AC 2012-5360: INTEGRATING SUSTAINABILITY PRINCIPLES IN UNDERGRADUATE ENGINEERING CURRICULUM: A HOME FOR ENVIRONMENTALLY RESPONSIBLE ENGINEERING

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Integrating Sustainability Principles in Undergraduate Engineering Curriculum – a Home for Environmentally Responsible Engineering

Abstract

The first two years of many engineering curricula are saturated with foundational mathematics and science, design skills, engineering fundamentals, and professional practices. The complexity of sustainability principles often forces its relocation later in the educational process, leading to a treatment which is too marginal to be meaningful. The Home for Environmentally Responsible Engineering (HERE) at Rose-Hulman Institute of Technology (RHIT) is an effort to incorporate sustainability principles early in the curriculum. The HERE program integrates sustainability throughout the freshman-year curriculum for a cohort of interested students across disciplines. The HERE students reside together in a living-learning community during their freshman year and take four courses as a group, including sustainability-themed sections of courses in college and life skills and rhetoric and composition, as well as a humanities elective course on sustainability in a global context. The fourth common course is the introduction to design course, where the HERE cohort will be able to implement a real sustainable engineering project on the RHIT campus, courtesy of a grant from Procter & Gamble. The goal of the common first-year classes and the shared residence hall is to provide the students a model for making sustainability a foundational part of their engineering education and practice. By assessing student knowledge of sustainability principles at the beginning and end of the freshman year, the effectiveness of the program is evaluated to show that the HERE program helps students learn to view sustainable design methodologies and awareness of the triple bottom line as integral to their understanding of the profession of engineering. Future plans are being developed to continue the program past the freshman year.

Introduction

Undergraduates that earn bachelor degrees in Science, Technology, Engineering, and Mathematics (STEM) disciplines find themselves well positioned to become not only experts in their fields, but also leaders in other areas of their disciplines and careers. One area to which graduates in STEM fields stand poised to contribute tremendously is sustainability. As issues of climate change, depletion of nonrenewable resources, and degradation of water quality prevail on local and global scales, higher education must respond to these challenges with a focus on STEM education that involves understanding and consideration of environmental, economic, and social impacts. For a host of reasons, however, STEM colleges and universities often produce overspecialized graduates that remain unaware of their majors' larger contexts, especially those that touch upon sustainability. Sustainability problems pose serious challenges for engineering education. As students learn engineering fundamentals, design skills, and professional practices, the complexity of sustainability principles and practices is routinely underplayed.

In the statement *Dialogue on the Engineer's Role in Sustainable Development – Johannesburg and Beyond* (NAE 2002)[1], a number of American engineering societies (including the American Society of Civil Engineers, the American Institute of Chemical Engineers, the American Society of Mechanical Engineers, the National Society of Professional Engineers, and the National

Academy of Engineering) formally stated the need for engineers to "deliver solutions that are technically viable, commercially feasible, and environmentally and socially sustainable." The American Society of Civil Engineering (ASCE) revised the first fundamental canon of its code of ethics: engineers "shall strive to comply with the principles of sustainable development in the performance of their professional duties."

If it is important to integrate sustainability concerns across the engineering curriculum, it is equally important to incorporate them in other areas of educational experience—most notably, the campus where students live. This is particularly notable for engineering students, as the campus's "built environment has come to us from engineers … who received their credentials at our institutions" (Calhoun 2006)[2]. Herein, we describe a living-learning community in its pilot year at RHIT, where students across disciplines learn about sustainability through course work, co-curricular activities, and their living environment.

Program Description

HERE is a student-focused, sustainability-centered, first-year, living-learning experience. Our goal is to help students develop communication, awareness, and design skills that will enable personal and professional contributions to global sustainability. Furthermore, the HERE program strives to provide a model for making sustainability a foundational part of engineering education, increasing students' awareness of environmental issues and skills in sustainable design methodologies. The HERE program integrates the best aspects of residential learning with a specialized pilot curriculum in which sustainability is incorporated into special sections of required courses that a cohort of selected students experience together. Curriculum and residential life inform one another to a degree that has not yet been achieved in engineering education. Students live together, but are also assigned to special course sections in which the disciplinary methodologies of engineering and the humanities and social sciences address sustainability concerns. The initial Engineering Education for Sustainable Development Conference in 2002 identified the need for "a more integrated multi-disciplinary style to develop bridges between the technical and physical sciences and the humanities" (Fenner et al. 2005, Mulder and Peet 2002)[3,4].

HERE is a living-learning community that aims at a high level of integration among curricular subjects and between residential and academic life. "Learning communities… intentionally link or cluster two or more courses, often around an interdisciplinary theme or problem, and enroll a common cohort of students…" (Smith et al. 2004)[5]. The small cohort approach to education has proven successful at a large number of schools in numerous contexts. Even investigations into possible negative outcomes of freshman cohort learning experiences acknowledge the tremendous value of these experiences (Jaffee 2007)[6]. Studies at Miami University and the University of Massachusetts have observed increased levels of student engagement and academic performance for students in living-learning environments (Newell 1992; Stassen 2003)[7,8].

As members of the HERE program, first-year students of varying majors live together in a designated residence hall. In addition to providing a living space, the residence hall is used for project planning meetings and for informal academic and co-curricular discussions. The goal "is not simply to teach concrete facts about the environment but to create an active, transformative

process of learning that allows values to be lived out and debated, and permits a unification of theory and practice" (Warburton 2003)[9]. Academic and social needs can be met without requiring (or allowing) students to sever their life from their work. While learning communities have been a part of American higher education for decades (Meiklejohn 1927)[10], the approach remains markedly different from the overall culture of universities—a culture in which academic instruction is frequently divorced from its broader contexts and in which faculty and students alike are encouraged to identify strongly with their own major disciplines. Because sustainability concerns require many scholarly disciplines' techniques, and are situated in numerous material and social contexts, they are particularly well-suited to a learning community's approach.

The first-year curriculum for the HERE cohort includes a sequence of four core courses, in specially designated sections taught by faculty who have chosen to take part in the project. CLSK100, College and Life Skills, a one-credit course for freshmen, is taught by Student Life staff. RH131, Rhetoric and Composition, is a required writing course that centers on the core academic skills of close reading, analytical and persuasive writing, and critical thinking. Students in the HERE cohort are also introduced to the basics of rhetorical theory and principles of sustainability in scientific, technological, and social contexts. GS399, Sustainability and Its Global Contexts, is a newly designed, interdisciplinary seminar. In GS399, students examine human relationships with their natural and built environments across a broad range of historical periods and geographical sites, from ancient Greece to contemporary Nairobi, using analytical tools from various disciplines in the humanities and social sciences. The fourth course, EM103, Introduction to Design, is required of most engineering majors. All majors in the cohort are combined into 2 sections of EM103 with the goal of enabling students to work in multidisciplinary teams to solve actual sustainability problems on the RHIT campus. The student learning outcomes for this course are supported by the multidisciplinary, project-based approach. All four courses meet existing graduation requirements for all majors. Students do not lose electives or lose ground in their progress towards a major. Because all four courses are interdisciplinary and sequential, they can be linked iteratively and conceptually to build for increasing confidence and competencies. The possibility to transfer this approach to other institutions is high because many engineering institutions require an introduction to college life, an introductory writing course, introduction to design, and a humanities course in the freshmen year. The sustainability approach described uses existing courses in the engineering curriculum.

Table 1 describes the broad learning objectives established for the cohort during the first-year. These objectives were derived by considering the learning outcomes and competencies established in 2006 by the American College Professionals Association (ACPA) in collaboration with the U.S. Partnership for Education for Sustainable Development and endorsed by other higher education associations, including the Higher Education Association Sustainability Consortium (HEASC) and the Disciplinary Associations Network for Sustainability (DANS), and by incorporating aspects from the EPA requirements for green engineering.

Table 1: Student Learning Objectives for the HERE cohort

1. Students will differentiate valid definitions of sustainability.
2. Students will explain how engineering systems are interrelated.
3. Students will formulate a design problem statement in an environmental, social, and economic context.
4. Students will engage communities and stakeholders in the development and implementation of engineering solutions.
5. Students will estimate life-cycle effects of processes and products.
6. Students will examine alternatives to minimize waste.
7. Students will describe behaviors that contribute to sustainable communities

Table 2 links the planned elements of the HERE curricular and co-curricular activities to the student learning objectives. While combining the disciplinary and the interdisciplinary, the classroom and the residence hall, and the curricular and co-curricular, HERE plans to help students towards all seven of established learning objectives in their first year.

Table 2: HERE Freshman Curriculum (Courses) and Co-curricular Activities with Learning Outcomes from Table 1

Fall		Winter		Spring	
Rhetoric and Composition (RH131)	Student Learning Objectives 1, 2, 7	Sustainability and Its Global Contexts (GS399)	Student Learning Objectives 1, 2, 5, 6, 7	Introduction to Design (EM103)	Student Learning Objectives 1, 2, 3,4
College and Life Skills (CLSK100)	Student Learning Objectives 2, 4, 7	Service Project: Energy Audit	Student Learning Objectives 4, 7	Earth Day Service Projects	Student Learning Objectives 4, 7
Sustainability Speaker	Student Learning Objectives 3	Sustainability Speaker	Student Learning Objectives 3	Design Competition	Student Learning Objectives 5, 6

Because students learn through shared experiences, and because “integrating for sustainability” calls for education to blend “the learning processes in academic formal and informal settings and that includes competencies developed in extra-curricular settings” (Sherren 2008; Barth et al.,

2007)[11,12], HERE's co-curricular design takes students from energy audit service projects through sustainability speakers to community service projects for Earth Day (e.g. tree planting and stream clean-up).

The HERE program culminates in a freshman design project that is both part of EM103 and external to it. Students in the cohort identify an authentic campus sustainability problem, determine specifications, and design a solution to be implemented in conjunction with the RHIT Facilities Operations team. There are scores of potential projects on campus ranging from lowering electrical costs, reducing waste, and reducing the carbon footprint of the campus. Grant money received from Proctor & Gamble will fund cohort-designed solutions to real campus sustainability problems, generating savings that will help fund the program itself. RHIT will return 50% of savings realized by sustainability projects for 5 years after implementation. The selected project will be implemented and students can observe the benefits of the project over their remaining career at RHIT. Students see their ability to use technology to implement sustainable solutions.

Assessment of Student Learning

A test was developed to assess student confidence and learning in the cohort. The test was administered at the beginning of the year to four different sections of RH131 (Rhetoric and Composition): two sections of HERE students and two sections of traditional students. The two sections of traditional students are considered as a control group. The students in all four sections were instructed to complete the surveys outside of class. 23 students from the HERE sections and 23 students from the control group completed the survey.

The test consisted of three sections. The first section had seven questions that asked students to self-report their knowledge of sustainability and their ability to meet each learning objective identified in Table 1. The second section consisted of fourteen multiple choice questions that covered basic knowledge of environmental issues and sustainability. The third section consisted of three discussion questions. The entire survey is contained in the appendix. The results of the pre-test indicated that there was no statistical difference between the groups. Furthermore, the majority of the students could not answer the multiple choice questions correctly. There was only one multiple choice question that students were able to answer correctly. The test will be administered near the end of the first year to both the HERE students and a control group. Results will be available for the conference presentation.

Pilot Year Review and Lessons Learned

The most important assessment measures—scores on the post-test indicating the extent of students' learning about sustainability during the first year—won't be available until the end of the year. Midway through the first year, though, we can identify several successes of the program. The concept was sufficiently attractive to students. We targeted a cohort of 22 men and 22 women, the capacity of two floors in Blumberg Residence Hall. Nineteen men and fifteen women enrolled in the program. On a campus where women comprise only ~20% of the total undergraduate student population, a 44% female cohort gave us an unusually gender-

balanced group. Geographic diversity is equally robust: the cohort includes seven international students from India, China, and Bosnia, and students from the US come from 18 US states.

Initial academic performance of HERE students, measured by fall quarter grade point averages and RH131 grades, showed no statistically significant difference (α=0.05) when compared to traditional first-year students. The mean fall quarter grade point average was 3.152 (standard deviation = 0.838) for HERE students and 3.083 (standard deviation = 0.747) for traditional first-year students. The mean RH131 grade point average was 3.241 (standard deviation = 0.892) for HERE students and 3.064 (standard deviation = 0.804) for traditional first-year students.

The ideal of the living-learning community—in which a single group of students experiences academic and residential life together—has only been approximated this year, due largely to a handful of conflicts with the academic plans and schedules of individual students. Several students were unable to enroll in the special sections of RH131, Rhetoric and Composition, designated for members of the cohort. Two international students were required to complete College English, a course for non-native English speakers, before admission to RH131; another took a leave of absence from the college during the quarter that the course was held. One international student chose to drop RH131 because of struggles with English. Two others opted not to continue with the cohort after fall quarter, but remain at the institute, compared to an institute-wide loss of 7 of 506 enrolled freshmen.

On course evaluations and anonymous in-class surveys, students reported a high degree of satisfaction with the academic coverage of sustainability topics. They did raise questions about the differences between their experience and those of students taking standard, unspecialized versions of the same required courses. Several expressed a sense that the sustainability focus detracted from the general learning objectives of the course—i.e. that they might have received more substantive writing instruction in sections of RH131 that weren't also teaching sustainability concepts. These themes have emerged before: sustainability has been introduced into the RHIT curriculum as the organizing framework for projects in other required courses—particularly an upper-division course in technical communication—and students have often perceived a tension between the emphasis on sustainability and other course content and learning objectives. On this point, some HERE students resembled their non-cohort peers more closely than we'd anticipated; despite enrolling in a sustainability-themed first-year program, they proved susceptible to the belief that an overemphasis on sustainability might prove detrimental to their overall learning.

Student feedback also reflected positively on the extracurricular activities hosted during the first half of the academic year. These included a welcome cookout, field trips to nearby state parks and other wilderness areas, weekly faculty-student lunches, decision-making meetings and guest presentations at Blumberg Residence Hall, and participation in the campus Day of Service. To promote community involvement and professional development in sustainability, several HERE students and faculty attended a local Greentown conference where speakers and workshops focused on creating healthy, sustainable communities. Attendance at non-required events, however, was low. A trip to McCormick's Creek State Park—including a screening of *Green Fire*, the documentary about naturalist Aldo Leopold—drew only six attendees. Midway through the academic year, a requirement was implemented that HERE students must participate in two

extracurricular activities during the quarter and submit a one paragraph reflection of each activity. Student feedback thus far also showed a request for more projects. Potential upcoming projects for this academic year include performing energy audits for buildings at a nearby church camp and designing an observation deck at a local wetlands site. Attempts to involve students in organizing their own group activities have been successful only rarely. Greek life, athletics, and other extracurricular activities appear to have limited the time that cohort members have available for active participation in the organized extracurricular side of the program.

To some extent, we might have been able to anticipate this difficulty. One purpose served by living-learning communities on larger campuses is to provide closer, more cohesive communities within the potentially alienating academic environments of large comprehensive research universities. On one model, for instance, members of a cohort organized similarly to the HERE program might be enrolled together alongside hundreds of other students—or their small seminars together might be the only departure from the large-lecture format. The HERE students, on the other hand, have encountered the cohort experience as part of an academic community that already contains many of the important features of learning communities. The student-faculty ratio is 11.2 to 1, the average class section includes only 20 students, and residential life is already rated by students as a rewarding, enriching experience.

Future Plans

Faculty, staff, and students have expressed interest in continuing the HERE program beyond the first year. Potential courses that would allow students to continue developing include a science elective—possibly ecology—and an environmental statistics course during the sophomore year, technical and professional communication in the junior year, and capstone design during the senior year. In the latter course, we envision interdisciplinary teams of students collaborating on sustainability projects that draw on skills gained in both their respective majors and their HERE courses. We plan on developing a proposal for awarding a Sustainable Engineering Certificate upon commencement, akin to those currently offered in Robotics and German Technical Translation, that would signify a student's completion of all program courses and legitimize his/her skills to the larger college community, potential employers, and graduate/professional schools. Expanding HERE in these ways would allow students to gain additional interdisciplinary experience with sustainability, faculty to continue developing professionally, the HERE program to earn additional legitimacy as an innovative program.

Indeed, HERE has already expanded the influence of sustainability across the curriculum. In the spring of 2011, pilot sections of the freshman design course devoted to sustainability proved successful with non-cohort students. This spring, cohort students will complete another version of first-year design in which the best project proposal will be implemented on campus, thanks to a grant from Procter and Gamble. The project will become a permanent fixture—a sign of the cohort's presence and an alteration that will increase the environmental health of campus. In October 2011, as part of the campus Day of Service, students designed, prototyped, and assembled three dual-compartment outdoor recycling bins. There is also a burgeoning awareness in campus life for increased emphasis on sustainability, both in general and in the Office of Student Affairs and the Student Government Association. Moreover, the living-learning model, by no means our invention, has begun to gain traction in other areas of RHIT. There are initial

discussions about recruiting other cohorts that would be devoted to entrepreneurship and alternate energy generation. These accomplishments suggest strongly that the HERE program has begun and will continue to make lasting curricular and extracurricular impacts on the campus community.

We have begun envisioning how to work with the 2012-2013 cohort. We will again cap the group at 44 students—the maximum course enrollment for two sections of the required humanities courses and an amount that warrants housing them together—and have the students be involved with official on-campus and community service events. Additionally, we want to continue offering and planning relevant and frequent activities. This year's activities have proved successful; however, certain experiences with this year's students have taught us what to avoid in the future years in terms of structuring activities. For instance, in September 2011 we had the students organize themselves into different committees, in order to share some of the responsibility for shaping and facilitating the cohort, but this has failed to yield tangible results, and nearly all of the activity planning administrative work has fallen to the faculty and staff. We would also like to be more selective in our admissions process, in part by requiring, rather than making optional, a substantial application essay. In forming the 2012-2013 cohort, we plan to have the HERE application distributed to our incoming freshman class at least two months earlier than during the 2011-2012 admission cycle. It is our belief that a lengthier application period coupled with testimonial accounts of the program's successes from current cohort members will increase the number of applicants and allow more selectivity in populating the next cohort.

In order to enhance the engineering and scientific aspects of the HERE program, we will have future students complete a task, such as taking and recording water quality measurements, to introduce them to the applications of sustainability. Such a task will be done not long after the beginning-of-the-year cookout, which proved successful this year. In 2012-2013, we will also have the luxury of having students from the inaugural cohort serve as official and unofficial mentors to next year's group. Students have already expressed interest in serving as Resident Assistants and Sophomore Advisors, and planning welcome events at the start of the school year will provide opportunities for informal socialization. In all, the HERE program looks to improve in all its facets in the forthcoming and subsequent years. Furthermore, we plan to continue to solicit input for the program's direction from companies that hire our students and work with Career Services to get our cohort members placed in sustainability-themed internships.

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Appendix: HERE Pre/Post Survey

Please indicate your responses to the following questions by circling the best word or phrase.

1. I am able to differentiate between valid and invalid definitions of sustainability based on my current understanding of the term "sustainability."

Most of the time Some of the time Hardly ever Never

2. How confident are you in your ability to explain how engineering systems are interrelated if given a process, product or design method.

Very Confident Confident Unconfident Very Unconfident

3. Please rate your ability to formulate a design problem statement in environmental, social, and economic contexts.

Most of the time Some of the time Hardly ever Never

4. I am able to engage stakeholders in the development of engineering solutions.

Most of the time Some of the time Hardly ever Never

5. I am able to estimate life-cycle effects of processes and products.

Most of the time Some of the time Hardly ever Never

6. I am able to minimize waste through sustainable social practices and sustainable design.

Most of the time Some of the time Hardly ever Never

7. I am able to describe behaviors that contribute to sustainable communities.

Most of the time Some of the time Hardly ever Never

8. The role of a greenhouse gas in the atmosphere is to:
    a. Absorb the reflected energy emitted from the earth
    b. Absorb energy directly from the sun
    c. Increase the amount of energy reflected from the earth
    d. Increase the amount of absorbed by the earth's surface

9. Eutrophication is caused by:
    a. An excess concentration of nitrogen and phosphorus
    b. An excess concentration of iron and manganese
    c. An insufficient concentration of nitrogen
    d. An insufficient concentration of calcium and magnesium

10. The effect most commonly observed result of the eutrophication of a lake is:
    a. The absence of nitrogen in the water
    b. The absence of magnesium in the water
    c. The absence of dissolved oxygen in the water

d. The presence of excess iron in the water
e. Don't know

11. Worldwide most childhood deaths are caused by:
    a. Improper use of child safety seats
    b. Contaminated drinking water
    c. Starvation
    d. Malaria
    e. Don't know

12. In 2010 which fuel accounted for the largest percentage of net electricity generation
    a. Hydroelectric
    b. Natural gas
    c. Nuclear
    d. Coal
    e. Don't know

13. What disposal method accounts for the largest percentage for municipal solid waste:
    a. Combustion with energy recovery
    b. Landfill
    c. Recycle
    d. Composting
    e. Don't know

14. The extinction of a species is predominantly the result of:
    a. Natural predatory effects
    b. Overhunting of a specific species
    c. Loss of species specific habitat
    d. Natural population cycles of a species
    e. Don't know

15. Acid rain is produced as the result of the emission of:
    a. Sulfuric and hydrochloric acid
    b. Sulfur dioxide and nitrogen oxides (correct answer)
    c. Carbon dioxide
    d. Methane
    e. Don't know

16. Acid rain is predominantly a problem in what part of the United States?
    a. Northeast
    b. Southeast

c. Northwest
d. Southwest
e. Don't know

17. The United States has lost what percentage of land area considered as wetlands?
    a. 10 %
    b. 20 %
    c. 50 %
    d. 70%
    e. Don't know

18. The cause of the majority of water quality impairment in the United States is the result of:
    a. Discharge from industrial sources
    b. Discharge from wastewater treatment plants
    c. Storm water runoff from urban areas
    d. Storm water runoff from agricultural areas
    e. Don't know

19. The most common contaminants impacting air quality in the United States are:
    a. Airborne particles and ground-level ozone
    b. Gasoline vapors and other hydrocarbons
    c. Mercury
    d. Carbon dioxide and sulfur dioxide
    e. Don't know

20. The largest percentage of the total U.S. energy consumption occurs in the following sector:
    a. Residential
    b. Industry
    c. Transportation
    d. Commercial
    e. Don't know

21. Drinking water in the United States is produced to meet very high health based standards. Select the activities that utilize drinking water. (all are correct answers)
    a. Flushing toilets
    b. Commercial car washes
    c. Fire fighting
    d. Landscape irrigation
    e. Don't know

22. Define the term biomagnification.

23. How would you summarize the principles of sustainability?

24. How does sustainability pertain to your intended major?