AC 2012-3782: COMPETITIONS FOR ENVIRONMENTAL ENGINEERING CAPSTONE DESIGN PROJECTS: STUDENT PREFERENCES AND LEARNING OUTCOMES

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Competitions for Environmental Engineering Capstone Design Projects: Student Preferences and Learning Outcomes

Abstract

There are a variety of national design competitions that can be used to form the basis of projects in environmental engineering senior capstone design courses. In recent years, teams of students in the Environmental Engineering capstone senior design course at the University of Colorado Boulder (CU) have participated in three different design competitions: the regional design competition organized by the local Water Environment Federation (WEF) chapter, the AECOM North American design competition, and an intra-collegiate competition sponsored by Halliburton. These competitions have been optional projects among service-learning projects for local and international communities and projects for local industries. This research compared the student preferences for different project types and the learning outcomes from the different projects. Matching the students' declared specialization within the environmental engineering degree program with a project helped improve student motivation, which is a challenge given the six different concentrations available to students at CU in water, air, ecology, remediation, chemical processing, and energy. Initially, students were not interested in participating in the design competitions. More recently the idea seems to have caught on, perhaps motivated in part by two teams winning their competition at the national level. However, student interest is still higher in service-projects. Similar learning outcomes could be achieved in both service-learning and design competition projects. This research points to the importance of offering a range of project options to students, and reinforces that competition projects can meet a broad range of learning goals.

Introduction

Capstone design courses form a critical component of undergraduate engineering education. They are a required element for ABET accreditation[1], in addition to providing a wealth of different learning outcomes for students. There are a variety of models for senior design courses.[13] Papers presented at the 2010 Capstone Design Conference[2] included a diversity of course models. The design projects ranged from one to two semesters and included: industry clients, service-learning projects for communities or individuals with disabilities, research-based designs for faculty, designs based on previous or on-going real projects but without industry involvement and not intended to be used, or theoretical designs (i.e. Sooner City). A single course type that was most effective was not apparent. This research project was particularly interested in capstone courses based on competitions. Of the 75 papers presented at the 2010 Capstone Design Conference[2], there were 13 that included some discussion of competition elements. Riley[3] provided a review of competitions as capstone projects, with a table that listed 27 national competitions.

One model for design competitions is to foster competition between teams at a university level. This typically involves a day when all of the different teams from across the engineering disciplines present their design projects, and these are then judged for awards. This model was found at Worcester Polytechnic Institute [4,5] and Widener University[6]. At Stevens Institute of Technology there is a Senior Day Exhibition with an "elevator pitch" competition.[7] Similarly, there is an optional business plan competition at the University of South Florida to encourage commercialization of capstone projects.[8] It appears that normally each team worked on a different project, and in many cases the teams were multi-disciplinary. This approach has the benefit of encouraging students to be more diligent in their presentation, because of the audience of peers, faculty from across campus, and industry sponsors who may be hiring graduates.

A different design competition model is to promote internal-competitions among students within a single course. At the University of Colorado Boulder (CU), the Civil Engineering capstone course has always used only one or two projects and therefore multiple teams all work on the same project. This engenders a degree of competition among teams, but competition was not directly encouraged until 2009. In that year the course was re-designed with a local municipal client and the projects were conducted as explicit competitions. The judging panel was comprised of the four faculty mentors and client representatives. The winning team had their names placed on a departmental plaque. The new course design has been popular. However, it is unclear if the success of the new course is based on the real nature of the projects with client involvement or the competition itself. Within an Information Technology course at Juniata College, a mention of informal competition between student teams working on different projects was noted to be fostered by students posting their progress toward project milestones on a white-board that was visible to all of the teams within the course.[9]

Alternatively, many capstone courses are structured around regional, national, or international design competitions. This practice appears common across all engineering disciplines. Some examples are given in Table 1. Many of these design competitions result in a final product that can participate in actual competitions (i.e. a robot[10], solar car, steel bridge, etc.); this removes a portion of the subjectivity from the judging. Wayroba[12] describes national competitions as less creative and open-ended because the judging rules are readily translated into performance requirements. Frequently the competition provides concise guidelines, constraints, and specifications,[12] which differs significantly from the real-world process of establishing these with a client. In some cases these same projects are outside of senior design courses as extracurricular activities.[14,15]

Table 1. Examples of National Design Competitions

Sponsor / Competition	**Target Disciplines**	**Web URL; Reference**
American Institute of Steel Construction / American Society of Civil Engineers (ASCE) Steel Bridge Competition	Civil Engineering	http://www.aisc.org/content.aspx?id=780 &linkidentifier=id&itemid=780 3, 6
ASCE Geo-Challenge	Civil Engineering	http://www.ascemidpac.org/ competitions/geo-challenge; 6
American Society of Mechanical Engineers (ASME) Human Powered Vehicle	Mechanical Engineering	http://www.asme.org/events/competitions 3, 6
International Society of Pharmaceutical Engineers (IPSE)	Biomedical	7
SAE International: Aero Design, Baja SAE Series	Aerospace Engineers, Mechanical Engineers	http://students.sae.org/competitions/ 6

In environmental engineering there are a range of competitions that could be used in a senior capstone design course. These competitions are summarized in Table 2. Basic elements of these projects as summarized from the competition websites are shown. However, the documented learning outcomes from participation in these projects are scarce. Of particular interest is to compare the learning outcomes from these projects to alternative types of capstone design projects, such as service-learning or more open-ended client-based projects.

Table 2. Examples of Design Competitions for Environmental Engineering

Competition / Sponsor	Location	Summary	Web URL and/or Reference
AECOM	North America	2 project statements; 1 DW and 1 WW	http://www.aecom.com/What+We+Do/Water/Design+Competition; 6
Federal Aviation Administration (FAA)	U.S.	Multiple project topics in Environmental area	http://faadesigncompetition.odu.edu/; 3
PB Environmental & Water Resource Student Design Competition (ASCE EWRI)	U.S.	Any project; submitted for consideration	http://content.asce.org/files/pdf/2012PBCompetitionFlyer_08.15.11.pdf
U.S. EPA P3 competition	U.S.	Self-generated project proposals (Phase 1); compete to win Phase 2	http://epa.gov/P3/ 3, 16
Waste Management Education and Research Consortium (WERC)	U.S.	On-site hands-on competition	http://www.ieenmsu.com/werc-2/ 6, 11, 17, 18
Water Environment Federation (WEF)	Regional	1 project selected per region; regional winners advance to national competition	http://www.wef.org/PublicInformation/page.aspx?id=136

A key ingredient in student learning and therefore senior design appears to be student motivation.[19,20,21] Motivation can be primarily intrinsic (such as interest in the project and desire to learn) or extrinsic (such as winning a competition, getting a good grade). Service-learning projects might be more intrinsically motivating than competition projects due to the desire to have a positive impact on a community or individual. Intrinsic motivators are generally thought to be more compelling than extrinsic motivators for college students, and some data even suggests that extrinsic rewards can negatively impact intrinsic motivation.[20] In addition, self-determination has been indicated as an important contributor to intrinsic motivation.[20] Lin et al.[22] posited that extrinsic and intrinsic motivators are not so clearly distinct. Course grades, for example, may satisfy a personal need for achievement and reinforce self-confidence (intrinsic motivations). Their work found that college students with the highest grades had a medium level of extrinsic motivation and a high intrinsic motivation.[22]

Some motivation theories imply that a competitive project would be detrimental to student learning. Engineering is often already viewed as a competitive environment, so perhaps engineering students thrive on competition. However, there is some evidence in the literature that female students in particular prefer collaborative environments rather than competition.[23]

Capstone design courses based on competitions provide a mixture of these environments: collaboration within an individual team and competition between teams. If the competition is external to the course and even the university, this removes the competition element from course grades and across peers that the students know, so perhaps there are benefits that can be derived from this combination.

The findings from previous motivation studies provide interesting implications regarding the benefit or detriment of competition-based capstone design projects. Differences in the learning outcomes between types of projects may also be impacted by the more structured considerations common to most design competitions versus the more open-ended nature of other project types. The research questions that motivated this study were:

1) How do student preferences for competition-based design projects compare to other types of design projects (particularly service-learning projects) in a senior environmental engineering capstone design course?

2) How do the student learning outcomes from competition-based design projects compare to other types of design projects (particularly service-learning projects) in a senior environmental engineering capstone design course?

Overview of Capstone Design at the University of Colorado

When I first began teaching the Environmental Engineering Design course at CU in 1998, there were 28 students in the course and all 7 teams worked on the same project. This was the same course structure that the previous instructor had used. However, informal feedback from the students indicated that they did not enjoy the competitive nature between the teams which they felt developed and the lack of choice among projects. Some of this dis-satisfaction may have arose because the students had friends in mechanical or chemical engineering where the capstone course included a wide range of projects and only a single team working on each project. That scenario is likely given the fact that our Environmental Engineering program is built as a multi-disciplinary program based on courses in civil, chemical, and mechanical engineering.

Starting in 1999 there have been multiple design projects available in the course each semester. However, there have been times when multiple teams might work on the same project. This paper will focus on data from 2004 (when competition projects were first offered to students) through 2011. The design projects that were available to the students since 2004 are summarized in Table 3. Each semester the course has had a variable number of students and projects. The optimal number of students on the teams was three to six. Students have indicated a desire to work on a project that matches their specialty area. EVEN majors at CU select different specialization options from among the choices: water resources and treatment, remediation, ecology, air pollution, chemical processing, and energy.

Table 3. Design Project Availability (DW = drinking water, WW = wastewater, DC = developing community; italics = project not selected or executed)

Year	Competition Projects Available	Service Learning and client projects available	Other projects
2004	*M&E WW Competition (10 topics for New York city)*	DC WW treatment in-state Incinerator residuals in-state DW arsenic removal in-state * University biodiesel **	Site Remediation
2006	*M&E WW Competition (6 topics available)*	Biodiesel in-state Dairy waste in-state Mexico DC WW treatment	
2009	Regional WEF Competition Halliburton Competition	URG End-of-life vehicle salvage (client project)	
2010	Regional WEF Competition National AECOM Competition (DW, *WW*)	Peru DC drinking water treatment Peru DC sanitation University LEED dorm	
2011	Regional WEF Competition National AECOM Competition (DW, *WW*)	University waste-to-energy Biocoal in-state Ag waste biogas in-state Microhydropower in-state *URG Drive Green*	
2012	Regional WEF Competition National AECOM Competition (DW, WW) FAA Competition (4 topics)	Rural county waste-to-energy *Carbon-credit evaluation for multi-family housing*	*Gulf water cleanup*

* became a non-SL project because the community dis-engaged
** A student team began working on the project, but the university started to oppose the project so the project was halted and the students moved onto other existing teams

One challenge of the design course is for the instructor to find multiple projects each year. Many of the projects were conducted with local utilities, and over time the class had already worked with many of the willing local utilities. A key advantage of competition projects was that the instructor was relieved of the responsibility and challenge of finding and scoping the project. At our institution where a single instructor is responsible for the entire capstone course, this is a large advantage. In addition, by selecting regional or national design competitions, the competition aspect that appeared to be a previous concern became externalized. A single team of students from our university represented our program.

Team Formation and Student Preferences

There are three different types of students who commonly take the Environmental Engineering Capstone Design Course: environmental engineering seniors, civil engineering seniors, and graduate students. First, the course is the required capstone design for environmental engineering (EVEN) majors. EVEN was created as a new major in 1998, and the first EVEN majors started taking senior design in 1999. Over time enrollment in the EVEN Program has grown. For the 2013 capstone design course we anticipate 60 students. Civil engineering (CVEN) majors specializing in environmental engineering were required to take the course from 1998 to 2006, and may petition to take this course instead of the civil engineering capstone design from 2009 to present. [In 2008 the environmental engineering design course was combined with the civil engineering design course, and all students worked on a single project.] A few chemical engineering (CHEN) majors in the environmental specialization have taken the course as an elective. A few graduate students may also take the course. Traditionally, these have been students with a bachelor's degree outside of engineering. However, in 2004 and 2006 students in the Engineering for Developing Communities graduate program were required to take the course and participate in one of the service-learning projects; this requirement was removed in 2008. Demographics of the students in the course are summarized in Table 4. Some students are dual majoring in EVEN and another major; these students were counted fully as EVEN majors. Data from 2005 and 2008 has been omitted since the course had a different instructor.

In addition to student major, the sub-disciplinary focus of the students is an additional variable. EVEN majors select among six sub-disciplines (W = water resources and treatment, En = energy, Ec = ecology, R = remediation, A = air, C = chemical processing; S = special option created by student via petition). They generally would prefer to have a project that engages their strength and interest area. CVEN majors specialize in water resources and treatment while CHEN majors specialize in chemical processing. The distribution of these sub-disciplines among the EVEN majors in the course varies widely each year (see Table 4).

Table 4. Student Demographics

Semester	Total # of students	% *female*	# EVEN majors (W En Ec R A C S)	# CVEN majors	# CHEN majors	# graduate students
Fall 2004	15	*53*	8 (5 1 2 0 0 0 0)	3	*1	4
Fall 2006	21	*38*	9 (0 0 0 1 2 5 1)	6	*5	6
Spring 2008†	*15*					
Spring 2009	17	*41*	14 (4 0 2 3 3 2 0)	2	1 *2	0
Spring 2010	26	*35*	17 (2 7 3 4 0 0 1)	3	1	5
Spring 2011	29	*48*	28 (9 8 6 2 2 1 0)	1	*1	0
Spring 2012	36	*42*	34 (12 12 7 3 0 0 0)	0	0	2

* Dual majoring with EVEN, so not counted here; also take 2-semester CHEN capstone design
† Course was co-taught with CVEN capstone design by a different instructor; data not available

Over time, student teams have been formed in two different ways. In 2004, 2006, and 2009, the teaming process was negotiated in-class on the first day. Students indicated their preferences for the available projects on the blackboard, and negotiations ensued to result in teams of the appropriate size. In 2004 there were six different projects available to 16 students, and given a minimum team size of three that meant at least one project would not be executed. There was insufficient interest in the Metcalf&Eddy (M&E) Student Design Competition, perhaps due to the “wastewater” nature of the project, the vague project statements, and/or the more concrete local projects. In 2006, there were four different project options presented to the 21 students. However, interest in the international service project to enhance wastewater treatment for a developing community was so strong that three teams selected this project. The other two teams worked on service-learning projects for a local community and business facilitated by a local non-profit group. Reasons for the lack of student interest in the competition project may have been due to the vague nature of the M&E project descriptions, but more likely was due to the lack of a real community or client that could potentially benefit from their work.

In spring 2009, the 17 students in the class were presented with only three project options. This guaranteed that each available project would have at least 1 student team involved. No students were interested in the real project on end-of-life vehicle salvage for a client, but since a commitment had already been made by the instructor to execute the project, a group of three students were randomly selected to work on the project. It is unclear if that was due to the nature of the project (vehicle salvage with a focus on lifecycle assessment) or the lack of competition. The remaining students distributed between the two competition projects. Student interest was about equal in the regional WEF design competition to upgrade a local municipal wastewater treatment plant and a CU College of Engineering design competition for Halliburton with large cash prizes for the winners.

In spring 2010 and spring 2011, the team formation process was drastically changed. Students indicated their top project preferences in writing, in addition to completing a cognitive style inventory and Purdue’s CATME-Team-Maker (www.catme.org). The instructor used this information to form the teams. These student preferences are shown in Figures 1 and 2.

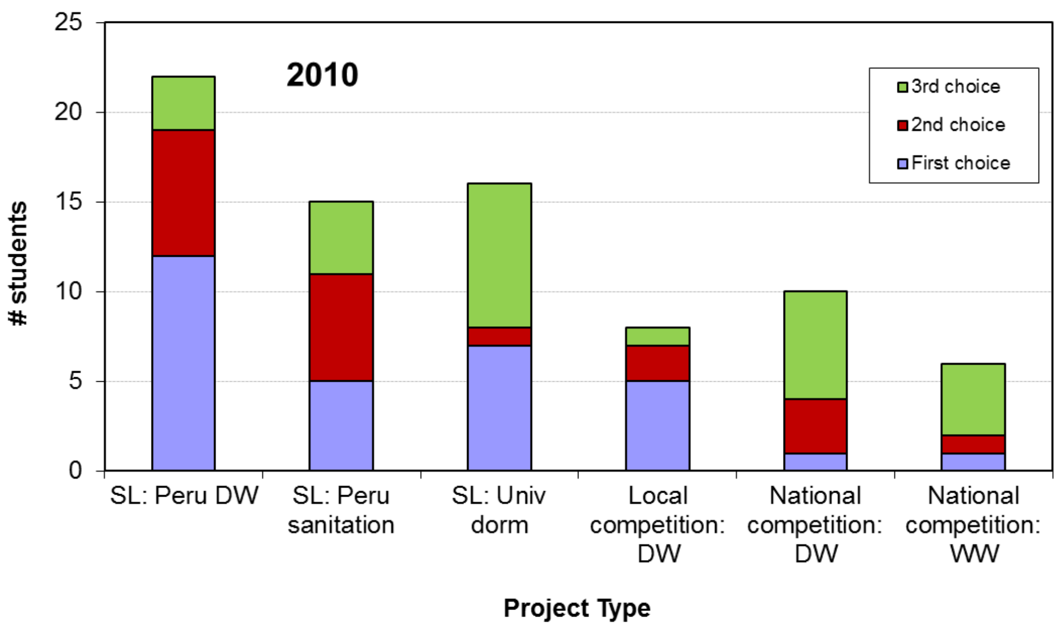

Figure 1. Student Project Preferences (2010), SL = service learning, WW=wastewater, DW = drinking water

In spring 2010, there were six projects available and 26 students in the course. This could easily have resulted in a single team working on all six projects, but student interest was distributed very un-evenly. The two international service projects for developing communities were the most popular, followed by a CU service project, the AECOM drinking water project, the regional WEF competition drinking water project, and the AECOM wastewater project; a single student team worked on each of the five most popular projects.

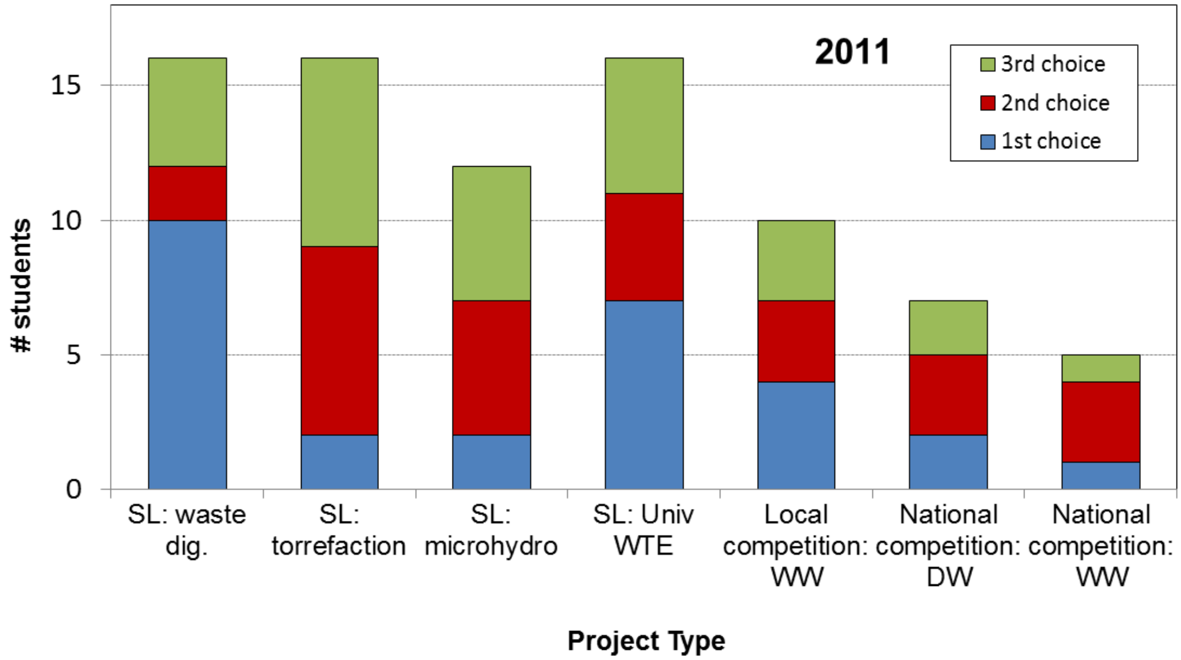

Figure 2. Student Project Preferences (2011), SL = service learning, WTE = waste-to-energy, WW=wastewater, DW = drinking water

In spring 2011, the relative popularity of the SL projects over the competition projects was again evident. The most popular project was a service projects for a local businesses, followed by the service project for the university, and then two additional SL projects. Among the competition projects, the regional WEF design competition was the most popular, followed by the AECOM drinking water project and the AECOM wastewater project. Ten of the 27 students did not rank any of the three design competition projects among their top four project choices. Student teams of 5 worked on all of the SL projects and the local WEF competition, a team of 4 students worked on the AECOM DW project, and we did not participate in the AECOM WW project. (Two students did not provide project preference ratings.)

In spring 2012, ten different project options were provided to students; preferences are shown in Figure 3. The most students rated the waste-to-energy service project among their top three choices (56% of the students). However, the second service project was quite unpopular. It was geared at evaluating the carbon credit benefits of energy retrofits to multi-family dwellings; the environmental engineering related design elements of the project seemed less clear to students, which may have accounted for its relative unpopularity. The specific client and topic of the competition projects was a clear factor. Of the competition projects, five had a local “client”: three FAA projects were linked with Denver International Airport, one FAA project (noise) with the local municipal airport, and the WEF project was working on a wastewater project for an in-state trailer park with discharge violations. Therefore, there may have been some sense by the students that their designs might have positive real-world implications. Among the FAA projects, the noise-control project was significantly less popular than the other FAA projects, perhaps because this topic is outside the norm of typical environmental engineering and the specialties at CU. Comparing the two national AECOM design projects, drinking water was again more popular than wastewater. But here it is clear that a local project can overcome the stigma of wastewater – the WEF wastewater project was the second most popular overall.

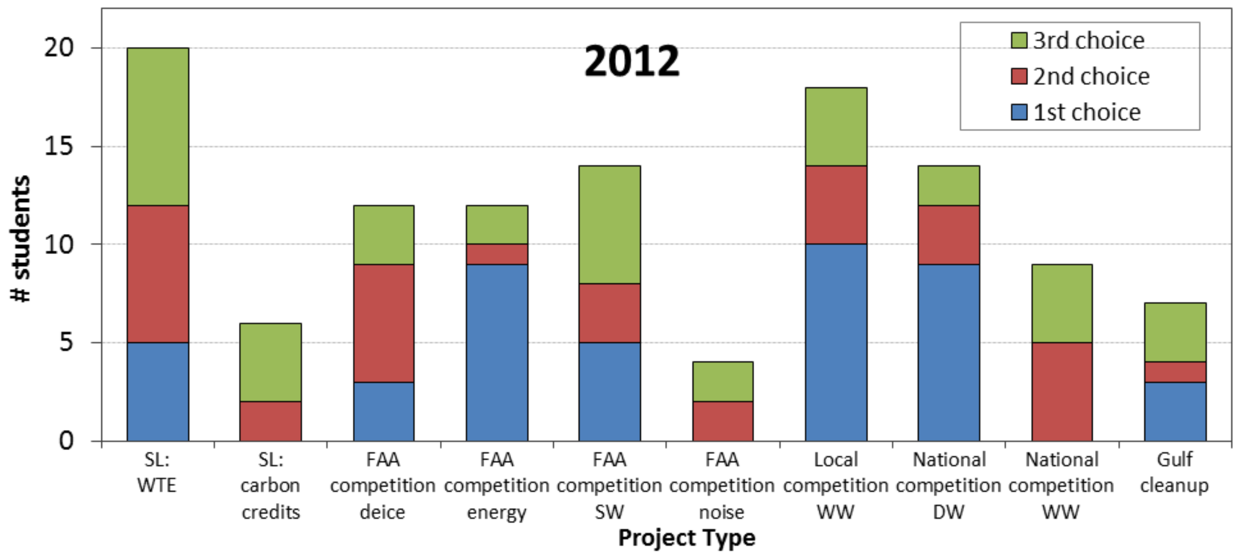

Figure 3. Student Project Preferences (2012), SL = service learning, WTE = waste-to-energy, WW=wastewater, DW = drinking water

Learning Outcomes: Final design grades

The learning outcomes evident from the graded course deliverables were similar in meeting the stated course objectives regardless of whether the project was based on a competition or service-learning. A very similar grading rubric is used for the course, regardless of the specific projects. Using the 2009 – 2011 data for consistency, there were 7 competition teams and 7 SL teams; Table 5 summarizes the written report scores. A 2-tailed t-test found no significant difference in the final written report grades based on project type. However, there is a greater range of scores on the SL projects: the very best and the lowest. The lowest score was from a team where the client (University representatives) didn't carry through with supporting the team, which severely decreased their motivation over the course of the semester. Some groups were very motivated by the service aspect of their project. By comparison, the competition environment seemed to ensure more uniformity of effort.

Table 5. Evidence of Learning Outcomes Based on Final Project Grades

Team Deliverable	Characteristic	Competition Projects	SL Projects
Final Written Report	Average score	95	93.9
	Median score	95.7	94.1
	Range	92.1 – 97.0	88.2 – 99.2
Final Oral Presentation	Average score	92.0	91.7
	Median score	91.0	91.6
	Range	87.7 - 98.8	86.8 - 96.7

Word content analyses on the final design reports revealed minor differences between the competition projects and service learning projects, particularly with respect to sustainability concepts. This comparison was made based on the seven SL projects from 2010-2011 and the seven competition projects from 2009-2011. The term "sustainability" or "sustainable" was used more frequently in the SL project reports (3-70 times, average 25 times, frequency 0.15/page) versus the competition project reports (0-45 times, average 11 times, frequency 0.05/page; statistical 2-tailed heterscedastic t-test on frequency with $p = 0.04$). Using specific terms that represent the three sustainability pillars (similar to Paterson et al.[24]), no significant differences were found in the sum of terms related to each of the pillars. However, based on the weighting given to decision criteria in the alternatives assessment matrix, social factors were more important in the SL projects compared to the competition projects (26% versus 16%, respectively). Technical factors were more important in the competition projects (average 31% weight versus 20% weight for SL projects). The importance of economic factors (primarily cost) and environmental factors were similar for both types of projects, averaging 38% and 16%, respectively. Specific terms with a significantly higher use in the SL reports were: community, energy, renewable, climate, and pay ($p<0.1$). The only sustainability-related term with significantly higher use in the competition projects was environment ($p=0.01$).

Students' Self Evaluation of Learning Outcomes

As a standard part of the departmental outcomes assessment process, the students were asked to self-evaluate the level to which the course contributed to the stated learning outcomes of the program using the so-called Faculty/ Course Questionnaire (or FCQ). The FCQs were administered in the 14th week of the 15 week semester. The rated outcomes map closely to the ABET criterion 3 A-K outcomes.[1] The statements read "the course improved my…." Students rated the outcomes using a 7-point Likert scale from 0 = not applicable to 6=highest. The data are summarized in Table 6. The 2008 course data is shown for comparison. The 2008 course was taught very differently where all of the teams worked on a single project to upgrade a local wastewater utility as an academic exercise; in addition, the environmental capstone was combined with the civil engineering capstone. As expected, the design course was normally very strong in outcome "c" (design) and "d" (teamwork), but the course also contributed to a very wide range of other learning outcomes. No obvious difference in the breadth of outcomes achieved is evident based on project type. However, due to the range of project types available each semester and the anonymous nature of the student responses, it was impossible to directly determine the relative efficacy of the project types as related to these outcomes.

Table 6. Average Students' Self-Evaluation of Learning Outcomes (rating scale 0 to 6)

Year: Dominant project type	2004 SL 73%	2006 SL	*2008* *other*	2009 Competition 82%	2010 SL 64%	2011 SL 69%
Number of student evaluations	15	18	*7*	16	25	28
Course rating overall	4.6	5.0	*2.9*	4.8	5.0	5.3
Workload, hours/week	7.3	10-12	*7-9*	13-15	10-12	13-15
How much learned	5.3	5.2	*3.4*	5.4	5.3	5.4

Year: Dominant project type	2004 SL 73%	2006 SL	*2008* *other*	2009 Competition 82%	2010 SL 64%	2011 SL 69%
Outcomes:						
Analyze & interpret data	NR	5.0	*4.3*	5.2	5.0	5.2
Design a system or process…	NR	5.4	*5.1*	5.4	5.6	5.7
Understand realistic constraints on design	NR	NR	*4.6*	5.4	5.3	5.7
Understand the role of a leader	NR	4.2	*4.7*	5.3	5.0	5.1
Project management	NR	4.5	*4.9*	5.3	4.9	4.7
Multi-disciplinary teams	NR	5.4	*5.1*	5.1	5.2	5.3
Solve engineering problems	NR	NR	*4.0*	5.0	5.0	5.5
Ethics & professional responsibility	NR	4.2	*3.3*	4.9	4.4	4.6
Written communication	NR	4.8	*4.3*	5.3	5.0	4.9
Oral communication	NR	5.0	*3.2*	5.6	5.1	5.0
Impact of engineering in a societal context	NR	4.7	*4.5*	4.8	4.9	5.1
Lifelong learning	NR	4.5	*3.5*	4.7	4.8	5.1
Contemporary issues	NR	3.6	*3.4*	4.6	4.6	4.4

NR = not rated since the question was not asked that year; items with ratings above 5.0 have been highlighted

Students' Reflective Essays

All students in the course were required to write reflective essays. This was a single large essay at the end of the semester in 2006, 2009 and 2010. Students were instructed to:

> "focus your attention on the non-technical issues that were important, non-technical things that you learned, or skills that you improved in this course. You should also reflect on the "service learning" aspect of your experience. Discuss the primary benefits of this course to you."

An ethnographic approach was taken to perform content analysis on the reflective essays. After two separate individuals read all of the essays, themes that were evident in multiple essays were determined and used to make a code book. Then the essays were re-read and scored for the presence or absence of the different themes. Inter-rater reliability was determined, with a correlation of 0.79.

First, from 2006, 2009, and 2010 combined the student essays were "richer" from the SL projects (n=28) compared to the competition projects (n=23), averaging 13 themes versus 11 themes. There were three elements discussed with much greater frequency by the students who worked on the competition projects vs. SL projects: communication with teammates (61% vs. 14%), oral communication via formal presentations (43% vs. 21%), and lifelong learning (30% vs. 4%). There were 7 themes that appeared more frequently among the essays from students who worked on SL projects compared to competition projects: public health, social/cultural acceptability, low cost/economics, lasting implementation, disagreement / differences among stakeholders, difficulty when information was in a different language (many of the SL projects were international), data poor so finding data or making assumptions was very important. A more specific evaluation of the essays for overall "sustainability" elements found an average score of 1.35 for the competition students compared to 2.71 for the SL students.

In 2011 and 2012 there were smaller, more structured essays on personal growth (following TIDEE[25]) and civic engagement (similar to Dewoolkar at the University of Vermont as described in Bielefeldt et al.[26]). A mid-point essay required students to reflect on the potential civic engagement aspects of their project. The final essay asked students to "list and discuss the three most important things that you gained from this course while working on your project this semester" and discuss civic engagement aspects. In these much shorter 2011 final reflections, the students working on the competition projects (n=8) had more discussion of written communication, real world experience, literature research experience, and confidence statements ("I feel more…"), compared to peers working on SL projects (n=17). Students who worked on SL projects had more discussion of disagreement / differences among stakeholders, resource conservation, cost, energy use/efficiency, profit and/or employment aspects, and the fact that non-technical aspects were truly important.

These reflective essays shed some light on how the students perceived the competition projects. Specifically, there was a big difference between the local projects for the WEF regional competition where the students met with the utility versus the generic AECOM projects. Three of the WEF students wrote:

> *Providing service was the point of the project, and it definitely mattered that there were community partners and stakeholders involved, and as such we integrated their objectives and interests fully into all aspects of our project. We also considered the project to be very real experience and really look forward to seeing how much, if any, of our final report will potentially be used. This project was really all about addressing the stakeholder's social and economic issues….*
>
> *Personally, this design project enhanced my understanding as engineer's roles in the community. A major aspect of the project was to cater to the needs of the client while keeping the current plant treatment scheme unaltered. This is very reflective of a real world project because you are getting paid to achieve the goal your client desires.*
>
> *One of the main reasons I was drawn to the [project] is because it feels real to me. I like the fact that I was able to tour the plant, and see the homes and people that it serves, and meet the plant operator. Knowing what I know about the community has changed the way I feel about the decision making process (and I think my team also holds this sentiment). Every time I consider cost for the project I think about how I would feel my utility bills were raised. Every time I think about the operational requirements, I imagine the plant operator Russ doing those things. If this were a made up plant I would consider these thing much differently. I think it is important for engineers to get to know the community and stakeholders on some level in order to make the best decision for them. I know that our solution may not be implemented. To me, this does not diminish the importance of finding the best solution for the client and the community. During the tour, it definitely seemed like Russ wanted all of our input... this makes me want to work even harder….*

In contrast, one of the AECOM project students wrote:

I don't feel [our report] will have any impact outside of the academic world. I suppose our project was a "real" project experience. It's difficult to claim it entirely as such because we never met our client. However, we assumed certain client needs, and developed our analysis around those needs, just as with any real project. It gets interesting when you factor in the competition aspect. Next week we'll be presenting to AECOM in New York City. I feel this experience will be more of a "real" project experience than what the rest of the class is experiencing because we'll be under pressure to communicate our report to real engineering executives at one of the largest consulting companies in the world!

Another student wrote:

Unfortunately, the scenario given to us by AECOM was hypothetical, so there is no direct community, client, or partner that will be benefiting from the process we designed. Having real stakeholders involved would have definitely changed the design process, because we would have been able to get input with regards to what the community wanted .... Also, there would have been a much different type of motivation for our team if we knew we were working for a real community. Despite the fact that our design scenario was hypothetical, I did consider the AECOM academic design competition to be like a "real project" experience. We encountered many of the difficulties that we would have encountered if we were dealing with a real community, and we most definitely got great experience seeing how a real consultant company might treat the situation. Additionally, the project felt very real in the professionalism that was required. The detail and precision required for the report, as well as the preparation needed for the videoconference interview was invaluable real world experience.

In addition, there were comments related to the competition aspect, both pros and cons. A male on the WEF project wrote:

One aspect of the project that I liked was presenting (competition) with the other universities. This gave us the opportunity to see what other students our age, with similar majors could produce.

Note that this opportunity to listen to presentations by the other groups is not provided to the AECOM teams; the videoconference interviews are closed and the two finalist presentations are also closed.

From the Halliburton competition one female student wrote:

Recommendations: No competition amongst classmates: it was particularly uncomfortable to be competing against another team within our design class. I recommend that only one team per class be entered into the contest.

Therefore, despite the fact that the Halliburton teams worked on two entirely different projects, they still competed against each other in the end. This could also be true in the AECOM competition, where it appears that a single team working on each of the two project statements is selected to advance to the finals, and then those teams compete. However, the two final teams have never been from the same university, although some universities have had multiple teams advance to compete in the semi-finals. The FAA teams also ultimately compete with each other in the environmental interactions category.

Instructor Observations

The design competition projects can provide strong learning outcomes. However, the AECOM problems lack of a specific location and data. By comparison, the regional WEF design competition is based on a real project submitted by a local municipal utility. The ability to tour the facility, receive detailed monitoring data from the plant, and interact with utility personnel is a strength of the WEF project. The instructor required students working on the AECOM project to identify a specific (hypothetical) site for the project, which enabled students to consider local socio-economic conditions, climate, etc. One difficulty of this approach was identifying a reasonable location that fit the design parameters identified in the AECOM problem statement. This exercise often required a significant time commitment on behalf of the students or instructor, which did not directly contribute to solving the problem.

Table 7. Summary of Pros and Cons of Two Environmental Design Competitions

	WEF	AECOM
Pros	Interact with local utilities Intensive panel judging of oral presentations a good learning experience Hear other teams oral presentations	Interesting design problems Video presentation preparation Potential for New York trip Potential job contacts with AECOM
Cons	Competition deadlines and expectations are different than other course projects	Generic project statements without specific location identified or client interaction available Deadline close to FE exam Some teams can work on project 2 semesters vs. our class is only 1 semester

Another challenge was that to meet similar course learning outcomes desired for all projects, some of the desired elements in the WEF competition were given less attention. This required additional work for students and/or disadvantaged them in the competition. Therefore, instructors need to carefully consider how the competition requirements do / do not meet their own course goals, and articulate to students the recommended course of action (do extra work to meet both requirements or simply be less competitive in the competition).

One challenge of integrating multiple competitions into the course was the different deadlines. The regional WEF competition has a number of deadlines, and these are for different deliverables than the requirements for the course. In addition, the final report and presentation deadlines are different for the course versus the competitions. This resulted in situations where the AECOM teams had to complete the written report up to two weeks before the other teams in the course. Also, the WEF deadlines were sometimes after the end of the semester, so the students had somewhat "incomplete" deliverables submitted for the course deadlines, because they were targeting the competition deadlines.

Although not evident based on the oral presentation grades, in both competition projects the students practiced for the oral presentations more than the non-competition teams. In particular, the students invested extra time after the class was finished and before the competition presentation. The class presentation was treated as a "practice" for the competition, despite the fact that it was graded. The students' motivation was probably driven by the judging panel and the heavier weighting on the oral presentations to the competition relative to the course grade. For the SL projects, the final presentations were for the class but community representatives were not in attendance. This likely diminished SL students' concern and therefore preparation for these presentations. [Because FCQ course evaluations are completed 1-2 weeks before the end of the semester, students may not yet have realized this extra practice and improvement would occur when they filled out the self-ratings.]

To date, multiple teams at our university have not competed on the same project in the regional and North American competition, although this is possible and appears common at other universities for both design competitions. For the regional WEF competition, there were two teams from each of the other participating institutions last year. For the AECOM competition, there were 13 teams from 8 schools in 2008-2009, 17 teams from 10 universities in 2009-2010, and 15 teams from 10 universities in 2010-2011.

Summary and Conclusions

The competition projects did not seem interesting to all environmental engineering students as compared to service learning projects, so it is recommended that multiple projects are available to students. It was initially difficult to get students interested in participating in the design competitions, but now both competitions have gained momentum and interest among our students. In particular, alumni who participated on the winning teams have returned to mentor later student teams. One challenge is accommodating different time deadlines and content expectations across the different course projects. The generic nature of the AECOM problem statements also makes the projects less contextualized to real community and client concerns. If instructors can accommodate these challenges, competition projects are recommended as good learning experiences in capstone design courses.

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