A Systems Approach for Civil and Environmental Engineering Education: Integrating Systems Thinking, Inquiry- Based Learning and Catamount[1] Community Service-Learning Projects

C PROJECT DESCRIPTION

C.1. RESULTS FROM PRIOR NSF SUPPORT (Related to Engineering Education) "Developing a Research-Based Undergraduate Experience Focused on "Systems" Thinking, Information Technology and Laboratory Applications" *NSF-02-091 (9/02 – 8/04) henceforth called the Planning Grant*

We found that much of our efforts during the Planning Grant centered on enhancing student and faculty diversity and experiences by; a) incorporating a better sense of community and teamwork within the department and beyond, and b) integrating social and environmental aspects into problem solving (e.g. a systems approach). Because such changes are difficult to assess, we also spent considerable effort developing a plan to evaluate changes made to the programs. During the Planning Grant we: 1) conducted an initial alumni focus group geared toward better understanding the needs of our graduates in today's current workforce; 2) performed a comprehensive review of institutional data, alumni survey data, graduating senior survey data; 3) developed (with the assistance of an education faculty member), and implemented a survey to first-year students that will continue to be utilized; 4) performed in-depth literature searches on engineering education programs and reforms, including NSF sponsored engineering education coalitions; 5) attended and hosted engineering education workshops and conferences, including SUCCEED and other NSF sponsored initiatives; 6) developed curricular and course reform as a result of the various assessment data and research conducted; and 7) implemented initial course and curricular reform. As a result of these activities, we firmly believe that adopting a systems approach to problem solving is necessary in order to better address complex engineering problems. By developing a better sense of community for students and faculty we can create an engineering culture that is more inclusive and supportive of all types of people, especially women and other underrepresented groups. Since finishing the Planning Grant we have instituted the new first-year introductory class and collected and analyzed some preliminary student data.

C.2 INTRODUCTION AND GOALS

At this critical juncture in our technological evolution, with the rapid depletion of the world's resources and an exploding world population, it is vital that we teach our current and future engineers a systems approach to engineering problem solving including concepts of sustainability. It is essential for the welfare and long-term viability of our planet that short and long-term social, environmental and economic impacts be considered and integrated into engineering solutions. ***Our goal is to implement an educational framework that shifts from addressing problems in isolation to one that adopts a systems approach, cutting across traditional disciplinary lines and fostering an integrated approach not only to problem solving, but problem definition as well.***

Figure 1 shows a visual representation of our proposed reform (a catamount paw) that will be used as a key throughout this proposal. The framework for our reform is a systems approach for engineering education, one that includes environmental, social, political, regulatory and economic issues as well as incorporates systems thinking at all levels of the program. Systems thinking or a

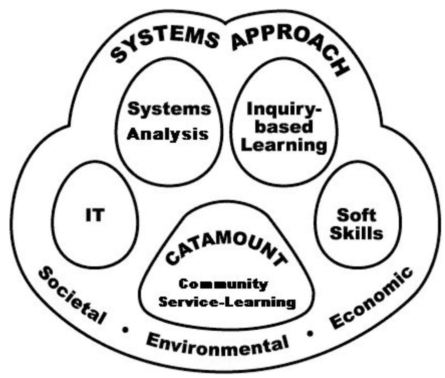


Figure 1: Catamount paw outlining our reform.

[1] Catamount is the name given to the mountain lions that once roamed Vermont. It is the University's mascot.

systems approach, according to Senge (1994), is a framework for seeing and working with wholes, for focusing on interrelationships and repeated events rather than things. Systems thinking consists of a set of general principles, specific tools, and techniques that have been developed with the aim of discovering the "constructs" underlying complex problems. Systems thinking is something that everyone, not just engineers, should do. We believe it is the only way for humans to start developing sustainable solutions to world problems.

At the core of the reform (the main pad) is the concept of community, exemplified by our **Catamount Community** component. The idea is that each incoming class will adopt a small town in Vermont interested in working with civil and environmental engineering students on real-world engineering projects. Throughout their tenure at UVM and in numerous engineering courses, students will work on service-learning projects with their town. By service learning we mean service learning as outlined by Furco (1996) and followed by others, that emphasizes the equal focus on both the service being provided and the learning that is occurring. The principles set forth by Howard (1993), provide an excellent guide for ensuring successful service-learning projects and will be followed in our projects. Developing a sense of community will also occur at the departmental level, expanding to these across-the-curriculum service-learning activities with Catamount Communities, thus providing students with multiple, first-hand opportunities for studying and solving real-world, complex problems. A strong sense of community for our students and faculty will create a supportive, exciting environment for learning, and foster the development of crucial technical and non-technical skills. Establishing student communities has been demonstrated as a way to increase retention in undergraduate engineering programs (Ohland and Collins 2002). Working with Catamount Communities in a service-learning format will allow students a mechanism for constructing and personalizing a true systems approach to problem solving. We believe that integrating social and environmental components into our curricula will be a means for increasing social, racial, gender and intellectual diversity within our programs and thus serve as a model for other engineering programs.

The most essential tools and skills that engineers need to solve today's complex problems are shown as the remaining pads of the paw (Figure 1) and include systems analysis, IT applications, inquiry-based learning (IBL) and personal/interpersonal (P/I) skills also called "soft" skills. ***Systems analysis*** is a branch of systems thinking that deals with decision making and optimizing social and technological systems. It includes a variety of complex numerical and modeling techniques for application to complex, multi-dimensional problems. ***Information Technology (IT)*** is an essential tool that is important for engineers and included in our reform. Due in large part to the continuous advances in IT, today's engineers must also be able to keep up with the dramatic explosion in scientific knowledge. From microscopic sensors to satellites, technology has increased the spectrum (well beyond the visual) from which humans gather data, observe patterns, process and analyze information. ***Inquiry-based learning*** (also called research-based learning) focuses on open-ended problem solving. It can be defined as a multifaceted activity that involves making observations; posing questions; examining the literature; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (NRC 1996). ***Personal/Interpersonal (P/I) skills, also called "soft" skills***, include teamwork, communication, leadership and other personal/interpersonal skills needed by engineers, especially in dealing with large, complex projects. These skills are also crucial for successively adopting a systems approach to problem solving.

Instituting this type of curricular reform results in educational questions related to learning and the construction of knowledge. Thus, our proposal also includes important educational research components and a strong evaluation and assessment piece that will be interwoven throughout our reform process. We also propose to reform by repackaging and reformulating our existing coursework to provide a more integrated, connected and meaningful experience for our students. We will institute further change by changing the way we teach. Thus we are taking a systems approach to the reform itself by considering not just what we teach, but how we teach it, where, and even when we will teach. The specific goals and objectives for the proposed reform and the methods and approaches used are outlined in Table 1.

The State of Vermont, the University of Vermont (UVM) and the Department of Civil and Environmental Engineering at UVM have a long history of environmental focus. This has been emphasized by our current President Dr. Daniel Fogel (2002-present) in a mission and vision for the University that includes environmental, technological and computational components as cornerstones to UVM. Given this, our plan with its key environmental and social considerations, advanced computational components, and community-based activities, compliments the strengths and mission of the University as well as that of our own department. (Please see support letters from Presidential, Dean and Chair.)

Table 1. Goals and objectives of the proposed reform and method for implementation

<table>
<tr><th>Project Goals and Objectives</th><th>Summary of Methodology</th></tr>
<tr><td colspan="2">Goal 1: Teach students a systems approach for engineering problem definition and solution that creates a socially and environmentally conscious student body</td></tr>
<tr><td>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</td><td>• New systems courses, system approach activities, better integrated curricula
• Practice what we preach by taking a systems approach to education
• Catamount Community projects incorporated into multiple courses, service learning projects, and other real world activities throughout program (early and often)
• Interweave ethics through curricula</td></tr>
<tr><td>Objective 4: Enhance faculty knowledge of and ways to incorporate a systems approach, sustainability, and service learning into their courses</td><td>• Faculty training and workshops. We will train each other, bring in visiting experts, attend workshops on and off campus. (UVM has considerable expertise in service learning)</td></tr>
<tr><td colspan="2">Goal 2: Increase social, racial, gender, and intellectual diversity in our programs and present data to show that this model works</td></tr>
<tr><td>Objective 1. Increase recruitment and retention activities specifically targeting diverse groups (e.g. women, minorities, socioeconomic diversity, alternative lifestyles)</td><td>• Coordinate with professionals at UVM in this area, as well as marketing company
• Target underrepresented groups in information and marketing pertaining to reformed programs
• Introductory course and better first-year advising and mentoring</td></tr>
<tr><td>Objective 2: Develop a stronger sense of community within the civil and environmental engineering programs and with other disciplines</td><td>• Introductory course in first year
• Catamount Communities
• Focus on teamwork
• Team up with other college faculty for capstone and senior project courses</td></tr>
<tr><td>Objective 3: Create more integrated programs and a better advising system and alumni network system.</td><td>• Integrated courses
• Incorporate themes into programs
• Closer contact with first year students through Intro course and advising</td></tr>
<tr><td colspan="2">Goal 3: Educate engineers that understand the interconnectedness of everything in our complex world, thus creating a more knowledgeable and effective workforce</td></tr>
</table>

Objective 1: Students learn to use systems engineering, systems analysis and inquiry-based learning approaches in problem solving ***Objective 2:*** Students are exposed to advances in experimental and computational technologies ***Objective 3:*** Students use IT skillfully ***Objective 4:*** Students develop communication, teamwork, and leadership skills	• Integration of systems into program and reformulating courses • Integration of programmatic themes • Better faculty training in these areas so that we can better incorporate into courses • Better organized and more formalized approach to integration
Objective 5: Students gain real-world experience	• Catamount Comm. service-learning projects
Goal 4: Incorporate lasting and sustainable reform within our programs that can be a model for other engineering (and science) programs at UVM as well as nationwide	
Objective 1: Better faculty training of needed skills, including networking and developing ties with community leaders	• Attending and hosting workshops • Faculty working with Dr. Downer on Catamount Communities
Objective 2: Broad dissemination of our approaches, results, education and assessment piece, and conclusions to colleagues and administrators at UVM, other institutions, the public, congress and other interested people	• Working with a marketing company for promoting our program as well as professionals in this area at UVM • Attending meetings, networking with colleagues at other institutions • Presenting results in papers, on websites, in newspapers and other media

C.3 BACKGROUND

C.3.1 Systems - A system is defined as a set of interrelated components that perform several functions in order to achieve a common goal. It is an entity that maintains its existence and functions as a whole through the interaction of its parts. Systems have several basic characteristics. First, for a system to function properly, all of its components must be present and arranged in a specific way. Given this, systems have properties above and beyond the properties of the parts from which they are made (these are known as emergent properties). In addition, when one changes one element in a system, there are always side-effects. Second, systems tend to have specific purposes within the larger system in which they are embedded, and this specific purpose is what gives a system the integrity that holds it together. Third, systems have feedback that allows for the transmission and return of information. This notion of feedback is crucial to systems operation and to systems thinking (Anderson and Johnson, 1997).

As pointed out by O'Connor and Mcdermott (1997), systems thinking looks at the whole, the parts, and the connections between the parts, studying the whole in order to understand the parts. It is the opposite of reductionism. It represents a broad-based, systematic approach to complex problems. In its elementary form, systems thinking stresses the need for the engineer to consider all factors, influences, and components of the system, including the environment and society that surround a particular problem as relevant to understanding and solving a problem. It calls for thinking of the "big picture", balancing short-term and long-term perspectives, recognizing the dynamic, complex and interdependent nature of systems, and taking into account measurable and nonmeasurable data (Anderson and Johnson, 1997). Capra (1996) notes that for solving today's complex problems, "from a systemic point of view, the only viable solutions are those that are sustainable." Sustainability is the idea that a society satisfies its needs and aspirations without diminishing the prospects of future generations. Thus, true systems thinking leads to thinking sustainably.

Incorporating systems thinking into civil and environmental engineering curricula is quite natural, since all problems within that discipline have social, human, environmental, regulatory, political and economic components as well as technical and engineering issues. Frank (2002) presents an excellent model that can aid in increasing engineering systems thinking within engineering curricula. He developed a three-dimensional model to describe the process of designing a curriculum intended to develop the capacity for engineering systems thinking. The three dimensions (3-D) of the model are 1) knowledge; 2) engineering skills; and 3) interpersonal as well as personal qualifications (behavioral competencies). Frank also suggests a learning environment that combines simulations, case studies, analysis of real systems, team exercises, and projects designed to develop and produce interdisciplinary systems through teamwork.

C.3.2 Community and Service-Learning Activities at Other Institutions - *Projects that Matter* (Tsang, 2000) is a book that presents examples and ideas of service-learning in engineering. Several engineering programs have introduced service-learning design projects (e.g. University of Michigan, Mechanical Engineering, University of Utah, Civil and Environmental Engineering, EPICS program at Purdue) (Tsang (2000), Schultz et al. 2000; Zitomer and Johnson 2003). The objectives of these programs are to encourage higher-level critical thinking with open-ended problems, alter the stagnant lecture-homework format typically found in undergraduate engineering courses, and introduce real-world datasets and updated technology into the classroom. Service-learning projects require both a community (or community group) need and a learning need. The four main components (University of Maryland) and outline in their PARE model; (1) Preparation which includes choosing a partner, determining the scope of the project and learning outcomes, (2) Action which includes doing the project, (3) Reflection which means relating the service project to the learning, and (4) Evaluation looking back on the experience and how it worked. Both NSF and ABET believe that undergraduate engineering programs must provide a curriculum that teaches graduates to understand the impact of solutions in a global and societal context (NSF 1996; ABET 2003). According to Tsang (Tsang 2000) "coupling service-learning with design-across-the-curriculum thus offers an innovative pedagogy to achieve the desirable student outcomes described by ABET". These activities also support a systems approach to engineering education.

C.3.3 Engineering Methods, Tools, and Skills

Systems Analysis **-** The birth of the field of modern systems thinking can be largely attributed to series of conferences organized through the Josiah Macy Foundation, which took place between 1942 and 1951. In these conferences, several innovative thinkers in biology, computer science, anthropology, engineering and philosophy pushed back the boundaries of systems thinking, and the field started developing in different directions. One direction was *general systems theory*, which came from the work of biologist Ludwig von Bertalanffy, and is based on the notion that complex systems share several principles that can be uncovered and modeled mathematically. Another direction was the field of *Systems Analysis*, which is similar but deals more with decision-making to control and optimize social and technological systems. Systems Analysis uses various computational and mathematical methods for modeling, visualizing and investigating systems and will be one of the skills that this reform will incorporate into the programs.

Information Technology **-** Recent advancements in IT, in part, have led to dramatic changes in the profession of civil and environmental engineering. The dream of smart structures, intelligent transportation systems, and self-monitoring remediation systems is beginning to materialize thanks to the recent advancements in communications, electronics and computer technology. Advancements in computer hardware, software, mathematical modeling and systems analysis are also allowing engineers to tackle problems that no one would have imagined a decade or two ago. Given this, it is essential that current and future civil and environmental engineers be well-versed in IT and computational applications. Also, effective use of IT during class time, increases the depth and breadth of topics that can be covered in an undergraduate engineering course (Smith and Komerath 2000).

Inquiry-Based Learning **-** Given the dramatic explosion in data and information education specialists are promoting critical thinking and knowledge discovery skills as core aspects of undergraduate education. One of the best means of helping students develop those skills is through research-based or inquiry-based education. As Huber (2000) points out, learning through research, an idea rooted in the classical concept of a university as conceived at the beginning of the 19^{th} century, should be regarded as an indispensable element of a university education. Two recent reports (Boyer Commission on Educating Undergraduates in the Research University, 1998; Center for Science, Mathematics, and Engineering Education, 1999) stressed the importance of research-based and inquiry-based approaches to teaching and learning in the early undergraduate years. The NSF/5C5E Handbook: Doing Science Research in the Classroom outlines methodologies for implementing research activities in the classroom. Inquiry-based learning is also a major focus of the NRC's standards for scientific learning (NRC 1996; Olson and Loucks-Horsley 2000). Learning through inquiry and research, however, is a new experience for most students. Teaching in this manner is also new for most faculty members. Therefore, it requires a significant change in attitude and behavior on the part of both groups (Olson and Loucks-Horsley 2000, Bransford et al. 1999).

Personal/Interpersonal Skills - Education in personal/interpersonal skills includes not only training in writing and public speaking, it also means improving social and interpersonal skills such as leadership, the ability to work with others in teams (Breslow 1998), and metacognitive skills (NRC 2000). Metacognition is the ability to gauge one's own learning and understanding, and often takes the form of an internal dialogue. Metacognitive instruction should be integrated into curricula (NRC 2000). Teamwork, like metacognition, is also a skill that needs to be taught but is more often left up to the students to figure out for themselves. Many faculty members assume that by assigning group projects the students will actually work in teams. This is often not the case. Breslow (1998) stresses the need for training students and faculty in teamwork skills. In undergraduate engineering education, it has been shown that employing a teaching style that emphasizes skills such as teamwork and communication increases student retention and motivation (Gordon, Schrage et al. 1996; Porter and Fuller 1997).

C.3.4 Civil and Environmental Engineering at UVM - The Department of Civil and Environmental Engineering at UVM is a small department with currently 10 faculty members. We offer two undergraduate degrees, a B.S. in Civil Engineering, and a B.S. in Environmental Engineering. Our programs are made up of about 120 undergraduate students and about 20 graduate students. For the past several years we have maintained 25% women in our undergraduate programs with an average of 27.4%. Our graduate program has been greater than 50% women for the past 7 years. Except for a small private military college, UVM offers the only BS Civil and Environmental engineering programs in Vermont. It has the only engineering Ph.D. programs in the state. This makes our programs a valuable resource.

While small, we maintain considerable rigor and have been able to make changes within our curricula to meet changing times. These include: 1) NSF Planning Grant (2002-2004); 2) reintroducing a modified first year course (direct outcome of freshmen engineering workshop hosted by UVM, put on by M. Ohland of SUCCEED coalition and related articles (e.g. Hoit and Ohland 1998); 3) creating a new B.S. in Environmental Engineering;4) modifying and upgrading laboratory activities and equipment (e.g. geomatics, hydraulics, soil mechanics, hydrology, groundwater); and 5) providing research opportunities for undergraduates through the Barrett Foundation Grant, faculty research grants and University grants.

C.4 METHODOLOGY AND APPROACH

Creating a systems approach framework by incorporating social and environmental components will very likely increase our success in retaining a more diverse student body. Likewise, developing projects and linkages with Catamount Communities will likely increase our success in recruiting and retaining a more diverse group of students. Given the complexity and interrelated nature of the goals and objectives presented earlier we have presented our methods and approaches to meet our goals by following Figure 1. Portions of the icon are darkened to show the reader the part of Figure 1 we are discussing, and the linkages to goals and objectives. These have also been highlighted in Table 1.

C.4.1 The Framework: A Systems Approach - Incorporating systems thinking within the curricula is our fundamental goal. We believe that engineers must understand the interrelationship between engineered solutions and the environmental, social, and economic components in which they are placed. Furthermore, engineers must consider these non-technical components during the problem definition stage, within the design process, and then in the final solution. We want to challenge engineers to think critically about their role and responsibility in technological and engineering applications, and to incorporate not only a professional ethic, but a social and environmental ethic as well. The crux of this matter, however, is how to teach this to students. The first step is, and will continue to be, for the faculty to take a systems approach in our educational programs, in our roles as educators, and even in our daily lives. This will involve education and continual learning in this area as well as practice. The whole Planning process in combination with writing and rewriting this proposal has been a part of our systems training. We now recognize that everything in our programs, including the people and infrastructure, is interrelated.

First, systems thinking will be integrated throughout the four years in many classes and in multiple venues. The best way for students to construct new knowledge is through personal, eye-opening experiences. Thus the focus of our newly instated first-year Introduction to Civil and Environmental Engineering course is systems thinking. During the Planning Grant, we expended a significant effort in developing this course. We wrote a course booklet that includes information and background on the various activities for this course. ***This is a hands-on course that focuses on a systems approach to engineering problem solving and is geared for the first-year engineering students. It was a direct outcome of our Planning Grant.*** If awarded, we would incorporate a Catamount community activity and visit for this course (the graduating class of 2009). We will also institute junior/senior mentors to help with this class (See support letter from Student chapters). Short hands-on projects in transportation, geotechnical, and environmental engineering will be related to the community and geared toward first year students. These projects will be designed to help students develop systems thinking skills.

Second, we propose to reformulate three existing courses; Transportation engineering, Introduction to Environmental Engineering, and Engineering Economics and Analysis into a series of three systems classes (Systems I, II, and III). These courses will use ecological systems, and engineered environmental and transportation systems as the major examples. The series will start in the second semester of the sophomore year and run consecutively for three semesters. Through this venue we will be able to introduce conceptually and quantitatively systems thinking and systems analysis. These courses will be developed and co-taught by Hayden, Sadek and Rizzo, and although we are aware of some of the pitfalls in this integrated approach, we believe it is the best way to really teach and practice systems thinking.

Third, we propose to reformulate Fluid Mechanics and Soil Mechanics into two consecutive courses (Fluid and Soil Mechanics I, and Fluid and Soil Mechanics II). This will allow greater depth, breadth and continuity of basic continuum mechanics ideas, and allows more of a systems approach to understanding soil/water systems. A course in Materials will also be revised to include environmental and nanomaterials, systems and inquiry-based approaches.

The Catamount Community approach is central to incorporating a systems approach to engineering problem solving and will help us meet several of our specific objectives under Goal 1. This idea will be discussed in the next section. We will also create other opportunities within the curriculum including the following.

1) Integrating systems thinking concepts through existing required courses for all years of our program (across-the-curriculum) primarily through a variety of activities ranging from homework problems to service-learning projects that utilize the systems approach to problem solving.
2) Integrating concepts of Sustainability and Ecology into the Curricula. Ecological systems provide some of the best examples of showing what a system is. Also, to really address sustainability issues, students must have a basic understanding of the earth and its ecosystems. Materials cycling, energy flows, feedback loops, nonlinear processes are important features of ecosystems, as well as all systems. Capra (1996) notes that systems thinking is prerequisite to addressing sustainability issues.
3) Interweaving ethics discussions, concepts and case studies into the programs. Again, starting in the first semester and continuing throughout. Social responsibility, sustainability and environmental considerations all require important ethical considerations, thus ethics is also integral to systems thinking.
4) Senior Seminar Course is required of all seniors and will be moved to the fall semester of senior year to facilitate discussions in systems, critical thinking, ethics and sustainability prior to the final capstone design experience.
5) Workshops, seminars and training programs will be developed and instituted for engaging and enhancing faculty member awareness of this comprehensive approach in order to institute changes to

traditional civil courses such as Materials and Structures. Information and ideas for such integration is available (e.g. Broman et al. 2002).

C.4.2 The Core: Catamount Communities - The central piece of our educational reform and one in which numerous ideas and enhancements are embedded is what we call Catamount communities. As defined earlier, each incoming class will adopt a small town in Vermont and throughout their tenure at UVM and in numerous engineering courses (starting in their first year), students will work on projects with their town. This introduces an engaging service-learning component very different from "virtual" city projects of other programs, but more integrated and manageable than what is often done at larger schools with their service-learning courses.

Many small communities in Vermont and elsewhere are dealing with difficult social, environmental and technical infrastructure problems. Often these communities lack the technical expertise and resources to even investigate their problems. The Catamount communities program can provide a real service to these communities while providing students with an opportunity for real-world problem-solving and design experience. Coursework, tours, and design projects will be based on real community issues, providing a link between engineering education and local projects (Table 2). Depending on the town and their needs, some of the possible projects listed in Table 1 will be implemented. We anticipate that students will be involved in at least six different activities and course projects throughout their four years with at least one activity in each year.

Table 2. Potential Catamount Community activities for each year in the program.

Year	Catamount Community Activity
1st	Introduce Catamount Community and town manager in ***newly developed*** Civil and Environmental Engineering course, labs from the course (e.g. transportation, hydrology, and soils) will be related to town concerns; the AutoCAD course in the first year can include homework problems related to the town
2nd	GIS labs in Geomatics course will be related to town. System I course will use examples and mini service learning project from the Catamount Community
3rd	Design and research projects in Systems II and III, Water and Wastewater, Fluid and Soil Mechanics.
4th	Various Engineering Electives (e.g. Hydrology, Waste Management, Traffic Design, Foundation Design); ***Capstone Design Course -*** Larger project with Catamount Community

Our Catamount Community plan involves hiring a coordinator; an emeritus professor (Dr. Downer – see letter) from our department still actively involved in FEMA and town assistance projects. He will assist us by organizing and developing potential course projects, work with town leaders to obtain the necessary information required for projects, and assist students in the field. Dr. Downer will also train the faculty and help us in networking so that we can maintain this program beyond NSF funding. Consultant liaisons (local alumni committed to UVM) will assist at various levels (e.g. reviewing student preliminary designs, assisting students and faculty, as well as interacting with Dr. Downer). It should be noted that student designs and projects will be used to assist town leaders in decision making.

The University of Vermont Community-University Partnership and Service-Learning (CUPS) program (see letter) will also be used as a valuable resource. Dr. Hayden recently was awarded a Service-Learning Fellowship that provided intensive week-long training and follow up on Service Learning. CUPS can also assist in service-learning networking and assistance. Through their office, Dr. Hayden has already been in contact with David White from the Burlington Planning Dept. regarding civil engineering projects. Burlington (a city of about 40,000) could potentially be our first Catamount Community.

The Catamount Community idea not only ties directly with the systems approach goal, but will make a real difference in recruiting and retaining a diverse group of students. By broadly disseminating real successes through various media outlets, including news articles and the web, we hope to attract students who want to implement social and environmental change who might not have thought of engineering as a career choice.

Developing a Sense of Community - Creating a supportive atmosphere for students, especially underrepresented students, is critical for recruiting and retaining a more diverse, creative workforce, and this lies at the very heart of our curricular reform. Drexel's E4 program, which restructured their engineering curriculum to include more laboratory projects, team-orientated exercises, and faculty-student interaction, increased student retention by 15% over the existing program (Quinn 1993). Creating a supportive community that encourages diversity and helps each student to achieve their true potential both in technical skills and non-technical aspects is one of our primary objectives. Two specific examples of how we propose to do this are given. Numerous other activities related to this are already integrated into other sections of the proposal.

1. Increasing Diversity - By instituting the outlined changes, we hope to provide a more attractive educational experience for women and other underrepresented groups, which will help in retention. We have already started working with our College recruitment specialist (Josie Herrera - see letter). We will get the message out about our new program reforms, and actively promote our new program by capitalizing on existing K-12 programs in the college, as well as outreach to schools in Vermont and the region. Existing K-12 activities in the College include: National Engineering Week , K-12 School Tours of engineering at UVM, Girl Scouts –Gizmo Girls (http://www.emba.uvm.edu/gizmogirls/), Design TASC – Technology and Science Connection (TASC) Competition www.emba.uvm.edu/tasc, SUMMER DISCOVERY – Engineering Robotics Rescue Vehicle Course, TEAMS Competition and many more. We will also work with a local training and marketing company (called MSI) to develop custom recruitment and retention multimedia materials including live video to help promote the exciting "real world" experience that a student will gain while advancing through this program. MSI will also perform many Public Relation functions that will help promote the programs (e.g. avenues for local and national media attention, traditional press releases as well as advanced multimedia based materials.)

2. Active-Learning Classroom -We propose to modify our main teaching classroom to help us better integrate the teaching components of lectures, a wide-range of IT/computer related activities, project-oriented instruction, and effective community-building. Appropriate classroom design is essential to provide a highly collaborative, hands-on, computer-rich, interactive learning environment (Beichner et al. 2000). The space must provide for a diverse spectrum of instructional activities and styles and be sufficiently flexible to incorporate future upgrades and innovations in teaching methodologies. We feel that "studio" classrooms, as implemented at RPI (Jackson 2002), NCSU (Beichner et al. 2000) and Clemson (Moss and Melsheimer 1999), are the most appropriate models. We propose to instrument the classroom with laptop computers, one for every two students arranged as workstations, so that groups of two to four students can work independently on team projects. Laptops were chosen for several reasons (see Beichner et al. 2000). They state that "laptop computers on the students' tables are an absolute requirement."

C.4.3 Integrating programmatic themes (Systems Analysis Tools, IT, Inquiry-based learning), and P/I skills throughout the curricula - A continuum of technical concepts, techniques, skills and methodology will be emphasized throughout the courses in the undergraduate curriculum. We call these our programmatic themes and include systems analysis, IT applications, and inquiry-based learning (IBL). These are the necessary technical tools that will be important to create a knowledgeable and effective engineering workforce capable of solving complex engineering problems. In our reformed programs, students will acquire this core set of thinking and analysis skills that they will consistently apply to solve increasingly difficult engineering problems within their courses, culminating with a senior capstone project. By introducing a core set of skills in the 1st year and developing these further in successive courses and years, students will be empowered with the tools necessary to critically analyze complex problems as well as understand the interconnectedness of their coursework.

In addition, we will integrate training in and application of personal and interpersonal skills. The idea of educating students in personal/interpersonal (P/I) skills is one whose time has come. The message from ABET, NSF and other quarters is the need for engineers to develop skills beyond the traditional technical/problem solving venue. Teamwork, writing, public speaking, ethics, leadership, and decision-making are just a few of the important P/I skills that are needed by engineers now and in the future. These skills cannot be taught in one course, but need to be threaded throughout the undergraduate experience both in the classroom and in outside activities. One of the challenges is that the faculty is often not knowledgeable enough in these areas to teach them. One aspect of our approach will be to train ourselves and other faculty through attendance at various workshops, and developing workshops on campus through UVM's Center for Teaching and Learning.

The integration of programmatic themes and P/I skills will occur along four main dimensions: 1) workshops for faculty training; 2) course content reform; 3) laboratory reform; and 4) undergraduate research experiences.

***1) Workshops for Faculty Training* -** As a first step toward integrating the programmatic themes (Figure 2) into our curriculum, the principal investigators will develop and conduct workshops aimed at training faculty members. One example includes a systems thinking workshop to introduce the systems thinking methodology, its focus and tools, as well as provide examples for how this methodology might be introduced into our classes. Another will be an IT workshop that will present an overview of MATLAB, and examples on how it can be used to support the way we teach many if not all of our classes. The workshops will allow easier integration of the programmatic themes into a majority of the classes, although the intensity and depth of these activities will vary with the class. Other workshops on teamwork, leadership will be attended or hosted by various faculty members and shared to the department through presentations and mini-workshops. In addition, we will team up with UVM's Center for Teaching and Learning and CUPS to develop workshops for our faculty.

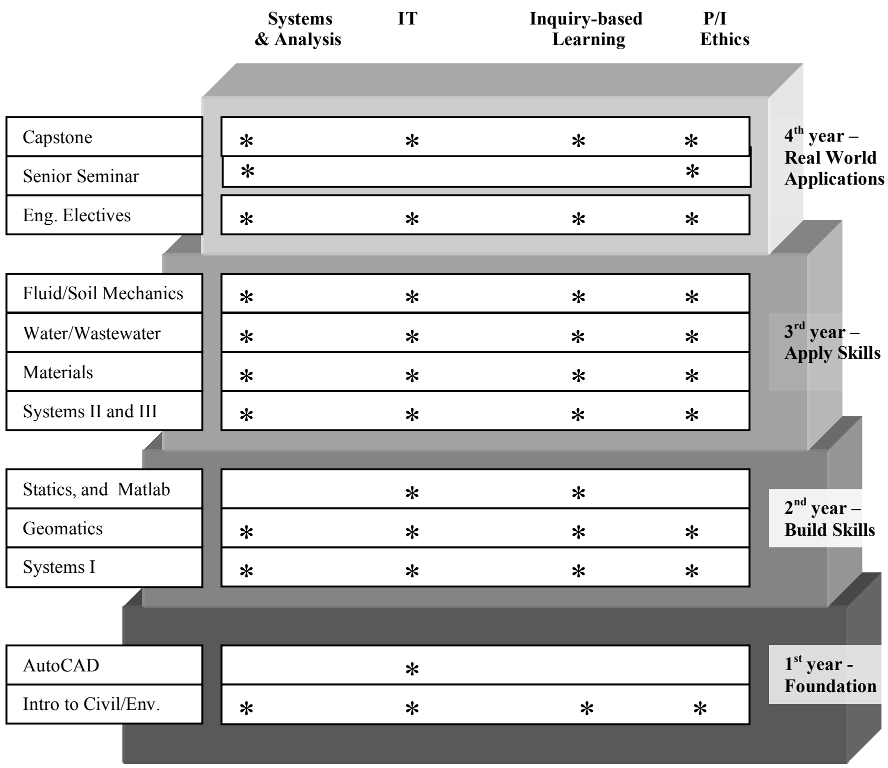


Figure 2. Integration of programmatic themes.

2) Course Content Reform - While our programmatic themes (i.e. systems thinking, systems analysis, IT and IBL), and P/I skills are currently included in some of our courses, this is done in a piecemeal fashion. We will implement a more integrated and formalized approach to incorporating these themes through a number of course reforms. These may take the form of educational modules and projects, but major modifications to courses will also be done (see Systems below). Figure 2 lists existing courses and modified courses that will be targeted initially to integrate the programmatic themes. As shown, first year classes lay the foundation for these themes/skills. The following years then build on this foundation.

New systems courses (reformulated from Transportation, Environmental Engineering and Engineering Economics and Analysis) will allow the instructors to delve deeper into important ideas and concepts not covered in existing courses, including systems analysis tools, ecology and sustainability concepts. The systems sequence is also an integrated systems approach to teaching that is a dramatic pedagogical shift in presenting this material. While we anticipate some difficulties with this approach, in the long run, we believe this to be the best approach for ourselves and our students. A brief outline of the sequence of systems courses is provided.

COURSE	HIGHLIGHTS
Systems I: *Environmental & Transportation Systems*	• Introduction to systems thinking and the systems approach • Description of ecological, and engineered environmental and transportation systems focusing on system component interactions & relationships, concepts of feedback and emergent properties; concepts illustrated using Stella • Fundamentals of optimization, focusing on model formulation for civil, environmental and ecological systems • Application of Probability and Statistics (which is a pre-requisite for that course)
Systems II: *Environmental & Transportation Systems*	• Builds on concepts developed in Systems I, but in a more quantitative fashion • Data analysis and visualization • Fundamentals of engineering economy • Decision analysis applied to systems problems, including multi-objective problems, risk analysis and uncertainty handling • Transportation planning, environmental impact, ecological & environmental systems
Systems III: *Advanced Systems Analysis Tools*	• Numerical methods applied to problems in environmental engineering, traffic flow and structural analysis • Simulation modeling in traffic and environmental systems

A similar approach is taken with Fluid and Soil Mechanics. Fluids/Soils I **-** The principles of continuum mechanics applied to fluids and soils will be introduced in the fall of the junior year. Discussions on capillarity and cavitation in fluids will be followed by how they affect soil shrinking, swelling and frost action; discussions on buoyancy will be followed by the effective stress principle; Bernoulli's equation will be followed by Darcy's law and steady state seepage; and so on. The same philosophy will be followed in the laboratory section and will tie them together through similitude and dimensional analysis in Fluids/Soils II. This setting facilitates easy incorporation of systems thinking, and other areas of interest.

Inquiry-based (research-based) learning will be incorporated into several existing courses (some examples are listed below) and will include the following necessary components; 1) a student-developed hypothesis, 2) an unknown outcome, 3) development of a well-defined and documented approach to testing the hypothesis, 4) an "experiments", 5) analysis and discussion of results, and conclusions. These components are included in the various modules even though they may not be explicitly mentioned in the descriptions due to space concerns. It also should be noted that while the modules are primarily designed as IBL modules, they still are very useful in integrating IT and systems skills themes into the curriculum. We have numerous additional IBL examples for the junior and senior year, but space does not allow for their description here.

A) Introduction to Civil and Environmental Engineering (1st year) - Waste production, waste audits, sustainability-The United States produced over 230 million tons of garbage in 2000, over half was landfilled (USEPA 2002). Waste management and disposal is a major national issue with enormous environmental consequence (as they often have profound effects on groundwater and air quality, traffic, land value, and environmental habitat). Waste reduction efforts in Vermont have been very successful,

however, a waste composition survey revealed that approximately 24% of household refuse could be recycled with pre-existing programs and an additional 21% are food wastes which could be composted. This project will involve researching waste composition and practices at UVM compared to other places.
B) Geomatics (2nd year) - In recent years, a number of new "high-tech" instruments have been revolutionizing the way surveys are conducted. Among the most significant of these new tools are global positioning systems (GPS) and geographic information systems (GIS). We will introduce an environmentally-based research module into our Geomatics course focused on GPS surveying. The module will involve a small research project aimed at allowing students to design and implement a research project to discover for themselves the advantages and limitations of GPS surveys and GIS analysis. Students will be able to; determine accuracy and understand the factors that impact GPS accuracy, organize and analyze GPS data in a GIS, design a research project, evaluate data, and develop a critical review of results.
C)–Fluids/Soils (3rd year) and Open Channel Flow (4th year)- We are one of the few engineering departments that still have a hands-on laboratory experience as part of our Hydraulics and Open Channel Flow courses. The laboratory experience is essential for illustrating the application and relevancy of the theoretical and computational components of the course. We have evaluated the laboratory exercises and equipment to create a more up-to-date lab experience with direct links to ongoing research by our faculty. One example of an IBL project is the design, construction, and implementation of laboratories by our Open Channel Flow students for use in our Fluids/Soils course. A 6 m recirculating-flume, purchased for research activities on a previous grant, will be used for these new lab exercises providing students with an opportunity to use state-of-the-art flow and topographic measuring devices (e.g. acoustic Doppler, velocimetry and laser scanners for 3-D image analysis).

3) Laboratory Reform – The main purpose behind laboratory reform is to allow IBL, IT and systems thinking and analysis to be more easily incorporated into the program. In addition, upgrade to specific laboratory capability will allow sampling and analysis from our Catamount Community projects thus ensuring integration of service-learning into certain courses. Geotechnical, Water, and Transportation engineering are three areas that we want to increase capability to link with our Catamount Communities. The ideal service learning project would be one in which the students could run "research-type" testing and analysis as a true IBL project, as well as incorporate systems analysis and modeling with it. Thus the project would combine ALL aspects of our reform. While this may not be possible in all service-learning projects, we think that given the right engineering equipment and software, it will be possible in many.

A) "Re-engineering" the Geotechnical capability at UVM –A suite of experimental and computational tools are requested to facilitate automatic testing of different soil samples for different soil properties. Understanding and determining soils properties is fundamental for all civil engineering projects and will be important for most of our Catamount Communities. In addition, physical and numerical modeling will be an important component of IBL in the Fluids/Soils course and tie them through dimensional analysis and similitude, and other Geotechnical electives. We are requesting : (1) fully automated direct shear and triaxial consolidation testing machines to complement existing old-fashioned counterparts (off-the-shelf items), (2) tank models to demonstrate seepage in models of such earth structures as earth dams and sheet pile cutoff walls (to be built in-house), (3) instructional centrifuge for physical modeling of such earth structures as embankments, retaining structures and foundations (to be built in-house with drawings obtained from Professors Dobroslav Znidarcic and Hon-Yim Ko who recently obtained NSF DUE grant (award number 0341327) to develop an instructional centrifuge), (http://bechtel.colorado.edu/web/grad/geotech/faci/centrifuge/centrifuge.html and (4) commercial software (GeoSlope, widely used in the industry) for numerical modeling of the earth structures from items 2 and 3.

B) Integrating State-of-the-art Physical Water Models with Systems, IT and IBL in various Water courses (e.g. Hydrology, Systems III, Capstone Design). A large-scale groundwater physical model (MRI grant, http://www.emba.uvm.edu/~gwtank/) and a 6 m recirculating flume (NSF EPSCoR grant) are housed within the department and available for educational use. We plan to better integrate both models into the systems analysis courses and for use in modeling and better conceptualizing water issues in our Catamount Communities. Modest funds of additonal sensors, software and supplies are also requested.

C) Development of a Virtual Traffic Operations Lab - For transportation engineering the real-world is the best laboratory for formulating and testing hypotheses, building and calibrating models, and for learning and knowledge discovery. The purpose of the Virtual Traffic Operations Lab is to bring the real-world transportation system to the classroom through the use of IT. The idea is to install Closed Circuit TV Cameras to monitor traffic flow at one or two signalized intersections on the UVM campus. These cameras would feed their images, in real time, to the Transportation Systems Group Computer lab, where the images would be posted on the web, allowing them to be accessed from any place that is connected to the Internet. Traffic volume, speed and occupancy data will also be collected and archived in the lab. This lab would provide data for several projects and assignments designed to allow for systems thinking, inquiry-based learning, and IT.

One example of a project is the *Calibration of Traffic Simulation Models* in which the students will develop a traffic simulation model for the intersections being monitored by the virtual transportation lab. Students will then compare the output from their models to observations obtained from the virtual lab. They will then be asked to attempt to calibrate the model to bring its results closer to reality.

4) Undergraduates Independent Research Experiences-Due to our small size and close ties with our students, we have relied on undergraduates to assist us in our research projects. Talented and interested students are often recruited for research during their junior and senior years. One of the motivations for some of our reforms is to develop the necessary skills in students so that they can participate in our research activities. The makeup of the faculty requires students to be skilled in systems engineering, computational and IT applications and "research thinking". Incorporating the tools early into the program will prepare students to solve the kinds of complex problems (both in class and in research) that are pertinent to the faculty and society. Recently, a summer scholarship program has been developed in our Department (The Richard Barrett Research Scholarships). Four undergraduates from our department have been selected through a competitive, proposal-based process to receive a summer 2005 stipend and equipment funds to conduct self-directed research under 1-2 faculty mentors. We fully expect to expand this program in the future. In addition, usually 6 undergraduates are supported on faculty research grants in the summer.

C.5 PROJECT ASSESSMENT and ENGINEERING EDUCATION RESEARCH

The assessment of this project will have formative and summative components of both faculty and student learning. The formative assessment will provide ongoing feedback to engineering faculty to guide the progress of the **project**. It will document the **project's** activities, identify successful components and necessary modifications to develop strategies for improvement. The summative assessment will examine the project's effectiveness in meeting its goals (Table 3).

Faculty change will be measured through a combination of observation RTOP (Reformed Teacher Observation Protocol) and evaluations of in-class assessments, syllabi and faculty developed educational research. These will be compared to normalized gains from in-class assessments and longitudinal survey data. The surveys and assessments will document changes related to the project objectives and goals and measure the effectiveness of the changes on student learning. All survey and other work will be reviewed by the Institutional Review Board (IRB) for approval prior to initiating the assessment tool.

***Baseline Data* -** Extensive review of baseline data during the Planning Grant including review of Institutional data (1996-2003) on recruitment, retention, GPA, SAT scores, and student demographics was done. We also conducted a first year student survey (with IRB approval) on all 1st and 2nd year engineering students to collect baseline data.

Education Research Questions - As part of this research grant we plan to systematically examine the implementation process and its influence on students and faculty. The education faculty and graduate student will investigate: How the faculty work to enhance their program and curriculum plans? How does

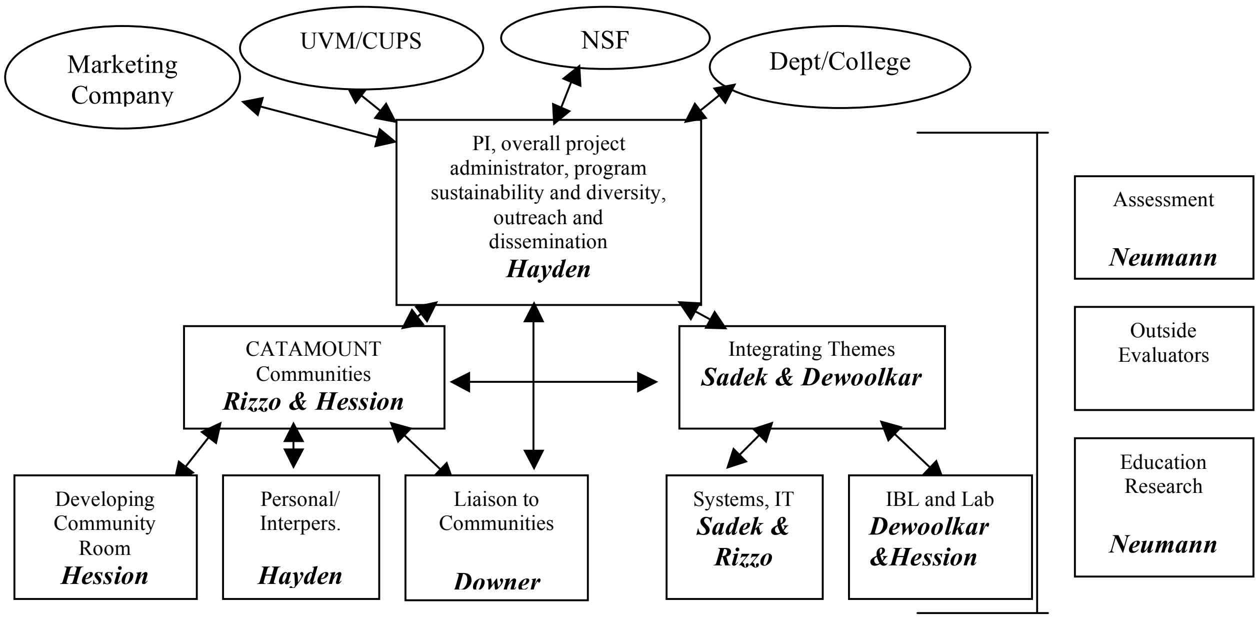
this program change influence student learning? The education researcher will also investigate how these changes affect the experiences of women and minorities in the civil engineering department.
Outside Evaluation and Training- Drs. Gayle Garson and Diane Ebert-May (Ebert-May et al. 2005) will serve as outside consultants and evaluators of our assessment procedure to ensure the necessary rigor and objectivity for the type of proposed comprehensive reform. In addition, this grant would be used as an opportunity for training the faculty in developing a sustainable evaluation and assessment procedure beyond NSF funding. For example, we will encourage faculty research in teaching and learning, determine the best use of alumni and senior survey data, institutional data and the first-year student surveys.

Table 3. Summative assessment strategies cross-referenced to project goals

Objectives	Evaluation Strategies/Data Sources
Goal 1: Teach students a systems approach for engineering problem definition and solution that creates a socially and environmentally conscious student body	
Objective 1, 2, 3, 4	• Observations of CE classroom instruction and RTOP • Examination of class projects and labs and Interviews with CE faculty and students • Various surveys (e.g., course and ABET surveys) that are already in place • Comparisons of course syllabi, normalized gains and assessments, before, during, after project implementation to demonstrate what has been added
Objective 5:	• Survey faculty after attending workshops, meetings, collect agendas,
Goal 2: Increase social, racial, gender, and intellectual diversity in our programs and present data to show that this model works	
Objective 1, 2, and 3.	• Statistical analysis of students entering into and remaining in the programs • Surveys on student experiences • Interview with CE students and faculty advisors • Analysis of student body composition before and after program • Survey recent alumni who have experienced the changes • Statistical analysis of advising meetings
Goal 3: Educate engineers that understand the interconnectedness of everything in our complex world, thus creating a more knowledgeable and effective workforce	
Objective 1:	• Alumni and employer survey data • Examination of class projects, interviews with CE faculty, RTOP, normalized gains and assessments
Objective 2, and 3:	• Examination of class projects, syllabi, course materials, normalized gains • Interviews with CE faculty and students
Objective 4:	• Interviews with CE students, surveys on student experiences, RTOP • Course project review especially capstone course, and course surveys • Alumni participation in professional activities
Objective 5:	• Surveys and interviews on student experiences and with service learning partners • Examination of service learning projects and reflections
Goal 4: Incorporate lasting and sustainable reform within our programs that can be a model for other engineering (and science) programs at UVM as well as nationwide	
Objective 1:	• Interviews with CE faculty and faculty evaluations of training • Implementation of ideas from training into courses (evaluate projects, syllabi, in-class assessments, RTOP) • Observations of faculty curriculum planning meetings
Objective 2:	• Data on publications, other programs at UVM incorporating ideas, information dissemination, web site hits, requests for information, invited speakers.

C.6 ORGANIZATIONAL STRUCTURE and ROLES OF PARTICATING FACULTY

Participating faculty will take charge of various aspects of the project ensuring that progress is continuous and successful, however, it should be noted that we work extremely well as a team, having done so for more than three years. We take a systems approach to the organization and management of the project. The overall structure is shown in the following diagram.



C.7 INSTITUTIONAL FIT AND SUPPORT

The proposed planning activities have full support of the administration at UVM and fit in with the overall strategic planning activities that have been ongoing at the University for several years. Letters of support from the Department Chair, the Dean of the College, and the President of the University are included in the Supplementary Documents.

C.8 OUTCOMES

The overall expected outcome for this project is a better educational experience for our students and our faculty, and the graduation of a more effective, diverse group of engineers that understands a systems approach to engineering and the interconnectedness of everything in our complex world. We believe our reform will be part of the solution, not the problem, when it comes to educating our future engineers. We expect to make numerous presentations about different aspects of this work at a variety of professional meetings. The PIs have strong records of presenting abstracts and papers at national and regional meetings including ASCE, AGU, AEESP, ACS, IEEE, ASEE. We will work with College and UVM personnel, as well as a local marketing company, to enhance our recruitment, outreach and results dissemination efforts, thus ensuring **a broader impact** of our reform. Our programs will serve as a model for engineering and science education at UVM and nationally. All project team members are regular contributors to citizen education and outreach. Please note that education and outreach activities have been separately identified on individual CVs. Especially noteworthy are an Aldo Leopold Fellowship awarded to Hayden, and an NSF awarded *UMEB: Diversity and Excellence in Environmental Biology* to Rizzo (Co-I). We believe the new programs will motivate students for learning and get them excited about areas of engineering that we are excited about, thus creating a positive feedback for our own experiences as educators and researchers. We believe that focusing on systems, service-learning and sustainability issues will make engineering a more attractive major and career for different kinds of students, and will improve retention, especially of underrepresented and diverse groups in engineering. If successful our program reforms promise nothing less than a significant engineering cultural change.