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Incorporating a Systems Approach into Civil and Environmental Engineering Curricula: Effect on Course Redesign, and Student and Faculty Attitudes

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ABSTRACT

This paper presents a brief overview of the changes made during our department level reform (DLR) process (Grant Title: *A Systems Approach for Civil and Environmental Engineering Education: Integrating Systems Thinking, Inquiry-Based Learning and Catamount Community Service-Learning Projects*) and some of the effects of these changes on our students and ourselves. The overall goal of the reform has been to have students learn and apply a systems approach to engineering problem solving such that when they become practicing engineers they will develop more sustainable engineering solutions. We have integrated systems thinking into our programs in the following ways; 1) new material has been included in key courses (e.g., the first-year introductory and senior design courses), 2) a sequence of three related environmental and transportation systems courses have been included within the curricula (i.e., Introduction to Systems, Decision Making, and Modeling), and 3) service-learning (SL) projects have been integrated into key required courses as a way of practicing a systems approach. A variety of assessment methods were implemented as part of the reform including student surveys, student focus groups, faculty interviews, and assessment of student work. Student work in five classes demonstrate that students are learning the systems approach, applying it to engineering problem solving, and that this approach helps

meet ABET outcomes. Initial student resistance to changing the curriculum has decreased post implementation (e.g., graduating class 2010), and many students are able to define and apply the concept of sustainability in senior design project. Student self-assessments show support of SL projects and that the program is influencing student understanding of the roles and responsibilities of engineers in society.

Keywords: Undergraduate engineering education, civil engineering, environmental engineering, systems approach, service learning, assessment, sustainability.

INTRODUCTION

This paper presents an overview of the changes made as a result of our department level reform (DLR) grant (*A Systems Approach for Civil and Environmental Engineering Education: Integrating Systems Thinking, Inquiry-Based Learning and Catamount Community Service-Learning Projects*) and highlights the effects of these changes within the curricula, on courses, student work, and on student and faculty attitudes. We also discuss challenges and opportunities encountered for others who may want to implement similar curricular changes.

The overall goal of our DLR is for our civil and environmental engineering (CEE) students to learn and apply a systems approach to engineering problem solving. A systems approach challenges students to consider the environmental, social, economic and other non- technical aspects of a problem as essential components of the engineering solutions, in essence to be socially and environmentally responsible engineers. The systems approach occurred at different levels within our DLR. First, we took a systems approach in terms of creating curricular reform. Our focus was on educating the whole student including the enhancement of personal/interpersonal skills, development of inquiry-based learning and cooperative learning opportunities within the curricula, and the incorporation of civic engagement, social and sustainability awareness within the program. Secondly, we incorporated the systems approach (e.g., systems thinking and systems analysis tools) within existing and newly created courses and used service-learning projects as a way to practice the systems approach. These ideas resonate well with recent initiatives at the University of Vermont (UVM) (e.g., service learning, Office of Sustainability, UVM's environmental mission), as well as recent literature on engineering education needs for the future (e.g., NAE 2004, 2005; NSB 2007; Duderstadt, 2008; ABET 2008; ASCE 2006, 2007 and 2008). What is widely recognized in these reports and papers is that engineers need to be able to deal with complex interrelationships that include not only traditional technical issues as major components of the problem definition and solution, but human and environmental factors as well (NSB, 2007).

These ideas specifically align with many of the outcomes mandated by ABET (program outcomes a–k). Our program outcomes have been strengthened by our reform efforts. In addition, we wanted our reform to have a strong inquiry-based, hands-on approach through which students are actively involved in the learning process while still providing them with a strong foundation of technical fundamentals. More information can be found on our website; www.uvm.edu/~sysedcee.

Organizational Reform and CEE Programs at UVM

The various reports and UVM initiatives mentioned in the introduction provided justification in the larger context for our reform. We also formed an advisory committee during our planning process to garner input and ideas from professional engineers and former alumni, including recent graduates. We were also strongly motivated by our own personal feelings to teach courses dealing with systems thinking and analysis, inquiry-based and hands-on learning, sustainability, and service-learning projects. We believe that the personal motivations of the faculty are critical core criteria for any successful reform effort and should not be taken for granted. Strong personal motivations helped guide and encourage us during some of the more challenging times of the reform. Student feedback during the implementation was also useful in terms of our ongoing evaluation of the reform.

The B.S. program in civil engineering at UVM has a long and important history officially starting in 1867. It has been continuously accredited since 1936. The B.S. in environmental engineering program is a relatively new program that received ABET accreditation in 2005. Between 2005 and 2010 there has been an increase in the total number of CEE students from less than 150 to over 300. This increase is likely due to a combination of factors including the addition of the environmental engineering program, increasing engineering enrollments nationally, and increasing University enrollments. We also hope that some of it is due to our recent reform efforts. Overall, the number of women students has remained steady at about 24% over the past five years. The percent of women in civil engineering is at about 20%, while the number of women in environmental engineering is over 30%. This is consistent with national trends in civil and environmental engineering. The number of minority students has remained constant at about one percent (~1 %), and is much lower than the national average, yet fairly consistent with the State of Vermont demographics (about 2%).

Since the start of the grant, we have experienced many faculty and administrative changes and continue to go through changes as we near completion of the DLR. During 2005–2009, we averaged nine program faculty members consisting of five men and four women, with several members originally from foreign countries. In 2009, we hired three new faculty members (a full-time lecturer and two tenure-track faculty members) and lost two other tenure-track faculty members. The DLR proposal involved five CEE faculty members out of the nine; however, two of the five have moved to other institutions. Additionally two CEE faculty members (not part of the grant directly) retired and four new ones came on board during this time period. When we were awarded the grant in 2005, we were part of a Department of Civil and Environmental Engineering. We are now combined with mechanical and electrical engineering within a School of Engineering. Upper administration (e.g., the department chair, school director, college dean, university provost) personnel changed during this period. These changes are mentioned because they had an impact on the reform process and faculty attitude, but were unforeseen changes and were all largely outside our control.

Systems Approach and Sustainability

A systems approach to engineering problem solving takes a holistic view and considers the potential interactions among system components and the broader impacts of both the problem and possible solutions on the environment, society, and the economy in both the short and long term. Senge (1994) noted that systems thinking is a framework for seeing and working with wholes, for focusing on interrelationships and repeated events rather than things. Because civil and environmental engineers face engineering problems that are embedded within complex social and environmental systems, engineering students must become conversant with these types of issues and relationships as well as the technical aspects of the problem. Recent papers suggest that these ideas are catching on in engineering education (e.g., Adams and Felder, 2008; Hasselbach and Maher, 2008; Nehdi and Rehan 2007; Porter et al., 2006).

Likewise, sustainability has been a central piece of the reform as these topics are increasingly important in today's world. Sustainability has been stated succinctly as the idea of meeting the needs of the present without compromising the needs of future generations (United Nations, 1987). However, more current thinking defines it in terms of a triple bottom line (Elkington 1998), which means that for solutions to be sustainable they must be economically feasible, socially just (and acceptable) and environmentally sound. Jowitt (2004) noted the importance of sustainability in the formation of the civil engineer as well as the importance of incorporating sustainability into engineering curricula.

Service-learning

Service learning (SL) is an educational approach that couples service to the community partner with academic learning for students. Often SL goals include those related to academic or technical enhancement, civic engagement, and personal and interpersonal skills. In engineering, service learning offers the opportunity to place an engineering project within its social, environmental, and economic context. Service-learning projects also can be inquiry-based, in that students can pursue directions of research and investigation that are of particular interest to them. This can help students develop a variety of investigative, organizational, creative, and interpersonal skills (Tsang, 2000). Several engineering educators have also noted that service-learning projects can help programs meet ABET a-k outcomes (e.g., Duffy, 2000; Zhang et al., 2007; Phillips et al., 2007; Hokanson et al., 2007; and Christy and Lima, 2007; Duffy et al. – paper in this special issue).

A key component of service learning is critical reflection (Jacoby, 1996; McCarthy, 1996; Moffat and Decker, 2000; Collier and Williams, 2005), which helps the students in understanding the significance of the SL project in relation to the multiple service-learning goals. Through critical reflection, students connect thinking and action and stimulate the use of higher-order thinking skills such as analysis, comprehension, problem solving, evaluation, and inference (RMC, 2003). Reflections are often guided and include many forms such as in-class discussions, keeping journals, writing papers/reports and making presentations, among others.

IMPLEMENTATION

In this section, we briefly summarize the major components of our reform. They include the implementation of a systems approach and SL throughout our curricula, as well as specific efforts made to create opportunities for inquiry-based, experiential education, and development of personal/interpersonal skills.

Systems Approach and Systems Courses

The first major reform component focused on introducing core concepts, theory, and applications of systems thinking, systems analysis, and sustainability into five courses, the existing introductory freshman course and senior capstone course, and a newly created sequence of three systems courses (Table 1). The SL projects formed the key strategy for practicing and applying a systems approach which is described in this section.

The systems courses (Table 1) replaced three existing courses - Introduction to Environmental Engineering, Introduction to Transportation Engineering, and Engineering Economics. The first two (e.g., Environmental Engineering and Transportation Engineering) were junior level courses, and the engineering economics was a senior course. We wanted to introduce some of the material earlier so students could integrate and apply it in their final year. Also, because current issues in transportation, the environment and economics are all highly interrelated, we wanted to teach them in a more integrated and interconnected fashion. While some of the core content of the original courses needed to be preserved within the systems courses, the idea was to teach environmental engineering, transportation engineering and engineering economics within a systems framework.

Year		Course Title	Comments
1		Introduction to Civil and Environmental Engineering	New course (instituted during original Planning Grant) introduces systems and sustainability. SL was introduced during DLR.
2	Systems Courses	Introduction to Environmental and Transportation Systems	Introduction to systems, sustainability, economics, and environmental engineering, SL project.
		Decision Analysis in the Environment and Transportation	Continues with economics, introduces optimization and transportation engineering.
3		Modeling Environmental and Transportation Systems	Continues with economics, optimization, introduces systems modeling, dynamic simulation.
4		Senior Capstone Design	SL projects, inquiry-based learning, and civil and environmental design using a systems approach.

Table 1. Key courses and components of the systems reform.

Projects offered an excellent way to achieve this and included such things as biomimicry, global climate change, renewable commodities modeling to incorporate sustainability, land use planning and others. Some of these are described in Rizzo et al. (2009). The content changes were coupled to changes in homework assignments, reflections, and other methods of student assessment and are summarized below.

1. Systems thinking, a systems approach, sustainability and engineering economics are now formally introduced in the freshman and sophomore years. Introducing the material earlier and more often reinforced student learning and emphasized the importance of a systems approach in engineering problem solving. The previous curricula had engineering economics formally introduced in the senior year, and some of the other concepts introduced on an *ad hoc* basis in various courses at the discretion of the instructor.
2. Systems decision analysis concepts and modeling have been expanded, formalized and introduced in the junior year. Some of these concepts were introduced in the transportation and engineering economics classes previously (about 30%), but new material has been added with a focus on case studies that interrelate transportation, the environment, and economics.
3. Dynamic systems modeling (e.g., *Structural Thinking Experiential Learning Laboratory with Animation* [STELLA[1]]) is now introduced in the sophomore year, with a follow-up in the junior

1 http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx.

year. STELLA was not used previously. Traffic modeling introduced in the freshman year is followed up in subsequent years. Optimization and other systems analysis tools are introduced and expanded in the junior year.

4. Service-learning projects as a form of inquiry-based learning and application of the systems approach have been introduced into multiple years of the programs.
5. Incorporating sustainability concepts and projects in the SL aspects have included mentoring homeschooled children in the engineering design process using biomimicry, developing exhibits for ECHO (Lake Science Center), and the design of green roofs, bioretention facilities and porous pavement for stormwater mitigation strategies among others.

Vertical Integration of Service Learning

Our initial plan for the SL component was to have each incoming class adopt a town in Vermont that was interested in working with CEE students on real-world engineering projects. However, during the initial phase of the implementation, we realized it would be quite difficult to work with the same town on relevant projects that align well with individual course objectives for four consecutive years. Therefore, we decided to match individual course objectives with the needs of appropriate community partners (towns as well as nonprofit organizations), but still have an SL component in at least one required course per year. Because our course enrollments have more than doubled during the period of this reform, we have realized that this initial objective is difficult to achieve. Nonetheless, since 2006 every undergraduate student has participated in significant service-learning experiences, and the commitment to SL continues.

Table 2 summarizes the SL courses and projects conducted thus far. Relevant information such as weight of the SL project grade (in percent), community partners, and total number of projects/teams per course is included. It is worth noting that for all courses listed in Table 2, student teams (3-5 students per team) worked on separate, self-contained projects or different aspects of the same overall project. These SL projects are almost always inquiry-based in that they are open ended and students have the freedom to research and explore areas of particular interest to them, within the context of the course/project. In most courses, students are required to write team technical reports and make presentations to the community partners, peers, and faculty. As an assessment, various forms of reflections (self, as well as guided) were conducted. Those included in-class discussions, written papers, and journals.

Dewoolkar, et al. (2009a) described the vertical integration of SL into the curricula in greater detail. Thus far, more than 200 civil and environmental graduates participated in SL projects in their programs. SL has been especially effective in the freshman and senior courses.

Yr	Course	Requir-ed or Elective	Terms	Brief Description of Projects	% of grade	Community Partner	No. Teams per yr*
1	Intro to Civil and Environ-mental Eng.	Req.	Fall 2006, 2007, 2008, 2009	Analyzed/designed traf-fic solutions; Developed interactive exhibits on engineering and environment, historic building assessment, stormwater.	25	2006: Essex, Monkton; 2007, 2008: ECHO Lake Aquarium and Science Center Burlington, UVM physical plant dept, Streams Project	12–16
2	Geomatics	Req.	Fall 2006	Mapping a bike path in Chittenden County	5	City of Burlington	15
	Environ-mental & Transpor-tation Systems	Req.	Spring 2008, 2009	Rain Garden monitor-ing, analyzing runoff and design using Hy-droCAD	10	AWWA Student Chap-ter and UVM	10–20
3	Water & Waste-water Eng.	Req.	Spring 2007	Onsite wastewater treatment for two com-munities	25	Monkton Long Point Com-munity	8
	Modeling Envir. & Transpor-tation Systems	Req	Spring 2008	Mentored home-schooled children on the engineering design process using biomim-icry to solve problems associated with mobil-ity/congestion	20	IBM, ECHO Lake Aquarium and Science Center Burlington, and UVM	10
4	Capstone Design	Req.	Spring 2006, 2007, 2008, 2009, 2010, 2011	Building, hangar design, stormwater design, wastewater treatment, water purification and distribution, small hydroelectric, parking lot design, intersection redesign, green roof de-sign, outlet works rede-sign of a dam, landslide mitigation, building preservation and design, bridge reconstruction, street reconstruction	80–100	Towns of Essex, Taluabe, Greensboro, Chelsea, Milton, Jericho, Shelburne, Barnet, Hinesburg, Middlebury, Burling-ton, Recycle North, Burlington Airport, Ag Museum; UVM, Preservation Trust of VT, Winooski Valley Park District, VT Dept of Forests, Parks & Recreation	6–11
	Geotech Design	Elec.	Fall 2005, 2006, 2007	Analyzed/designed remedial measures associated with historic structures	35	Preservation Trust of VT, Shelburne Farms, Shelburne	4–5
	Hazardous Waste Manage-ment	Elec.	Offer-ed 7 times (1993-2004)	Pollution prevention projects in local institu-tions and businesses that benefit whole com-munity	35	Examples: Fletcher Allen Hospital, UVM, Blodgett Oven, Offset Printing, Dynapower, Medical Center of VT	2–5

*Each team typically consisted of 3–5 students.

Table 2. SL projects integrated into civil and environmental engineering courses.

Research and Interpersonal Skills

As a part of the reform, we also incorporated new hands-on opportunities for students to develop their research and interpersonal skills. We developed soil testing devices, such as flow tanks and an instructional geotechnical centrifuge, and acquired new fully automated soil testing devices (e.g., direct shear, triaxial and residual shear) for use in SL projects and inquiry-based learning projects. In soils courses (junior year Geotechnical Principles and senior year elective Geotechnical Design) students participated in various research projects. Each project culminates in students writing a co-authored technical paper that adheres to ASCE conference paper guidelines. In addition to introducing the students to new tools, these projects help students understand the basics of research, the importance of validating concepts and solutions, the ethical responsibility in exercising care and due diligence in performing labs, and the fundamentals in a hands-on way so they are better prepared to lead complex projects in their careers.

The details of these research modules, associated student self-assessment results, and assessments of student work are reported by Dewoolkar, et al. (2009b). The assessments indicated that many of the curricular reform objectives, ABET outcomes, and higher levels of Bloom's taxonomy (Bloom 1956) could be achieved through these modules.

Many opportunities for developing interpersonal skills were created in the reform. All SL projects included technical reports and presentations to community partners, both engineers and non-engineers. For example: students presented their museum displays on the environment to the general public including elementary school children; they mentored home-schooled middle school children. Upper level SL projects (e.g., electives and Senior Capstone Design) allowed development of leadership skills. The students assumed ownership of the projects, developed a code of conduct, developed a scope of work, executed it, and went to town meetings, if necessary. Some SL projects involved historic structures and sites that demanded sensitivity to cultural heritage while ensuring public safety when designing the retrofits. In spring 2010 and 2011, senior design students were asked to prepare a 5-minute long photo/video stories of their projects. These were used to evaluate their ability to convey project information to people at large who may or may not have technical background. Example photo stories can be found by clicking on this link: Example Photo Stories. All SL projects involved a variety of reflection exercises both written and oral. In addition to traditional lab reports, students wrote technical memoranda and technical papers in conference format (mentioned above). Overall, this wide range of opportunities enabled students to strengthen and improve interpersonal and collaboration skills.

Program Evaluation

Our reform goals have centered on student learning and applying a systems approach to create a socially and environmentally responsible engineer. We want our programs to attract and retain a diverse group of students and be sustainable beyond the duration of the grant. Initially, we outlined four broad goals and each had a subset of objectives. The goals were:

1. To teach students a systems approach for engineering problem definition and solution that creates a socially and environmentally conscious student body;
2. To increase social, racial, gender, and intellectual diversity in our programs and create data to show that this model works;
3. To educate engineers who understand the interconnectedness of things in our complex world, thus creating a more knowledgeable and effective workforce; and
4. To incorporate lasting and sustainable reform within our programs that can be a model for other engineering (and science) programs at UVM as well as elsewhere.

For each of the goals and subsequent objectives, we determined a method of achieving the objective as well as methods of program evaluation. For the purpose of this paper, we focus on the work we have done to achieve Goal 1, as outlined in Table 3.

For the program evaluation, we employed a longitudinal, concurrent, mixed method research design (Creswell, 2003). Quantitative data collection included a first-year experience survey, attitude surveys given in year 2 through year 4 (n = 165), senior exit surveys, service-learning surveys, course content review, and project and assignment review. All quantitative data were analyzed using SPSS (Statistical Package for the Social Sciences) Inc. PASW (Predictive Analytics Software) v17.0.2. Surveys are available online at http://www.uvm.edu/~sysedcee/?Page=educators/surveys-forms.php&SM=educators/_educatorsmenu.html.

Qualitative data collection included written responses to open-ended survey questions, classroom observation, and student and faculty interviews. Written student responses, first year experience survey, the attitude survey, and the senior exit survey were transcribed, coded and analyzed using HyperResearch[2] software. This software allowed us to quantify the number of times students used certain phrases or words as part of oral or written responses. Faculty interviews (n = 4) were conducted with all civil and environmental faculty members responsible for redesign and implementation of systems approach courses. A sample of students (n = 8) were interviewed from the graduating class of 2006 and 2007. Additionally, focus group interviews (by education researchers) were held with seniors (n = 39) at the end of the spring 2008 semester and again in spring 2009 (n = 30). Student focus groups sessions were divided into two groups depending on gender. The interviews, of approximately 60 minutes each, followed a semi-structured interview protocol were conducted by members of the research team. Interviews were audio recorded, transcribed, coded (using HyperResearch software) and analyzed for recurring themes. The qualitative data analysis

2 http://www.researchware.com/products/hyperresearch.html

Project Goals and Objectives	Implementation Method	Program Evaluation Methods
Goal 1: Teach students a systems approach for engineering problem definition and solution that creates a socially and environmentally conscious student body.		
Objective 1: Enhance student awareness of the role and responsibility of engineers in solving social and environmental global issues ***Objective 2:*** Enhance student awareness and understanding of sustainability issues ***Objective 3:*** Require that students incorporate social, environmental, economic, sustainability aspects into design projects	• New systems courses, systems approach activities, better integrated curricula • Practice what we preach by taking a systems approach to education • Service-learning projects incorporated into multiple courses, inquiry-based, and other real world activities throughout program (early and often) • Interweave ethics and sustainability in curricula	• Compare course syllabi before, during, after project implementation to determine what has changed • Examine class projects and labs to determine student learning • Interview CEE faculty and students to explicate experiences, attitudes, dispositions, etc. • Observe and analyze CEE classroom instruction using Reformed Teaching Observation Protocol (RTOP) • Analyze various surveys (e.g., attitude, freshman experience, senior exit)
Objective 4: Enhance faculty knowledge of and ways to incorporate a systems approach, sustainability, and service-learning into their courses	• Faculty training and workshops. Train each other, bring in visiting experts, and attend workshops on and off campus. (UVM has considerable expertise in service-learning).	• Analyze faculty interviews, course and faculty workshop observations, and collected meeting/workshop agendas

Table 3. Example of Goal 1 highlighting objectives, methods for implementation and evaluation.

plan follows the measures described by Miles and Huberman (1997) and Patton (2006). Qualitative data are sometimes misconstrued as anecdotal evidence, but in actuality can provide additional insights into important issues related to the reform and understanding the quantitative results. The use of the HyperResearch software allowed us to quantify various aspects of the written and oral comments.

Instructional lessons (n = 46) have been video-taped and transcribed, and are currently being scored using the Reformed Teaching Observation Protocol (RTOP) created by the Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers (Piburn et al., 2000). The RTOP protocol addresses five constructs that assist the evaluation of instructional strategies found in classrooms. These include: 1) lesson design and implementation; 2) content (propositional knowledge); 3) procedural knowledge; 4) classroom culture/communicative interactions; and 5) student/teacher relationship. This protocol is being used to evaluate Goal 1 and the extent to which faculty-prepared lessons address each objective. Findings from this analysis will guide future professional development activities with CEE faculty. These results are forthcoming, but will comprise an important component of the education research of the grant (i.e., how did faculty members' instructional practices change due to the DLR?).

RESULTS AND HIGHLIGHTS

The vertical integration of service-learning and the development of research projects and interpersonal skills (described earlier) are discussed in more detail in two papers, Dewoolkar et al., 2009a and 2009b. Similarly, a complete description of the mixed method longitudinal study, including initial data and analyses of student attitudes about the roles and responsibility of engineers, is presented in Lathem et al., 2009, 2011. This section highlights some of the interesting implementation aspects of the systems courses and the overall systems approach within the curricula.

Effect on Course Design

The reform has been significant in that five required courses (Table 1) in both the civil and environmental programs have been substantially modified in terms of course content, pedagogy, project work, and reflection activities. However, with that said, these courses only represent slightly more than 15% of each of the curricula. Although the reform influence has spread to other courses that the authors teach (as well as courses offered by other program faculty), much of the curricula did not change drastically.

The effect on student performance products has been largely in the design of projects and assignments that address specifically systems thinking and sustainability. Table 4 provides examples of the assignments and activities used to meet Goal 1 and its four objectives specifically related to problem solving that required students to design systemic and sustainable solutions.

To understand how well CEE students were able to articulate their understanding of sustainability, we developed a sustainability survey and administered it to 35 students enrolled in the Spring 2010 senior capstone design course. This survey contained several open-ended responses that asked students to define sustainability and describe its practices. Students were also asked to rate the importance of sustainability in selected fields within engineering. Results showed that 34 out of 35 students had some sustainability understanding and 26/35 had good understanding of sustainability. Only one (1) student showed no understanding. Of this same group, over 97% felt learning about sustainability in their college education was important or very important. Only one (1) student was neutral. Additional information about this survey and results is presented in Hayden et al. (2010).

Members of the DLR grant team reviewed examples of senior projects that former students (prior to implementation of DLR) had completed. This was an informal review to see if these senior projects contained evidence of systems thinking and sustainability in the design solutions. While we found that the student reports contained high quality work, they did not contain information related to social and environmental impact in a broader context, nor were the topics related to sustainable solutions as compared to many of the senior design projects that students now develop.

Project Goals and Objectives	Examples of assignments or activities that help achieve objectives and goal
Goal 1: Teach students a systems approach for engineering problem definition and solution that creates a socially and environmentally conscious student body.	
Objective 1: Enhance student awareness of the role and responsibility of engineers in solving social and environmental global issues ***Objective 2:*** Enhance student awareness and understanding of sustainability issues ***Objective 3:*** Require that students incorporate social, environmental, economic, sustainability aspects into design projects	• First-year course SL project requires that students address environmental and social impact of project. Also, final reflection question addresses this: *How has the project enhanced your understanding about the role of engineers in today's society? Think about this in terms of broader ideas (e.g., systems thinking, sustainability, civic engagement), technical and scientific know how, and personal/interpersonal skills (e.g. communication, teamwork).* • Sustainability module also included in first year course. • Systems courses content and pedagogy vary significantly from previous courses that they replaced specifically to address these objectives. • Social justice, environmental impact and economics assignments, readings incorporated into all four years. • The above issues also incorporated in sophomore, junior and senior projects. The senior capstone course includes multiple drafts of the project report to encourage more thoughtful research and effort in these areas. Students are required to write about how their design was influenced by the systems approach and where they considered sustainability within the project. • Reflections in senior capstone design course include questions related to systems thinking and sustainability. • Senior essay required: *The role and responsibility of the civil or environmental engineer in affecting environmental and/or social change.*
Objective 4: Enhance faculty knowledge of and ways to incorporate a systems approach, sustainability, and service-learning into their courses	• Three faculty members (grant members) have become SL fellows at UVM. Two faculty members are sustainability fellows at UVM. Two faculty members received teaching and education related awards at UVM (grant members). • Hosted multiple workshops and seminars that have expanded beyond the original faculty members. Created a culture of learning about teaching that includes some post docs and grad students. • Grant members have attended conferences, done additional reading, and incorporated reflections, systems modeling, and sustainability assignments within courses.

Table 4. Implementation activities to address Goal 1 and objectives.

This difference is primarily due to the fact that the previous instructor did not include the concept of system thinking and sustainability in the course. In contrast, the senior DLR grant team members currently teach this course, and these components are intentionally emphasized. Although we would like to say that overall quality of student work has improved since implementing the reform, there are no conclusive data to substantiate this. Our students before the DLR exhibited a similar range of scholastic aptitudes as they do now. What has changed, however, is the inclusion of the broader social and environmental considerations into various projects. Student reflections related to these concerns are now standard, and more systems and sustainability approaches to engineering solutions can now be found in many of our courses and electives.

ABET Outcomes and Objectives

Demonstrating that a program is meeting ABET program outcomes is imperative for successful accreditation. The introduction of a systems approach has helped the program better meet almost all of the outcomes but especially g-k (highlighted below). Outcomes stipulate what graduating seniors have met, while objectives stipulate what graduates achieve within a few years after graduation (ABET 2010). We have added an ABET objective to each program that states**: Graduates of the Civil (or Environmental) Engineering Program are expected to consider the social, economic, and environmental aspects as part of the engineering solution and problem definition.** We currently collect data of our alumni five and ten years post graduation so we will not obtain data related to program objectives from our first graduating DLR class until 2014. Whereas this program objective now aligns with our DLR objective 3, we will be able to assess this as part of ABET assessment well beyond the ending of the grant.

Table 5 summarizes the ABET outcomes and the ways that the DLR has helped faculty members design activities that enable our students to demonstrate these outcomes. Although we do not present specific assessments here because of space restrictions; specific projects and assignments are being mapped to the Program Outcomes.

Program Outcome (shortened form)	Grant aspects that have helped meeting program outcomes and are used to assess outcomes
a. apply knowledge of mathematics, science, and engineering to engineering problem solving	Has not impacted this outcome much.
b. design and conduct experiments, to analyze and interpret data	Geotechnical course has been modified to incorporate research-based learning projects (Dewoolkar et al., 2009b).
c. design a system, component, or process to meet desired needs	Capstone design SL projects.
d. function on multi-disciplinary teams	SL team projects implemented in multiple years of program, and team function assessed.
e. identify, formulate, and solve engineering problems	SL projects in multiple courses including senior design, modeling and other projects in systems courses.
f. professional and ethical responsibility	Professional and ethical responsibilities included in the first-year course and thereafter, specifically in systems and capstone design courses.
g. communicate effectively to technical and nontechnical audiences	SL projects, working with community partners, presenting results, research-based projects.
h. the impact of engineering solutions in a global and societal context	Courses which specifically address a systems approach to engineering solutions (Table 1).
i. ability to engage in life-long learning	Research and SL projects
j. knowledge of contemporary issues	Most of the required courses introduce contemporary issues related to that topic but especially the courses listed in Table 1
k. use techniques, skills, and modern tools necessary for engineering practice	New software introduced as result of the DLR (SYNCRO, STELLA, HYDROCAD, SEEP/W, SLOPE/W); automated geotechnical equipment.

Table 5. Program outcomes (ABET a-k) and grant related activities that help our students demonstrate these outcomes. The gray boxes show the outcomes most affected by the DLR.

Socially and Environmentally Conscious Student Body

By incorporating a systems approach into our curricula, we hoped to create a more socially and environmentally conscious student body (goal shown in Table 3). We used graded assignments and project work to demonstrate that students gained understanding in these areas, but we specifically wanted to evaluate whether we were influencing student attitudes. A student attitude survey was designed to measure the program's influence on student attitudes. The survey contained questions addressing the ABET professional standards coupled with measures concerning current engineering issues such as wetlands and storm water management. Four open-ended questions were included that asked students to describe the strengths and weaknesses of the CEE program, as well as ways in which the program influenced their understanding of their roles and responsibilities as future engineers.

Lathem et al. (2009) presented the methodology for evaluation of student attitudes and provided baseline data to compare with post reform students (graduating class 2010 and beyond). The attitude survey was conducted to help identify differences in attitudes as students moved through the program, as well as a comparison between graduating seniors pre- and post-DLR implementation. For the data collected, no statistically significant differences were found in students' self assessment of the CEE programs' abilities to influence their ***technical*** knowledge by cohort level or academic major for the years before implementation and during the reform except in the area of economics. This was welcome information, because some students and faculty members not part of the reform worried that including a systems approach within engineering would reduce the technical knowledge of students. Students' knowledge of economics was dramatically increased early within the program as compared to students before the DLR. The FE results also show similar levels of success. This was due to the fact that it is now introduced earlier in the curriculum (second semester sophomore year) and reinforced in the junior and senior years, as opposed to only being taught in the second semester senior year.

Women engineering students indicated statistically significant higher means compared to men in their attitudes toward the programs' abilities to increase: their technical skills and knowledge (Kruskal-Wallis H test $\alpha < 0.01$); their attitudes related to the roles and responsibilities of engineers ($\alpha < 0.05$); and the importance of diversity in engineering ($\alpha < 0.01$). Focus group discussions with senior women students revealed that overall women held more positive attitudes toward their engineering program experience and their professors than their male counterparts.

Comparison of different sophomore classes (graduating 2008-2011) surveys revealed significant growth since implementation of the DLR in student attitudes concerning: technical skill ($\alpha < 0.01$); knowledge of economics ($\alpha < 0.01$); and roles and responsibilities of engineers ($\alpha < 0.01$). This is not surprising because the implementation of the DLR resulted in moving the first systems course into the second semester of the sophomore year. Previously, students did not acquire this level of technical information beyond core physics, statics and dynamics classes, until their junior year. Also, previously they did not learn about engineering economics or gain insight about roles and responsibility until their senior year courses.

Student attitudes and adoption of new language were noticeable in analysis of written responses from students in the Class of 2009 (during implementation), 2010 (post implementation), and 2011 as compared to graduating classes before the reform (2006, 2007). Terms such as systems thinking, service-learning, and sustainability were more prevalent in written responses than in previous cohort responses, indicating that these concepts and attitudes were being assimilated earlier in the program due to classroom and programmatic experiences. For example, no references to service-learning were found in the written comments of seniors in the Class of 2006. However, in student comments from seniors in the Class of 2008, 28% of students made references to service-learning projects. A similar trend was found regarding the topic of "systems thinking." For example, no references to systems thinking were made by seniors in the Class of 2006, but 37% of juniors from the Class of 2009 included references to systems thinking in their responses about program influences on their understanding of the roles and responsibilities of engineers, and twenty-two percent of student responses from the sophomores in the Class of 2010 (10 comments) indicated systems thinking. Increased awareness of concepts such as systems thinking and service-learning may lead to the development of engineers who do "take into account … the social, ethical, and moral consequences of [their] decisions" (Rugarcia et al., 2000).

Based on the attitude and other surveys, we believed more attention was needed in the areas of understanding and articulating sustainability issues within civil and environmental engineering. During the final year of the grant, we have specifically enhanced and modified our content related to sustainability and have implemented a new sustainability survey specifically to evaluate this factor. This is a key component of an implementation process; that the ongoing evaluation and analysis helps inform the thinking about teaching and the reform measures, indicators that ABET requires for continuous improvement. We designed a plan, we implemented components of the plan, we reflected and reviewed gathered data, and then made revisions to the plan. Our own critical reflection informed our teaching and reform efforts. We are modeling the attitudes and behaviors we want our students to possess.

An Engineering Systems Approach – Are Students Getting It?

While we have shown that course content and curricular changes have been made in our programs, that open-ended SL projects have been integrated into the curricula, and that students are aware of the CEE programs' abilities to influence their understanding of the roles and responsibilities of engineers as well as technical content, it has been much more difficult to assess whether these curriculum reforms have made a real difference in student understanding and attitudes of systems and sustainability issues. Some students have demonstrated an understanding of the complexity of issues surrounding a SL problem as evidenced by their written reports which now include social and environmental considerations within the various SL project reports (Table 1); and some students have not done as good a job as we had hoped. This could be due to their rejection of these ideas as a result of their underlying attitudes and perceptions about what engineering should be. We have investigated this further in Rizzo et al. 2011. Critical reflections, the idea that students relate the work or experience to learning goals, have provided a method for deeper assessment of student attitudes and understanding of the systems approach.

One of the challenges with engineering problem solving in education is that because so many courses use mathematical formulations that lead to one correct answer, students learn to believe that this type of problem solving ability represents the craft of engineering. Interpersonal skills, communication skills, leadership, systems thinking, critical thinking and decision making are either not perceived as important for engineering students, or are thought to be add-ons to the *real* engineering work. A systems approach requires that engineers see engineering problem solving as comprised of a multitude of components (e.g., social impacts, environment effects, economic factors, communication, decision making, interpersonal skills, as well as the technical aspects). Too often, just the technical is equated with "real" engineering.

In the case of SL projects (see Table 2), those projects that dealt with significant engineering calculations, analyses and design such as the capstone design projects were perceived by students to be worthy engineering projects, whereas those projects that dealt with mentoring school children in the engineering design process or outreach to community members about environmental and social impacts of civil infrastructure were not always perceived by some students in the same light. This was a junior-level systems class that incorporated a SL component that paired engineering students with the local Lake Science Museum and professionals from IBM. The SL project involved mentoring homeschooled children on the engineering design process to solve problems of mobility using biomimicry as inspiration. This SL component provided an opportunity for engineering students to practice a systems approach. The technical component included project development and process design, but a greater emphasis was placed on personal and interpersonal skills development. Although there was some grumbling and complaining about the lack of high-level technical content within the project, critical reflections revealed that most students gained considerable experience in interpersonal and personal skill building, thus meeting those project goals. Coding of the final project reflections and the use of the HyperResearch software revealed that personal and interpersonal skills were frequently mentioned. For example from 28 student reflections, comments related to leadership came up 71 times, communication came up 89 times, creativity 85 times, and the design process came up 102 times. There were over 100 comments related to mentoring. One student (2009–4) put it this way:

> Overall, this project taught me negotiation skills and mentoring skills necessary for public interactions. I got a greater understanding of how to achieve cooperation and deal with setbacks. I hope the knowledge of biomimicry and of engineering design I offered to the mentees helped their problem solving skills evolve with this experience.

These types of personal/interpersonal skills, while valued by many students, were not necessarily thought to be real engineering. Note in the quote above, the student related the "engineering design" with the technical component. Another student (2009–15) from the class was not as open to the experience.

> On the whole I did not feel that this project was that useful for the class or my education as an engineer.

These reflections suggest that more discussion with engineering students and practice on what engineering work really entails is in order. We have already begun some modifications to various courses in response to these results. These reflection results, coupled with reflections from the senior and first-year courses, are currently being analyzed and will be presented at an upcoming conference.

The Process of Change (and How to Avoid Some of the Pitfalls?)

Implementing change is itself a complex process and requires not only vision but planning. As Fullan (1991) notes there is often considerable resistance to change and change can involve conflict because of the various constituencies and their competing goals. Although we thought we had incorporated the various constituencies (e.g., faculty, administrators and students) within the planning process, there was some tension and conflict when the reform was actually implemented. Better communication may or may not have helped in this regard. In any event, it is important for anyone implementing change to consider the change process itself and be prepared for things that may not always go smoothly.

The class of 2009 whose comments were noted above was classified as the DLR transitional group. The curriculum changed while they were sophomores and many were resistant to these changes. Several students went to the professors teaching the first systems course, as well as another professor from the department, to complain about the reform. Another student wrote a letter which summarizes some of their concerns. An excerpt is shown below.

> The faculty has argued that the curriculum is identical and is simply in a different format. This appears to be correct. One cannot, however, disregard the extent to which the format of education has on students. This situation is analogous to receiving change for a five dollar bill. Getting 50 dimes or 20 quarters is the financial equivalent of five ones, yet few would opt for anything but the five bills. As students, we have been conditioned to learn one subject at a time. It is extremely difficult to deal with three professors who are very knowledgeable but also very different (2009–13).

As this student aptly noted, a large part of the course change dealt with the context of the material. Because of the integration, we also team taught the first course. In subsequent years, we did modify the multiple professor aspect, both in response to student concerns as well as our own. Also, we continued to make improvements to these courses although always with the systems format. In implementing change, it is important to be flexible and continuously reflect on the changes being made. However, it is also important to know when to stand your ground. The comment "we have been conditioned to learn one subject at a time," speaks volumes to the challenges for engineering educators who want to take a more integrative systems approach to education.

Student perceptions and reflections about the program's integration of the three systems courses predominated senior focus group sessions held with members of the Class of 2008 (about 12% of this group had taken the systems classes) and Class of 2009 (100% had taken the systems courses). Some CEE students expressed concern (and in some cases displeasure) over the changes taking place. Some students feared that they were not learning the content of each subject area (transportation, economics, and environmental engineering) as fully as they would if these disciplines were taught separately as they had been in prior years. Students were concerned that the integration of a systems approach would lessen their technical knowledge and subsequently reduce their ability to perform well on the Fundamentals of Engineering (FE) exam. These concerns were not realized as evidenced by these students' (Class 2009) performance on the FE and their work in their senior courses and capstone design projects. However, these concerns informed our need to better articulate and demonstrate the systems approach specifically noting that a systems approach is inclusive of the technical components.

In the open-ended questions on the attitude survey, students were asked to comment on weakness in the program. Ten comments from 30 respondents of the 2009 class specifically mentioned the systems classes as weaknesses. There were no comments related to the systems classes in the question asking students to indicate the strengths of the program. In the 2010 class, however, four students out of 40 mentioned these courses as strengths of the program, while only two mentioned them as weaknesses. It will be interesting to see how the perception of these classes by students manifests itself as time goes on. After one year, findings from the student attitude surveys and focus group indicate that students now largely accept the incorporation of the systems classes as a norm, since they do not know the history of these courses. Also, as many of these topics (e.g., systems thinking, sustainability) become more mainstream it is possible that students will see these courses as real innovation within the curricula.

Some of the negative reactions to implementation of the systems courses as well as projects that were less technical in content may be influenced by students' perceptions of what they think engineering education should be. Lortie (1975) succinctly wrote that "occupations shape people" and that occupations with long-established norms and values have a powerful impact to shape a new member's identity and sense of community. Engineering students may therefore enter college with preconceptions about the knowledge, skills, and dispositions they believe future engineers should be taught. What constitutes useful engineering knowledge for some students might be gleaned from previous exposure and stereotypes presented through the media, prior experience with construction work, family members or friends who are engineers, and traditional engineering courses like statics and mechanics.

Negativity in some student responses toward SL initiatives (as uncovered in the focus group sessions and reflections) are not necessarily atypical. Kezar and Rhoads (2001) have described that "dynamic tensions" are inevitably at play with SL projects in higher education. They identified four questions to answer when evaluating the applicability of SL projects within a course or program: 1) what are the learning outcomes, 2) how do organization structures impact the ability of SL to meet educational goals, 3) how does SL fit within the expectations of organization, and 4) how will the SL be implemented and assessed. These questions have also been useful in understanding student attitudes toward the curricular reform of the DLR and in contemplating changes in implementation strategies for future cohorts.

The SL projects for CEE students were intentionally located within required courses within the program. Therefore, in this case, student participation in SL was situated within a cognitive domain. In theory, an out-of-class SL experience should extend in-class experiences and yield a more holistic approach to learning that is both theoretical and applied. A strong connection between the theoretical constructs articulated in-class and the applied out-of-class experience should be apparent and understood by students. Students who expressed dissatisfaction in the student focus group sessions were those who did not see or appreciate this connection. Students who provided favorable comments on the experience were able to articulate this connection. Areas of improvement for SL instructors might be better articulating learning goals and ensuring that out-of-class experiences extend in-class learning.

Although students may be uncertain about the value of the personal and interpersonal goals of SL projects, these affective skills and dispositions are ones valued in the body of knowledge articulated by ABET 2009, AAEE 2009, and the American Society for Civil Engineers (ASCE). In the ASCE 2008 report, *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future*, engineering education programs are encouraged to provide opportunities that enable students to build capacity in the affective domains found in Bloom's taxonomy. The committee asserts that "the profession wants individuals who possess more than knowledge and skill," acknowledging however, that attitudes can only be "taught about" and not directly taught. Overcoming preconceived student attitudes about the value of course experiences that build capacity in one's affective domain presents a challenge that perhaps can be overcome by making the learning outcomes of the project more explicit and understood by students.

CHALLENGES AND OPPORTUNITIES

Some of the major challenges during our DLR came from within our own faculty. As mentioned earlier, two of the original six core faculty members (five CEE and one from Education) left UVM for other institutions. Both were tenured CEE faculty members who already had established traditional research programs. This meant that more of the burden of implementing reform was left in the hands of the remaining four members, three (two CEE and one Education) of whom were untenured. Understandably, new faculty members who subsequently joined the programs did not want to take on additional educational reform work in their starting years at UVM, although they have expressed interest in the reform effort and goals. The change in faculty resulted in some delays in the reform efforts as well; however, we have been able to implement our original ideas, occasionally with some modifications. It is worth noting that of the remaining four faculty members on the grant, three are women, and that a strong camaraderie exists among the four remaining members.

Interviews of the reform faculty members also revealed some signs of disillusionment after the first few years. Some members questioned whether they really could make a difference and whether it was worth it. Increasing enrollments and the need for additional staffing caused increased stress and workloads. Hands-on activities such as SL projects, research projects, and laboratory modules often required more faculty interaction with students which has been difficult to manage especially with increasing enrollments. Integrating the systems courses, especially in the beginning when we attended each other's lectures meant we were increasing our teaching loads without subsequent reductions in other areas. Resistance from students and administrative staff was also discouraging. However, recognizing that disillusionment is often common among change agents, and being excited about and committed to the importance of what we were teaching, helped make these challenges easier to handle.

The change from a small relatively autonomous department into a program within a larger School structure within a larger College was also challenging. Changes in administration can result in lack of interest from those outside the reform efforts. However, this should not come as a surprise, and although a challenge, it can also provide opportunities for educating others about these important education initiatives.

Engineering education research and reform is not always considered “scholarly research” within the realm of promotion and tenure of engineering faculty. Endorsement of engineering education as important avenues of research by ASEE and other organizations has been slow to take hold in many universities. This was also observed in this case as evidenced by some of the reappointment and promotion letters written by administrators for the engineering faculty involved in the reform. Although the junior faculty members were praised for their teaching efforts, they were encouraged to spend more time on their “research” and cautioned against expending too much effort on curricular reform at the early stage in their careers (Administrator A). Regardless of this lack of appreciation of the DLR efforts, the junior engineering faculty members on this grant did receive tenure and promotion and two Engineering DLR faculty also received a total of three teaching related campus awards, largely selected by their peers.

The tensions that occur between innovations in education such as integrating systems approaches and SL projects, and the culture of academia and its preference for traditional engineering research over teaching and service is a noteworthy challenge. From a faculty perspective, the amount of time needed to implement the systems courses as well as set up community partnerships that provide meaningful student projects is significant and in competition with pressures to conduct traditional research. Kezar and Rhoads (2001) noted that applied research projects such as SL are “often denigrated in favor of more esoteric forms of scholarly work.” They also noted that any lack of commitment within the administration, the faculty, and support staff would denigrate successful implementation. Although they were speaking of SL, their message seems appropriate for other pedagogical innovations as well.

Working with local community partners and making a difference in the surrounding communities has been an exciting opportunity for the students and faculty. Student presentations of SL projects at the Vermont Society of Engineers annual fall meeting has been a way to expose the Vermont professional society to our reform efforts and has garnered support and enthusiasm from that group. Working with state and municipal governments has greatly improved our networking capability and provided good public relations for our programs, as well as providing employment opportunities for some of our graduating students.

CONCLUDING REMARKS

Implementation of curricular reform, whether large or small, takes dedicated faculty committed to the reform and knowledgeable about the change process. Change takes time, but often this time can be used to make incremental lasting changes that can be evaluated and modified as needed. Time also allows others to get on board and learn about the reform efforts.

As mentioned earlier, we had our own personal reasons for implementing this reform, and these aligned well with ideas and initiatives of the University and others (e.g., ASCE, ASEE, NSF and NAE). Personal conviction coupled with institutional support is a must for anyone interested in making changes. Support from NSF, and other organizations, not only provides the needed resources to implement change successfully, but also provides the credibility within one's own institution for the reform efforts. While university administrators often speak about the need for higher education reform, all too often they do not back up the talk with resource allocations. Therefore, it is imperative that the NSF and other foundational grant agencies continue to support engineering education reform.

Going through our own critical reflection process has helped improve our teaching, our personal understanding and application of systems thinking, SL, and sustainability. It helped maintain and improve our programs, even when changes outside our control affected us. Although we are still making modifications to our curricula, we are proud of the student experience we have created and hope to sustain it for years to come. We have learned new educational pedagogies, have read the education literature, obtained guidance and insight from our colleagues in education, all of which has helped us become better engineering educators and researchers.

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