that the EDW 2005/2006 course taught the broadest range of engineering skills (4.7 avg), followed by the Environmental Design course with service learning projects (4.1 avg), and significantly less in the Civil Engineering projects course (3.3 avg). This is not entirely surprising given the longer duration and more individualized attention in the year long EDW course (in addition to the fact that one of the 3 students noted on his survey that he was answering the questions based on his EWB-CU plus EDW course experiences). The breadth in the Environmental Engineering design course has remained fairly consistent over the years, with an average student response to the ABET criteria of 4.2 for students who took the course in 2001 to 2004.

Project Type Questions

Although the surveys contained 11 to 16 questions asking students to respond to various statements about project types, only a few of the responses will be highlighted in Table 2 below.

Table 2. Responses to project-related questions on the survey by students in different courses

Statement	EDW 05/06	EDW F06	EVEN Design	Civil Eng Project
I think that the EDW/developing community projects are less relevant to most engineering professions than the projects taught in typical capstone design courses.	2 neutral 1 strongly agree	6 disagree 1 neutral 1 agree 1 no response	5 disagree 1 neutral 2 agree	<i>not asked</i>
I think that service learning EDW/developing community projects are not appropriate as replacements for capstone design course requirements in BS degree programs	1 disagree 1 neutral 1 strongly agree	7 disagree 1 neutral 1 no response	7 disagree 1 agree	<i>not asked</i>
I think that service learning projects are appropriate to include in: engineering curricula (EDW survey) this course (for fall 2006 courses)	1 agree 2 strongly agree	9 agree	8 agree	1 disagree 6 neutral 8 agree

Student comments from reflective essays

In the fall 2006 Environmental Engineering Design course, all of the students wrote a reflective essay on the service learning and non-technical aspects of their projects. Preceding this written exercise, there was an in-class discussion of service learning and the impacts of having a service project on their motivation and learning. There were some powerful statements in these essays which indicated that there were unique aspects that could only be realized on an EDW service learning project. These statements give a richer indication of the learning outcomes than the student responses to the survey questions. For example:

“As an engineering student I was rarely asked to perform without knowing that there was a correct answer. There was in fact no one right answer to Pesqueira’s real-world wastewater problem while there were many wrong ones. With the aid of the service learning project I was able to see where my education left off and I still needed practice.”

“I was interested in working with developing communities and have wanted to participate in Engineers Without Borders but never had the spare time in my schedule.... By traveling to the community, we were able to immerse ourselves in their culture and see how they lived day-to-day. By forming these relationships I felt that I was more a part of their community and really wanted to help them out and design a reliable wastewater treatment system.”

“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. There is economic disparity in Mexico. We enjoy so much prosperity that we take it for granted. There [are] not enough classes offered in the College of Engineering that deal with sustainability.”

“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 and then it was our job to come up with solutions and numbers that got them what they needed. Then once we got what they needed we had to be able to explain it back to them in a way they could understand. That is definitely the first time I have done that in my education.... This time I might actually be able to go look at what I did one day and say, “See, I did that. It is real and it is helping a lot of people that really needed it.” This is a complex project with complex goals and 40 hours a week for sixteen weeks probably wouldn’t have been enough.”

Students working on the other environmental engineering projects also had similar comments about the real world complexity and motivation unique to working on service learning projects. Therefore, projects for domestic developing communities are likely to provide very similar benefits to international projects in the developing world.

Instructor Comments

From a self-serving perspective, it is important to note that the department did not count the initial EDW course toward the professor’s yearly teaching load due to its small size. So although having such a small group allows for much better one-on-one mentoring, it is burdensome to professors. In addition, some colleagues are skeptical that students can get a significant technical design experience in an EDW setting. Therefore, the use of assessment tools is particularly vital to document the learning outcomes from the experience. However, the longer time scale of the project (2 semesters) was a significant advantage. In particular, the ability to fit in more significant visits to the community provided a huge benefit. Also, having a long-standing relationship with the partner community was also strongly beneficial.

Fitting the EDW project into the single semester so that it could “count” as a required capstone course in the BS-degree curricula was helpful. However, this resulted in attracting fewer students outside the capstone major(s), in contrast to the year-long EDW course the first year. However, since all of the EDW students in year 1 were already interested in the developing world as evidenced by their EWB-CU participation, fitting the EDW project into the typical capstone course allowed a broader range of students to experience this type of project. Also, not all students are interested in participating in an EDW-related activity. Some feel that it won’t be as helpful to them when they are looking for a job as a consultant or in industry. Even with the three projects available in the Environmental Engineering design course, students commented

that they would have preferred a wider range of project options be available. In two previous semesters of Environmental Engineering Design, there have been 4 projects available with one of the four a non-service learning project. However, as the main technical mentor for all of the projects in the Environmental Design course, this was a bit overwhelming. Therefore, a good model might be to have 2 to 3 project types available to students, one fitting the definition of an EDW course. Because all of the student teams give oral presentations to the entire class, all students in the course still gain some exposure to the unique sustainability, cultural, and global aspects of the EDW course. This benefit was indicated by contrasting student responses in the Environmental Engineering Design course in years where there were no EDW projects available vs. years with one or more EDW projects (see previous capstone paper). In previous years when the Environmental Design course included projects for Nicaragua and Belize, we were unable to fit a site visit into the semester. Those students had a much poorer grasp of the real challenges and priorities of the communities that the projects were intended to serve, with the exception of ~1 to 2 students each semester who had visited the community prior to the semester in association with related EWB-CU projects.

Summary and Future Recommendations

Service learning projects for developing communities, either domestic or international, provide a much richer experience for students than typical capstone design projects. Because making a real connection with the community or client is very important, it is important to select a project that allows this contact to occur rather than selecting a “distant” project that may be too time consuming or expensive for the students to visit. As curriculum allows, a 2-semester experience will have a greater likelihood of yielding a true benefit to the community being served and a less stressful learning experience for the students. However, if only a single semester is available in a curriculum, it is still worth giving students an option to work on a service learning project. The implementation aspects in the 2-semester EDW experience are difficult to realize in a 1-semester course or when the projects are complex and not small-scale.

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