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Diverse Models for Incorporating Service Projects into Engineering Capstone Design Courses*

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There are a variety of ways in which service projects have been incorporated into senior engineering capstone design courses. Some of these experiences fulfill the rigorous definition of service-learning (SL) and others meet some but not all of the true SL requirements. Many students and faculty find service projects particularly motivating, and educational theory indicates that motivation is a crucial ingredient for higher-order learning. Different course models from civil, environmental, and biomedical engineering, ranging from a single semester to a full calendar year, are compared and contrasted. Most of these courses and/or service projects are optional capstone projects for students, but in other cases all students are required to complete service projects for the capstone design course. Reflection exercises are an important component of SL projects, and a variety of structured and semi-structured reflection exercises have been incorporated into these capstone design courses. Data indicate that service projects are effective at teaching students both a depth and breadth of technical and non-technical skills. SL projects may be particularly superior for increasing students' understanding of sustainability, cultural competency, and sense of civic responsibility. It is particularly difficult to balance educational outcomes for the students with benefits for the community/client partners in single semester courses. Projects for local communities or individuals seem to yield the most tangible results for partners in a one-semester time span, while international projects with a development focus offer an array of logistical and cultural challenges. The instructors must devote time and attention to developing relationships with partners in advance of the course and follow-up to help ensure optimal outcomes for the partners. The lessons learned from these courses may help others effectively incorporate service projects into their own capstone design courses.

Keywords: appropriate technology; assessment; assistive technology; capstone; community engagement; design; service-learning

1. Introduction

Engineering capstone design courses are intended to provide rich opportunities for student learning [1]. The projects that form the foundation of these courses may originate from a variety of sources. Communities or individuals may propose a project that has the potential to provide a tangible benefit, while also providing a rich learning opportunity to students. This paper begins by defining service-learning (SL), provides a brief review of educational theories relevant to SL, and then describes various SL-based programs around the country and the engineering disciplines that have engaged in SL projects in capstone design. Then five different service project models that have been applied at American universities to fit different course constraints are described. The student learning outcomes from these courses are reviewed, followed by community and faculty impacts.

1.1 Service-learning

The incorporation of service projects into capstone design courses may or may not fit the complete definition of 'service-learning' (SL). Engineering is a relative newcomer to the field of SL. Service-learning is rigorously defined as *a course based, credit-bearing, educational experience in which students participate in an organized service activity that meets (a) defined educational outcomes and (b) addresses community needs, while requiring students to (c) reflect on the service activity to gain further understanding of course content, a broader appreciation of the discipline, and an enhanced sense of civic*

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responsibility (paraphrased from [2]). Capstone design courses obviously fulfill (a), the first of these three requirements. The requirement to serve community needs is not always encompassed within the various models of service projects in engineering capstone design courses. For example, assistive technology devices are often designed for a single individual, although it could be argued that a generic form of the device could serve a broader 'community' of individuals with various cognitive or motor disabilities. Civil and environmental engineering (CEE) projects frequently serve communities, but these interactions may be facilitated via public agencies. In addition, if the learning goals of the course over-shadow community needs, the experience would again fail to meet a rigorous definition of SL. The last criterion of service-learning requires reflection to achieve multiple goals. These reflective practices may or may not be incorporated into capstone design courses, and with varying degrees of rigor. For example, the reflection component may be focused on course content issues without explicitly being structured to enhance the students' sense of civic responsibility. The service-based capstone courses described in this paper include true SL courses as well as closely related experiences that might be considered at the fringe of meeting the complete, rigorous definition of SL.

Depending on the specific capstone course, the student experience may be focused to differing extents by the learning outcomes versus the service to the community or individual (see Fig. 1). For these unbalanced situations modified capitalization of the acronym has been suggested [3]. Capstone design courses that deliver a final product to the community or individual are generally more balanced in terms of *SL* (year-long iDesign [4]; Devices for People with Disabilities [5]). By comparison, other course models in CEE deliver a feasibility study to the client and preliminary designs [6–7] or more complete designs [7–8], but liability concerns require that a licensed professional engineer (PE) reviews and stamps civil and environmental engineering designs before they are constructed. As such, these projects frequently are more heavily weighted to student learning outcomes, so called *sL*. A third model where students perform direct service to a community without a clear tie to learning outcomes such that the service dominates over learning, *Sl*, has not been found in engineering capstone courses.

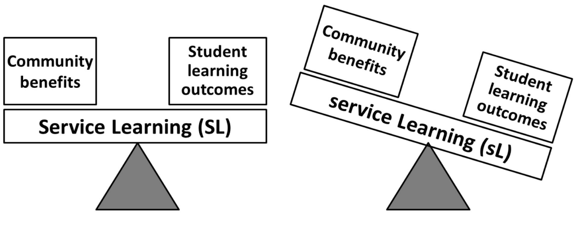

Fig. 1. Community benefits may be balanced or outweighed by student learning outcomes.

1.2 Educational theories

A number of learning theories have constructs that postulate why SL projects will be a particularly effective vehicle for student education. First, service projects that serve real communities or individuals provide a spark for student's motivation, which may exceed the motivation associated with capstone projects that are mere 'learning exercises'. Bruner [9] believed that student interest was the best stimulus for learning. Similarly, Kolb's [10] experiential model of learning begins with motivation, upon which theory, application, and analysis are founded. Both Dewey [11–12] and Piaget [10] stressed the importance of learning through life experiences, such that the real world challenges associated with a service project should stimulate significant student learning. The often 'messy' and difficult situations that students may encounter working with real communities may help stimulate the learning cycle. Concrete experience is also a key phase in Kolb's learning cycle; SL projects in particular may provide students with more varied experiences to facilitate the learning process. Kolb's constructivist pedagogy also emphasizes student autonomy in the learning process [13], which is common in many capstone design courses. Kolb's learning cycle, the Lewinian experiential learning model, and Piaget's model of learning all reinforce the importance of reflection in advancing learning [10], and therefore reflection at multiple points in the project should be encouraged. In addition, these theories indicate that reflection should be an important element in all capstone project experiences.

1.3 Growth of service programs in engineering

Over the past 20 years, service programs in engineering have grown substantially. One of the earliest successful programs was the Engineering Projects in Community Service (EPICS) program that started at Purdue University [14]. The program began in Electrical and Computer Engineering in 1995 with 40 students participating on five teams. In 2007 the EPICS program at Purdue had grown to 30 teams with over 400 students across eight departments; over the 12 year period over 2,500 students had participated to deploy over 200 projects [15]. EPICS has expanded to 20 universities; in 2003–2004 there were over 1,350 students participating on 140 teams (https://engineering.purdue.edu/EPICS/About). The EPICS program generally has local community partners, courses of variable credit hours (which in some cases can substitute for discipline-specific capstone courses), long-term student participation, and multi-disciplinary and multi-grade level teams. The projects generally fall into four areas: human services; access and abilities; environment; and education and outreach [15]. The long-term nature of the projects allows communities and students to benefit from experiencing the full project design cycle: define, design, build, test, deploy, and support.

Another example of a successful program focused on community service is Engineers Without Borders (EWB-USA). EWB was launched by Professor Bernard Amadei at the University of Colorado at Boulder (CU) in 2001. The goal of EWB is to sustainably serve the needs of developing communities worldwide while educating responsible leaders. It has rapidly expanded to 12,000 student and professional members at more than 295 chapters, with about 180 chapters at colleges and universities. In 2010 there were reportedly 400 projects in progress in 47 countries. EWB has also expanded to EWB-International, with member groups in 17 countries. The rapid growth of this organization can be largely attributed to student enthusiasm for the vision of EWB: to use engineering to improve the quality of life of impoverished people around the globe. When the students graduated, they often formed the core of professional chapters. Although most EWB projects are conducted as extracurricular activities, some integration into capstone design courses has also occurred at many universities; examples include the University of Colorado at Boulder, Lafayette College, Stevens Institute of Technology, the University of Nevada—Las Vegas, the University of Arizona, Washington State University, and San Diego State University. [16]

Both the University of Massachusetts—Lowell (UML) [17–18] and the University of Vermont [7, 19] have made a significant commitment to integrate service-learning into required courses. These efforts were funded by the National Science Foundation via Department Level Reform (DLR) grants. UML created the SLICE program—Service-Learning Integrated throughout the College of Engineering. The goal of the SLICE program is for all engineering students in every department to encounter service-learning in every semester. Capstone design is among the many courses that have integrated SL, including Intercollegiate/Interdisciplinary versions and department-specific capstone courses in civil, mechanical, electrical and computer engineering [17–18; http://slice.uml.edu/courses/]. At the University of Vermont (UVM), the goal of the civil and environmental engineering reform was to incorporate throughout the curricula a systems approach to engineering problem solving through inquiry-based learning. A systems approach means incorporating long-term social, environmental and economic factors within the context of the engineering problem solution and thus encompasses sustainable engineering solutions. A key strategy for practicing a systems approach was through SL projects that were introduced into existing courses culminating with the capstone design course. The reform began in 2005 and gradually included SL projects in at least one required course in each of the four years of the curricula [19]. SL projects have been incorporated within the capstone design course for the past six years (2006–present). During that time almost half (22 out of 41 total projects) dealt with topics that substantially related to sustainability issues, such as stormwater management and design, small hydroelectric, local water and wastewater solutions in Honduras, and historic preservation [7]. About half of the capstone projects thus far had community partners who were CEE professionals and the other half had none to limited engineering background.

1.4 Engineering disciplines

Service-learning projects can be integrated into capstone design courses in any engineering discipline. Most projects would optimally incorporate an inter-disciplinary team that extends beyond engineering. However, the structure of most academic programs coupled with differences in desired student learning outcomes often makes these arrangements difficult. The course examples examined in-depth in this paper encompass three primary disciplines with clear ties to service: civil engineering, environmental engineering, and biomedical engineering. Both civil and environmental engineering have a clear service mission and community focus to their normal activities. For example, the Vision of the American Society of Civil Engineers (ASCE) is: 'Civil engineers are global leaders building a better quality of life' with one of their five goals to 'advocate infrastructure and environmental stewardship to protect the public health and safety and improve the quality of life.' (http://www.asce.org/Content.aspx?id = 10216). Similarly, the Biomedical Engineering Society (BMES) states as one of its six missions: 'enhancing the impact of biomedical engineering on society and on human health.' (http://www. bmes.org/aws/BMES/pt/sp/mission) Thus, students in these disciplines are often motivated by serving individuals and society. A service-learning focus to the capstone design course is thus consistent with the core mission of these disciplines. SL may also be integrated into capstone design courses in other disciplines, such as the EPICS option for electrical and computer engineering at

Purdue University [14] and UML's capstone courses for electrical, mechanical, civil, and interdisciplinary engineering associated with the SLICE program [18].

2. Course models

Five different courses form the basis for the comparisons presented in this paper. These courses are summarized in Table 1. Some courses are explicitly SL based, and students elect to take the specific capstone opportunity instead of other capstone course options (BME course at Duke, iDesign at Michigan Tech). Other courses require SL projects for all students (UVM). Still other courses may offer both SL projects and non-SL projects within the same course, depending on specific projects available with local communities, and students have some ability to self-select onto the SL projects (South Dakota State University, SDSU, and CU). The courses also range in duration from a full year to a single semester. For courses without capped enrollment, the course is the sole required capstone course for the major so the number of students in an individual semester depends on the number of senior level students in the program. Critical elements for SL-based capstone courses will be described, including finding project partners, typical capstone design elements such as forming teams and project deliverables, structured reflection exercises, and other tips.

2.1 Finding project partners

Finding appropriate community partners and projects are the cornerstones for a successful SL experience for all involved parties. The community partner must have a vested interest and participate fully in the project. That does not necessarily mean that they have to invest a lot of their time. The partner should be available to meet with the instructor, provide information and ideas prior to starting the course, and be available for questions during the project. It is helpful when student teams can meet directly with the community partners, visit the relevant site, and give formal oral presentations to community representatives. Therefore, scheduling and transportation are important additional criteria for selecting appropriate projects. Some universities have service learning offices that can facilitate interactions with community partners. In all cases finding SL projects gets easier with time as partnerships are built and developed, and the local community becomes aware that the university is interested in partnering.

For individuals considering SL projects, project sites close to campus will be an easier first step than working on international projects for distant communities. Universities often have projects that can benefit from student input and provide a context that is familiar and motivating for students. These projects have been successful at CU, SDSU, and UVM. For example, SDSU had three capstone design projects related to university master planning and site development which are mentored by engineers in the physical plant. The outcome of the runoff analysis and stormwater management design from one of the projects affects the design of one of the other projects, requiring two student teams to collaborate during the design process.

Local organizations may be a good source for projects and/or to facilitate connections with communities. At CU, the International Center for Appropriate and Sustainable Technology (iCAST) identifies projects serving local communities or individuals with limited financial resources who are also interested in becoming more sustainable. iCAST is a non-profit organization with engineers on staff, and so they both start projects before student teams get involved and can continue projects after the semester. For example, business and marketing plans are often required prior to implementation, and iCAST arranges for teams of business students to work on those elements. At SDSU many projects are identified through contacts made by various community groups. The SDSU department head develops additional projects as well as consulting engineer mentors for possible projects during annual visits to constituent companies. At UVM projects have been found through contacts with state agencies (Vermont Pollution Prevention Division, Agency of Transportation, Department of Forests, Parks and Recreation) and cold calls/emails to relevant non-profits, town engineers and UVM alumni. Once an SL program has been established, sometimes inquiries are made by the communities. In these cases, it can be helpful to direct potential community partners to a website with examples of past projects; at UVM this website includes short video stories describing the projects.

International projects often require more time to develop strong partnerships. At CU the Engineering for Developing Communities (EDC) program provides good facilitation for projects. In 2010 two PhD students had been working in Peru for over a year and provided two projects for the class. The EDC graduate students had developed contacts with local NGOs already working on water and sanitation issues. The graduate students were able to meet with the capstone design teams in January, then returned to Peru to facilitate surveys to the communities while maintaining contact with the design students via the internet. The graduate students remained in-country for another year to facilitate project implementation. At Michigan Tech,

Table 1. Summary of Five Models Incorporating Service Projects in Capstone Design

Course name	**Devices for People with Disabilities**	**iDesign**	**Senior Capstone Design**	**Civil & Environmental Engineering Capstone**	**Environmental Engineering Design**
Department/Program	Biomedical Engineering (BME)	Civil and Environmental Engineering	Civil Engineering Program	Civil and Environmental Engineering	Civil & Environmental Engineering
Location	Duke University (Duke)	Michigan Tech University (MTU)	South Dakota State University (SDSU)	University of Vermont (UVM)	University of CO—Boulder (CU)
Service projects required in the course?	*Yes*	*Yes*	*Variable depending on projects acquired*	*Yes*	*No*
Duration	1 semester	1 year	2 semesters	1 semester	1 semester
Credits	3	7	3	3	3
Majors of students who participate	BME, BME-EE	CivE, EnvE, BME, ChemE, ME, EE	CivE	CivE, EnvE	EnvE, (CivE), (ChE)
Required or optional for students in the major	Optional	Optional	Required	Required	Required, (optional)
Total student enrollment per offering	18 (capped with application process)	20–30	30–45 (not capped)	30—45 (not capped)	10–28 (not capped)
# students / team	3 to 4	3 to 5	4 typical	4 to 5, occasionally 3	3 to 6; 4 optimal
Number of faculty teaching the course	2	2 to 3	1 overall faculty coordinator, and each 4-person team has a unique faculty advisor	1 (students seek help from other faculty for sub-discipline specific expertise)	1 (students may seek help from other faculty for sub-discipline specific expertise)
TA support	Yes	No: two alumni mentors	No	No	No
# Required structured reflection exercises (see more details in Table 4)	3 written essays and 1 set of activities	3 written essays	2, each with multiple elements	~5 essays plus in-class discussions and 2 peer evaluations	1 essay, 1 in-class discussion, 3 self/peer evaluations
SL clients / community partners	Individuals with disability, clinicians, therapists, teachers and schools, community rehab programs, hospitals	Rural communities in Latin America; U.S. Peace Corps volunteers	Schools, non profit community or private groups, municipalities	Towns, city municipalities and non-profit organizations	University; rural communities; municipalities
Frequency of client interactions	Minimum monthly face to face meetings, but usually 8 and 12 times per semester	Continuous for two weeks in-community (country)	Several times during first semester; clients invited to presentations. Occasionally, external presentations to clients.	About once a month face to face, and more often via email	~3x/semester to weekly; sometimes via non-profit facilitation organization
Sustainability theme?	No	Yes	Yes	Yes	Yes

needs expressed by partner communities in Central America serve as a starting point for community-based design. These collaborations are facilitated by Peace Corps volunteers serving in the partnering communities through a unique agreement facilitated by Michigan Tech's Peace Corps Master's International program in Civil and Environmental Engineering. At SDSU, a project kick off visit was made to Haiti in December 2010 by the department head and a consulting engineer; they developed field survey data to be used in a design project for water resource development in the 2011–2012 capstone course. It is difficult for student teams to interact directly with an international community in a meaningful way when constrained by a typical semester during which they are taking courses on campus. Students must also communicate across cultural and sometimes language divides which can also complicate the projects.

There are special considerations when finding partners for projects for people with disabilities. At Duke University, SL partners include the individual people with disabilities, their families, and the clinical professionals that work with them. Class instructors begin identifying potential collaborators several months before the semester begins to ensure time to review the potential projects and begin to establish a working relationship with the stakeholders. The project expectations are communicated to potential partners to ensure that they understand their role in the project. Project partners are expected to be available to meet with and answer questions from students. They are also cautioned that in most cases the students have little or no experience working with people with disabilities or clinicians, and that the students may make mistakes. The partners are also specifically informed about what engineering students can and cannot do in a semester long class, as partners frequently have unrealistic expectations of student capabilities. These same processes can be beneficial for SL projects with communities.

2.2 *Forming teams for the SL projects*

Similar to most capstone design courses, teams comprised of three to five students each appear optimal. However, these teams may be composed differently. By senior year, the students frequently know each other and have specific preferences of who they wish to work with. However, this 'self-selection' of teams is not necessarily an accurate reflection of what they will encounter on the job. Most SL courses have a model that allows students to voice their preference for particular projects. At Michigan Tech, these student preferences are the primary criteria used to form teams.

At UVM once the projects are introduced by the community partners, students submit a letter stating their choices for projects (most to least preferred), describe why they like their top two choices, and what skills they would bring to the project, along with their resume. They may also request to be separated from specific individuals, if strong reasons exist. Instructors then use this information to assign students to teams, including some factoring in of personality types based on instructors' observations.

At SDSU students are typically grouped to balance overall team performance as well as by expressed technical area preference. Projects may be assigned to groups or groups are allowed to rank project preference depending on the number and type of projects available as well as the number of teams in the current course.

Similarly, at Duke University students are presented with the project options and rank their choices from 1 to 5. They are encouraged to form teams and submit this project rating as a group. Students may also request to be separated from a particular student.

A similar process is used at CU, with students ranking their project preferences from 1 to 3, completing a brief description of their key skills that relate to the project, and completing the cognitive styles inventory of Wilde [20, 21]. Given the range of SL and non-SL projects available to the students at CU, the SL projects have been more popular, although a minority of students prefer to avoid SL projects. For example, in Fall 2010 when three SL and three non-SL projects were available, SL projects were among the top 3 choices of the students at a 2:1 ratio compared to the non-SL projects.

2.3 *Course elements*

All of these capstone design courses with service learning projects follow a fairly similar, traditional sequence of student activities (Fig. 2). Only one of the five example SL courses in this paper reaches the final construction stage within the context of the course. Within the single semester CEE courses, it is impossible for students to 'implement' their design. In addition, the complexity of many civil and environmental engineering infrastructure projects prevents implementation of the design by students and within a timeframe that the students can observe. In contrast, a key outcome for the Devices for People with Disabilities course is to create a custom assistive device that functions for a specific individual, after iteration through a prototype. Time logs are generally maintained throughout the process. Peer and self assessments generally occur after each set of major deliverables, and this feedback is useful to help instructors assign individual grades from the team submissions. The student reflection exercises

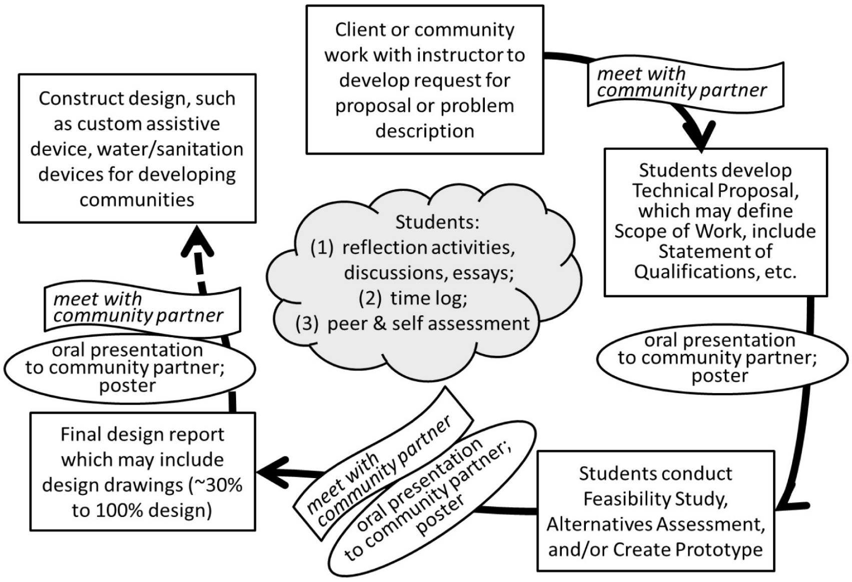

Fig. 2. Example of a typical process for SL-based capstone course projects.

may not be common among traditional capstone design courses, but are a critical element in service learning. These reflections can occur at any time throughout the design process, and are described in more detail in the next section.

Each course requires somewhat different deliverables to assess student learning and assign grades. The deliverables that are common to many of the course models are summarized in Table 2. In some courses the percentages in Table 2 do not sum to 100% due to additional elements being included in the grading criteria, such as time logs and reflection exercises. The different weights of the deliverables show that the different courses focus to varying degrees the phases of the engineering design process.

2.4 *Student reflections*

Reflective practice is a required component of rigorous SL experiences. Reflection has also been shown to be important for learning in a broader context, beginning to activate metacognitive processes to enhance student learning [31–32]. All five of the capstone course examples include multiple student reflection elements, as summarized in Table 3. These reflections can take the form of group discussion in the written design report, separate written essay assignments, and/or in-class semi-structured discussions. It is worth requiring multiple points for student reflection during an SL-based capstone course. However, it is difficult to get engineering students to warm up to the idea of writing reflections. At UVM, because SL is vertically integrated, senior design is not the first time for them to write reflections. These reflections have also been required for all students at CU and SDSU, regardless of the fact that not all participated in SL. The exercises should include some guiding questions to give the students an idea of where to start. The prompt questions can be stated to broadly apply to an array of capstone experiences. For example, at UVM the student reflections on Bloom's taxonomy and ABET outcomes are appropriate for both SL and non-SL projects. The exercise provides an opportunity to talk about lifelong learning and professional skills that are critical to career success. All of the capstone courses include a significant reflection element at the end. However, the specific questions that the students are asked to

Table 2. SL Capstone course deliverables and approximate associated percentage of course grade (N/A = not applicable).

Course	Proposal—problem definition and scope of work	Alternatives assessment / feasibility study	Design (partial to detailed), including report, users manual	Implement and iterate design (prototypes)	Oral presentations
BME, Duke	5%	15%	25%	35%	10%
iDesign, MTU	25%	25%	25%	N/A	25%
Civil Design, SDSU	15%	15%	35%	N/A	35%
Civil & Environmental Design, UVM	10%	30%	35%	N/A	15%
Environmental Design, CU	12%	25%	30%	N/A	23%

address in their individual essays vary significantly across the five courses; see Table 3 for more specific information. All of the courses award at least some portion of the students' grades to the reflection elements; this guarantees that all students participate and take them seriously.

In the course at Duke, one set of the reflection exercises have an 'active' element. Near the beginning of the semester the students participate in a set of disability awareness exercises, where they experience disabling conditions (impaired vision, mobility limitations, reach and strength limitations, cognitive experiences). The exercises are intended to make students aware of different types of conditions. The students are given reading information on '*people first*' language, and in-class the group discusses awareness, experience with different disabilities, and cultural attitudes towards disability. Similar 'cultural preparation' is also a key part of the iDesign experience at Michigan Tech, and is also a required element in the design reports at CU. This foundational knowledge is critical if the students are expected to design appropriate technology to serve clients and communities.

Beyond the intent that students benefit from these reflective exercises, the reflections can also be used for course and outcomes evaluation. Reflections conducted around the middle of the semester can be used by the instructor as formative assessment and to determine if specific interventions for the remainder of the semester are needed. For example, peer evaluations can also be viewed as a form of reflection on teamwork. The peer evaluations are very useful in identifying problems within a group and determining the relative contribution of each team member. Students may also provide information on community interactions and effectiveness in their reflections. The final reflection essays serve as a form of summative assessment. The qualitative information can be coded using approaches similar to ethnographic research methodologies, and therefore be transformed to quantitative data. For example, this approach was used to identify that sustainability was a key concern among SL students at CU (as will be further described in Section 3.3).

2.5 Other recommended practices

The authors have found that additional elements in the capstone design course may be very effective at enhancing student learning. These ideas are not restricted to SL projects and could be beneficial in any capstone design course.

- Stress the importance of the report, providing several deadlines for sections throughout the project
- Have students review other teams' reports
- Self and peer assessments to facilitate equal distribution of work among the students
- External examiners (such as local engineers with PE licenses)
- Detailed constructive feedback on project reports, requiring students to incorporate the feedback in subsequent versions

Elements that help to ensure a successful SL project in an engineering capstone design course include:

- Committed community partners are on same page as university partners.
- Helping students initially understand the project and develop a reasonable scope of work. This may require several iterations between the instructors, community partners and the student team.
- Regular student—community partner meetings. These may require the use of technology when project sites are distant from the university.
- Multiple formal presentations to clients, in addition to town meetings, local professional society meetings (such as the American Society of Civil Engineers), etc.
- Multiple reflection discussions and exercises that are a graded part of the course

3. Student learning outcomes

For a capstone course, the quality of student learning is of utmost importance. Student motivation is a critical factor to attain high levels of learning. Capstone courses offer the opportunity to encompass a great breadth of different learning outcomes; therefore, each course should define these outcomes and determine appropriate methods to assess students' achievement of these goals. For example, student designs can exhibit technical competence as well as an understanding of contemporary issues such as sustainability and the social responsibilities of engineering. This section will discuss these issues, focused specifically on the results observed for the SL projects at the five universities.

3.1 Student interest and motivation for SL projects

Educational theories have pointed to the importance of motivation to the learning cycle. Our data show that students generally are motivated and interested in SL projects. At Duke, the number of students applying to participate in the *Devices for People with Disabilities* course often exceeds the allowable enrollment limit. At UVM, when presented with the statement 'this project experience was better than another type of project (e. g. fabricated, 'made-up' project or a project which has already been done)', 79% of 43 students in 2008 and 100% of 27 students in 2009 said either 'strongly

Table 3. Types of Reflection Exercises and Questions in the Five Capstone Courses

BME, Duke	**iDesign, MTU**	**Civil Engineering Design, SDSU**	**Civil & Environmental Engineering Design, UVM**	**Environmental Design, CU**
(1) Critical reflection on the relationship between academic course content and the service experience. (2) Critical reflection on the ethical and civic dimensions of the service experience. (3) Disability awareness exercises. (4) End of semester essay: ● Do you feel that this experience has changed your perception of people with disabilities? In what way? ● How does your almost finished project compare to your original concept when you chose this project? ● What did you do well? What didn't you do well? ● How can you apply what you've learned this semester? (5) Individual lab notebooks	(1, 2) Pre- and post-departure reflection on intercultural experiences. (3) Post-reflection on personal and professional development from program involvement. ● Describe your professional gains through this experience ● Describe skills you need to improve to continue doing development work ● Describe how your professional and personal future may have been influenced by this program	(1) *End 1st semester, Poster:* Social problem or community need addressed: A. Learning objectives. B. Learning and service outcomes. C. Future directions for the work (for you or the organization). D. Connections between your service and future academic and/or career plans. (2) *End 2nd semester, Final report:* A. Describe the actual experiences that you had with your clients, mentors, advisors, and others in the community. (a) Is there a difference in the way you view problems as an engineer and the way people in other professions view them? Describe the differences; discuss why you think they exist. (b) Give examples of non-technical information that you learned about the project from the people you were involved with during the project development process. Discuss why the information was or wasn't relevant to your work. B. Discuss why it is important for Civil Engineers to work with community members to solve problems. Give examples. C. Discuss how your thought process as an engineer affects the way you view social issues. How will social issues impact your work as an engineer? D. Discuss roles and mechanisms that you can use after graduation to continue providing assistance to your communities as you define them. Why are these activities important to you?	(1,2) Essay on personal goals (what I want out of this project?) once the projects are assigned. Two-thirds of the way into semester another essay on how the personal goals are being met and if any are revised (~1 page long) (3) Essay in middle of semester. At least one paragraph on each of the three aspects of SL: civic engagement, academic enhancement, and personal growth; and a summary of overall experience. A list of questions is provided for each category to start the thinking process. (4) Written reflection on how the project work might be covering the six cognitive levels of Bloom's taxonomy [22] and ABET outcomes [1]. Students rate 0–2 and provide specific examples. This is followed by team discussion and synthesizing the response as a team. (5) Final 'semi-guided' written reflection on overall project experience, using guidelines similar to Reflection 3. (6) Throughout the semester students keep track of individual 'billable' and 'administrative' hours spent on projects and include a summary in their final report. (7) The instructor facilitates in-class discussions reflecting on different issues that arise. (8) Peer evaluations are conducted mid-semester and at the end.	(1) 2–4 page essay at end of semester that is very open ended. General prompts: ● Discuss the level to which non-technical aspects influenced your selected technical/engineering solution. ● Reflect on the 'service learning' aspect of your experience. ● Discuss the primary benefits of this course to you—include 3 most important elements personally. (2) May reflect in the three self and peer evaluations submitted with each deliverable. (3) Instructor facilitated in-class discussion in middle of semester on client issues and non-technical project elements.

agree' or 'agree'. At CU in 2011 there were eight project options offered to the 29 students in the course, five SL and three non-SL design competitions. Students ranked their preferences from one to four; these scores were reversed (top choice = 4 points, second choice = 3 points, etc.) and added. Four of the SL projects were ranked the highest by the students (59, 58, 45, 38 points), followed by the three design competitions (37, 25, 20 points), and finally the last SL project (16 points). The topic of unpopular SL project was significantly less interesting to the environmental engineering students than the other projects (design of salvage options for end-of-life vehicle recycling versus apple waste-to-energy, CU waste-to-energy, biomass-to-biocoal, microhydropower, municipal wastewater treatment, and municipal water treatment).

There is some worry that students may spend too much time on SL projects, to the point that it detracts from their other courses. At UVM students were presented with the statement 'the amount of effort I put into the project was greater than what I would have put in for an equivalent made-up project not involving service'; 60% of 43 students in 2008 and 89% of 27 students in 2009 said either 'strongly agree' or 'agree'. At Duke the students record effort as part of their lab notebook requirement, with typical ranges of hours worked outside of class of 4 to 8 hours per week per student; this appears similar to other non-SL capstone courses. At CU the data from the students' self-reported hours on their weekly timesheets also refute the idea that students spend more time on SL projects. The non-SL students ($n = 65$) averaged 144 ± 36 hours over the semester versus the SL student ($n = 58$) average of 140 ± 36 hours (not significantly different; $p = 0.56$ in two-tailed t-test). In addition, on the FCQs at the end of the semester the average workload per week reported by the CU students was 13–15 hours for semesters without SL projects and/or predominated by non-SL projects, compared to 10–12 hours in the semester predominated by SL projects. The CU SL students rated the workload relative to credit given less strongly in the 'too heavy' category compared to the non-SL students, seeming to indicate a greater willingness to devote the time to an SL project.

3.2 Breadth of learning outcomes

A wide variety and depth of learning outcomes may be achieved with SL projects. These outcomes map over most of the ABET Criteria 3 A to K outcomes [1], and also over many of the 24 outcomes in the American Society of Civil Engineers (ASCE) Civil Engineering Body of Knowledge (BOK) [22]. Table 4 gives a brief summary of different learning outcomes that have been strongly evident in the five SL capstone courses. Faculty judged the achievement of these outcomes for students who worked on SL projects based on direct assessment from course deliverables, with a high level of student achievement of the outcome rated as large (L) down to lower achievement commonly evident. In addition to direct assessment methods, students may self-rate their learning as an indirect outcome assessment; at MTU, UVM, and CU the students rate the ABET outcomes on a written survey at the end of the semester. The data from the UVM and CU courses are summarized in Table 4, scaled as 0 to 3 to correspond to the faculty ratings of not achieved = 0 to large = 3. The students were asked questions such as: the course improved my ability to function on multi-disciplinary teams. The average UVM ratings have been scaled from original student ratings of 0–2 ($n = 64$, 2009–2010). The CU data were scaled from original student ratings of 0–6. Outcomes in the table without numbers represent items that the students were not asked to rate.

The major outcomes achieved by these SL-based capstone courses are still consistent with the desired outcomes for typical non-SL capstone design courses. For example, some colleagues at CU were concerned that SL projects on water and sanitation for developing communities, similar to the projects often associated with EWB, would be too simplistic and not provide sufficient design experience for the students. The data argue against this concern, with example results from CU summarized in Table 5. Students rated the extent their abilities were improved on a scale of 1 to 5 (highest). The average student self-ratings of how much the course improved their abilities were not lower for students who worked on SL projects compared to non-SL projects. The SL projects were clustered into two types: international SL projects for Mexico (2006), Peru (2010), Nicaragua (2002) and Belize (2001); domestic SL projects for CU (2003, 2010) and communities in the U.S. (New Mexico and Colorado). Non-SL projects spanned 2000–2010, including design competitions and consultant-mentored municipal projects and site remediation. The SL projects were perceived by the students as more effective at developing their awareness of the impact of engineering in a global and societal context. Comparison numbers from civil engineering students in their project design course in fall 2006 are also included; these ratings were similar or lower than the ratings for the environmental engineering course. More objective measures of student performance also do not indicate significant differences, with average grades on the design reports which averaged 94 ± 4 for international SL projects ($n = 9$ teams), 90 ± 4 for domestic SL projects ($n = 10$ teams), and 92 ± 5 for non-SL projects ($n = 15$ teams).

Table 4. Learning outcomes associated with service projects based on faculty ratings (L = large, M = medium, S = small, N/A = not applicable, or v*ariable*) and student ratings (0 to 3 = highest)

	Outcome		Capstone Design Course				
Student Learning Outcomes	**ABET A-K [1]**	**ASCE BOK # [22]**	**Devices for People with Disabilities (Duke)**	**iDesign (MTU)**	**Civil Engineering Program Capstone (SDSU)**	**Civil & Environmental Engineering Capstone (UVM)**	**Environmental Engineering Design (CU)**
Design	C	9	L	L	L	L 2.9	L 2.8
Teamwork	*D*	*21*	*L*	*L*	*L*	*L 2.5*	*L 2.5*
Written communication	G	16	L	M	L	L 2.6	M 2.5
Oral communication	*G*	*16*	*L*	*M*	*L*	*L 2.6*	*M 2.6*
Impact in global / societal context	H	11	L	L	M	M 2.4	S 2.5
Professional and ethical responsibility	*F*	*24*	*M*	*M*	*M*	*M 2.4*	*S 2.2*
Lifelong learning	I	23	M	S	S	S-M 2.5	S 2.4
Leadership		*20*	*S*	*M*	*S*	*S*	*S 2.5*
Creativity			M	S	S	S	S
Critical thinking			*S*	*M*	*M*	*S-M*	*S*
Cultural competency			S	L	S	S	Variable
Self-efficacy, self-confidence			*S*	*M*	*S*	*S*	*S*
Sustainability		10	N/A	M	S	S-M	S
Globalization		*19*	*N/A*	*L*	*S*	*S*	*Variable*

It is the opinion of all of the authors that SL projects are equally capable of achieving the core technical outcomes generally expected in capstone design courses, with perhaps a stronger ability to achieve a broad array of additional outcomes when SL is implemented in a suitable manner. Rigorous documentation of these outcomes compared to non-SL courses has been difficult to obtain, due to small student numbers, confounding factors specific to individual instructors, and course models that are difficult to normalize. Three specific outcomes that appear particularly well suited to SL projects are highlighted below: sustainability, cultural competency, and sense of civic responsibility.

3.3 Sustainability

All of the civil and environmental engineering capstone design courses reviewed in this paper included a sustainability theme. Sustainability is an explicit knowledge outcome articulated for civil engineers in the ASCE Body of Knowledge (BOK) [22] and for environmental engineers in the American Academy of Environmental Engineering (AAEE) BOK [23]. The depth of sustainable practices varies depending on the specific type of project. The nature of these projects often has environmental issues at the core, such as drinking water treatment, wastewater treatment, sanitation, and site remediation. All of the projects include a cost analysis and may include broader economic considerations. Impacts on the public are also of key concern with all infrastructure projects. However, working directly with the communities likely increases the students' awareness of the importance of social issues, the difficulty of fully satisfying diverse stakeholders in the process, and ensuring the long-term viability for communities. For example, providing clean drinking water to impoverished communities has life and death implications in many global settings. The system designed by the students must be affordable by the

Table 5. Average ± standard deviation of CU students' self ratings of learning outcomes for different project types

	Environmental Engineering Design			Civil Engineering Design
	International SL	**Domestic SL**	**Not SL**	**Not SL**
Number student respondents*	15–21	13–30	5–29	14–16
Student Learning Outcomes				
Design	4.6 ± 0.5	4.5 ± 0.7	4.6 ± 0.9	3.9 ± 1.1
Teamwork	*4.6* ± 0.6	*4.4* ± 1.0	*4.5* ± 0.6	*4.1* ± 0.9
Written communication	4.2 ± 0.8	4.1 ± 0.9	4.3 ± 0.8	3.9 ± 1.1
Oral communication	*4.2* ± 0.8	*4.6* ± 0.7	*4.0* ± 0.7	*3.4* ± 0.9
Impact in global / societal context	4.4 ± 0.9	3.9 ± 0.8	3.5 ± 0.9	3.2 ± 1.2
Professional & ethical responsibility	*3.9* ± 1.0	*3.6* ± 0.9	*3.6* ± 1.3	*3.9* ± 1.1
Leadership	3.6 ± 1.1	4.0 ± 1.0	3.8 ± 1.3	3.1 ± 1.2

* Varied since some questions were not always on the survey and some individuals did not answer all questions.

poorest of the poor, who may live on as little as 1 USD per day, and be maintainable using local supplies and expertise. At Michigan Tech, a one-semester course, Colloquium on Sustainability, constitutes much of the first semester of the year-long iDesign program. At UVM, the projects related to stormwater and historic preservation have contained the strongest links to sustainability. The students are required to discuss environmental, social, regulatory (including permitting), and economic aspects of their projects in their report. In the conclusion section they are required to discuss what aspects of the systems approach and sustainability could be incorporated in the project and what aspects were not feasible. In the capstone design course at CU, the open ended reflective essays required of all students regardless of work on a SL or non-SL project found that from 2006 to 2009 only the SL students discussed sustainability in their essays. This was irrespective of the fact that a sustainability lecture was included in the course and all students were encouraged to include sustainability in their design criteria. Further, the self-reported ability to design within sustainability constraints was higher for CU students who worked on SL projects compared to non-SL projects; the average ± standard deviation was 4.5 ± 0.7 (n = 28) versus 3.0 ± 1.0 (n = 5), respectively. In the BME course at Duke, sustainability is considered in design and touched on during the ethics reflections.

3.4 Cultural competency

Most engineering design projects will require that engineers interact with non-engineers and non-technical community members or clients. Therefore, students need to develop the skills to communicate engineering concepts in a non-technical way and understand the motivations of different stakeholders. Working in a global setting on international projects requires that students have the ability to understand and communicate across sometimes vast cultural differences. This so-called 'cultural competency' is a skill particularly important for international projects (such as iDesign and EWB-affiliated projects at CU) [23]. At CU the Miville-Guzman Universality-Diversity Scale (MGUDS-S) [25–26] has been used as a simple indicator of students' attitudes that recognize and accept similarities and differences among people. These attitudes are useful for students working across obvious cultural divides and also important to recognize more subtle differences that will undoubtedly be encountered in multi-disciplinary teams as well as stakeholder interactions in all settings. At Michigan Tech the Intercultural Development Inventory (IDI) [27] has been used to evaluate students' intercultural sensitivity as it potentially progresses on a continuum from denial through defense, minimization, acceptance, adaptation, and integration. Based on the IDI quantitative results, a slight improvement (about 3% gain) was found by comparing post- to pre-program results. Most students showed gains, although 20% regressed slightly. On average the group moved from a state of Defense (usually a state of Reversal, indicating a perception that the host culture is somehow better than their own) to a state of Minimization (a belief that there are many similarities among people) [4].

3.5 Sense of civic responsibility

It is stated that a goal of the SL reflective essays is to instill a greater sense of civic responsibility in students [2]. There are assessment instruments that have been designed explicitly to measure this attribute, such as the Community Service Attitudes Scale (CSAS) [28–29]. The survey is rather long, and was used once with senior design students at CU. There were small but statistically significant differences in the Phase 4 Response score, the career benefit, and intention to engage in community service factors at the end of the environmental engineering course for students who worked on non-SL projects compared to students who participated in international SL projects for one or two semesters with travel to the partner community. However, these differences could have been inherent in the students who self-selected to work on the SL projects rather than developed as a result of the SL projects. Further research would be needed to determine if the SL experience itself engendered the impacts on community service attitudes. Evidence of civic responsibility may also be found within the reflective essays and reflective discussions. Three of the SL capstone courses explicitly ask the students to reflect on civic engagement and community assistance; see Table 3: Duke (2), SDSU final reflection element (2D), and UVM mid (3) and final (5) essays. Past surveys at Michigan Tech show that one of the top three reasons that the students chose to participate in international service was to fulfill ethical obligations to society [33].

4. Community outcomes

One of the three defining characteristics of SL is that the community is a true partner in the process, engaged in the problem definition and solution process, and benefitting from the interactions. However, this element has generally not been rigorously assessed, evaluated, and reported in association with capstone SL projects. At UVM the community partners assess the quality/usefulness of student work and students' professionalism, and this feedback is considered while assigning final grades. At

Duke, each community partner provides an assessment of the engineering team at mid-semester and the end of the class; the same time when the teams are evaluating themselves. Additionally, each community partner receives a follow-up contact three months after delivery of the assistive device to assess the performance and see if there are any additional thoughts regarding the experience. At CU, a survey has been given to community partners/facilitators, but this feedback was not used in the grading process.

The iDesign experience at Michigan Tech has been designed as a full-year experience with a clear goal to ensure that the community directly benefits from their involvement. The final designs are delivered to non-governmental partners within the community for later implementation (after construction resources are acquired), and an on-going relationship over multiple years with the same area helps ensure on-going support to support the sustainability of the project. This is similar to the International Senior Design course from which iDesign evolved [34–35].

The domestic civil and environmental engineering related infrastructure projects may have a somewhat extended timeline until the benefits from the student work are realized as a physical reality. At UVM in the past three years about half the project reports were used by community partners within one to two years. This included building on student work; massaging student work and requesting bids by contractors (when the community partner was a licensed engineer); or using student cost estimates for planning purposes. At CU, the students' design of solar water circulators to upgrade a non-discharging wastewater lagoon for a Native American Community was used as a basis for the community to receive a special 'sustainable energy' related grant and after 3-years their design was finally up and running.

The participation of the community partners is also a key to a successful and rewarding learning experience for students. Students are usually vocal if they have problems working with their partners. The community should be informed of the level of their input that is desired. They may perceive that once they provide the initial project description that their work is done and they can sit back and wait for a design. Overall, the student experience is better if community partner stays engaged throughout the course and the project is well defined. This is where the instructor must work with the community and/or individuals in advance of the semester to clearly communicate a realistic idea of what can be achieved within the course, and what cannot. The instructor may need to work with the community to craft a project that includes sufficient design, multidisciplinary aspects, and other criteria needed to fulfill the learning objectives of the course. At both CU and UVM the instructors have sometimes added to the scope of work beyond what the community partners wanted in order to provide the appropriate learning experience consistent with the over-arching goals of the capstone course. At Michigan Tech, preliminary international trips are helpful for faculty to work with non-profits and communities to better understand needs, resources, and logistics.

Local SL projects provide greater student access to their partners. At UVM the students typically visit their sites three to six times over the semester. Since the majority of the projects have none to limited data initially available the students often have to survey key aspects of the site, collect soil samples, etc. At Duke, all projects are local and within a 30 to 45 minute drive, so the students meet periodically over the semester with clients and community partners. Michigan Tech partners with communities in Central America, so the two-week community visit is both a highlight and an intense 24/7 field engineering period. With international projects, on-going contact directly with community partners throughout the design project is not possible, except via technology such as email, primarily via the non-governmental intermediary with the community.

5. Faculty experiences with SL

There are a number of factors that may encourage or discourage faculty from considering SL-based capstone projects. It is a general perception that SL projects require more faculty time than non-SL projects. This is not necessarily true. All capstone design courses are usually intensive in regards to their demand on faculty time. A course that uses hypothetical projects probably requires the least faculty work (particularly if the same project is used multiple years), versus an industry project that could require a lot of faculty facilitation. For SL projects, the faculty reported spending more time before the semester to identify community partners and develop a mutually acceptable scope of work. At Duke, for example, as much as 40 hours may be spent in the semester preceding the design semester. In the first two weeks of class faculty attends each project's introductory meeting and also attend follow up meetings at the request of community partners or students groups. At the project delivery at the end of the semester, faculty meets with each community partner and student group. Course faculty becomes the sole point of contact after graduation and responds to needs for trouble shooting or repair.

During the semester some of the greater workload may also be voluntary. Both students and faculty generally find SL projects more motivating than non-SL projects. This motivation can lead to a greater self-investment in the outcome and as such more time devoted to the project. In addition, faculty are likely to devote more time to detailed review of the student deliverables, since it is unacceptable to provide a poor design to clients (or at least a disclaimer would be needed). The reputation of the program for delivering quality designs to communities can impact future project partnerships, particularly when the bulk of the projects serve local communities. The faculty instructors can feel that their reputation is as much at stake as the students and work harder to ensure that the final project is stellar. International experiences, especially in resource-constrained communities, greatly elevates the workload for faculty as they meet concerns of university officials, parents, community leaders, and other partners, in addition to the participating students.

6. Summary

In summary, SL projects offer rich and rewarding learning experiences for students in engineering capstone design courses. SL projects can be integrated into existing capstone courses as project alternatives or form the basis of unique SL-based courses. SL projects can also be adapted to fit both single semester and year-long course models. SL projects are more motivating to many students than non-SL projects. Careful planning and linkage of desired student learning outcomes to the course experiences can determine if SL projects will provide learning benefits to students that exceed non-SL projects. Structured reflection exercises are particularly important to facilitate some non-technical outcomes, such as a sense of civic responsibility among students. SL projects have the potential to create real benefits for community partners, but the extent to which balanced student learning and community benefits are realized may vary. Faculty will generally devote more time before the semester to develop effective partnerships and may also review designs more carefully.

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