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Learning Sustainability through the Design Process

Dr. Jennifer Mueller Price PE P.E., Rose-Hulman Institute of Technology
Dr. Mark H. Minster, Rose-Hulman Institute of Technology

Associate Professor of English

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Abstract
First-year engineering students across disciplines who have joined the HERE: Living and Learning Today for Tomorrow program (formerly the Home for Environmentally Responsible Engineering) participate in a three-course sequence: Introduction to Sustainability, Rhetoric and Composition, and Introduction to Design. The program is a living-learning community where students live together on two floors in the same residence hall, participate in co-curricular professional development activities, and work on co-curricular team projects. For its fifth iteration of freshman students in the program, we introduced a new approach of presenting content through implementation of a basic design process in all courses. By working through the design process in each course, students in the HERE program made connections among various sustainability issues, created value by formulating solutions to global, regional, and campus-based problems, and fostered curiosity through co-curricular professional development opportunities and project work. We have integrated the design process into the curriculum for each separate course, with specific focus on certain stages of the design process in each course. Sustainability content in each course focused on energy, water, carbon, biodiversity, and food production in the context of global, regional, or local case studies. Design-based content includes project definition, exploration of solutions, proposal development, design validation, and reporting through oral and written communication. To assess the first year of this new approach, we conducted pre- and post-surveys for all students in the cohort. The surveys include content-based material to measure knowledge attained, as well as perspectives on sustainability in engineering to observe any changes from the start to the end of their participation in the program. Students also performed routine self-assessments and reflections, based on a developed set of program learning outcome, at the beginning, middle, and end of each quarter. In their reflections, students noted where they have achieved this level of learning (i.e. course content or specific co-curricular activities). Through implementation of the design process in the courses of the HERE program, we anticipated that students would reach higher levels of learning in sustainable design.

Introduction

Nearly all engineering professions and accreditation boards, not to mention a growing number of employers, require that engineering graduates be able to design for sustainability. And yet, until 2011, the principles and practices of sustainable engineering and design only entered the Rose-Hulman Institute of Technology curriculum piecemeal. The HERE program was developed as a living-learning community to immerse students in an environment of learning about the economic, social, and environmental impacts (the triple bottom line) of their lives and work. By setting this foundation of sustainability early in their academic career, students will be better suited to consider the triple bottom line when developing design solutions for complex challenges they will face as scientists and engineers, not to mention as citizens and consumers.

The academic part of the HERE program consists of three complementary courses that meet graduation requirements for most freshmen: Introduction to Sustainability, Rhetoric and Composition, and Introduction to Design. To faculty, the interconnections of these classes are clear and essential to the domains of sustainability, sustainable engineering, and sustainable design. In the first three years of the HERE program, however, students tended to see these courses as only tangentially related. Having students write a proposal to improve sustainability, for

instance, was seen by students not as an essential engineering skill, but as a composition task unrelated to "doing something," which uses engineering skills. As the mismatch between objectives on syllabi and comments on our evaluations shows, students often failed to see how providing technical evidence and information are an integral part of a writing task, or how communication and collaboration are necessary for successful engineers.

During the fourth year of the program, the courses Rhetoric and Composition and Introduction to Design were combined into a single course that spanned two quarters. In this course, students designed and communicated a project to improve campus sustainability. Their projects ranged from lowering heating costs, reducing food waste, and improving lighting in a residence hall, to building rain gardens and human-powered kitchen appliances. Integrating the two classes improved both the design and communication of these projects. Students helped real-world clients see needs in terms of triple-bottom-line thinking and shared value. Comments from members of Facilities and the school's Sustainability Team were overall more positive about this year's projects than about previous years' projects. This redesign also helped to clarify learning outcomes in the domains of sustainable engineering and design. Nevertheless, because the third course, Introduction to Sustainability, was not yet integrated with the other two, students were still not able to integrate crucial context and knowledge from the natural and social sciences into their design and communication outcomes. Most notably, the brief introduction to engineering and environmental economics that has been a part of Introduction to Sustainability would help students in the writing and design course think more systematically about the costs, benefits, payback, and life-cycle impacts of their project designs.

For the fifth year of the program, we integrated the Introduction to Sustainability course to complete the sequence and allow students to experience the iterative nature of design by framing their campus problem-solving in regional and global contexts. By linking the science behind global environmental issues and the contexts in which sustainability issues are framed, we think students' design and communication skills will improve by building these connections. Integrating the three courses allowed us to conduct one sequence of three linked projects, with emphasis on global sustainability in the fall, regional sustainability in the winter, and campus sustainability in the spring, to help students see the importance of appropriateness, scalability, and impact.

Curricular Structure

By working through a basic design process in the three course sequence, students in the program will make connections among various sustainability issues, create value by formulating solutions to global, regional, and campus-based problems, and foster curiosity through co-curricular professional development opportunities and project work. We integrated the design process into the curriculum for each separate course, with specific emphasis on certain stages in specific courses as indicated by the bolded font for the course wherein that stage was emphasized (Figure 1; Sustain = Introduction to Sustainability; Comp = Rhetoric and Composition; Design = Introduction to Design). The chronological course sequence is Introduction to Sustainability in the Fall Quarter, Rhetoric and Composition in the Winter Quarter, and Introduction to Design in the Spring Quarter. Co-curricular activities were aligned with course content to show relevance

and application of course content and to provide experiential learning opportunities for deeper understanding.

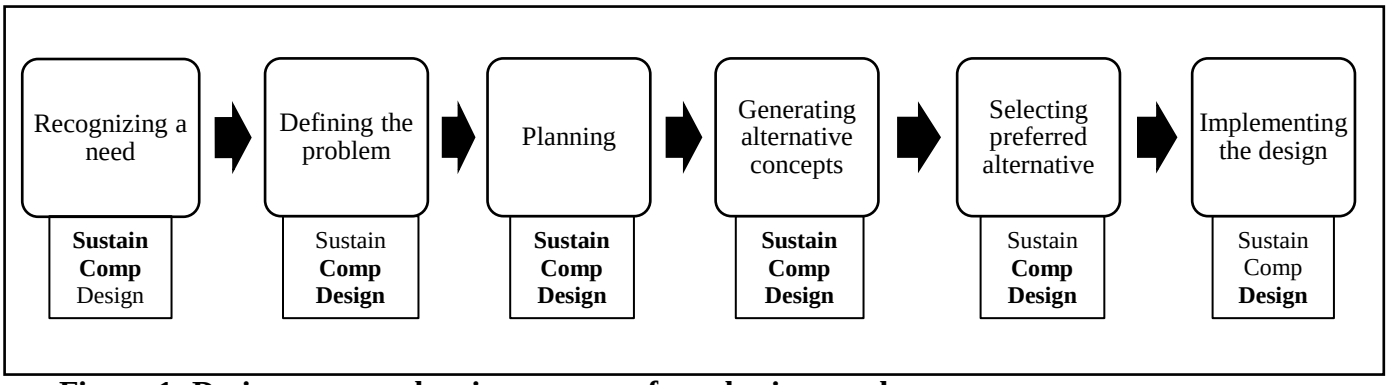

Figure 1: Design process showing courses of emphasis at each stage

Sustainability content was covered as five focused units: Energy, Water, Carbon, Biodiversity, and Food. Introduction to Sustainability covered this content from a global perspective, Rhetoric and Composition covered it on a regional scale, and Introduction to Design applied the content to projects on campus. Content in each unit was introduced in the context a specific case study. Students then chose one of the case studies to further develop strategies for improvement or problem solutions as a final team project for the course.

On the global scale, in the Introduction to Sustainability course, the Energy unit focused on renewable energy options and challenges at an orphanage in Honduras. Content for the Water unit was centered on Three Gorges Dam in China. Global warming and its potential impacts on coastal areas in Australia were the framework for the Carbon unit. Biodiversity was taught through positive and negative effects of ecotourism in the Amazon rainforest of South America. Global food security and food waste were built around the case study of India's school lunch program. Through these case studies, students learned logistics of the design process, conducted research, formulated problem definitions, explored alternative solutions, and developed design proposals.

On a regional scale, the same five units were revisited in the Rhetoric and Composition course. The Energy unit revisited the renewable energy challenges from the global perspective and centered around a local neighborhood, wherein residents struggled with energy shut-offs, and plans were developing for transition to a net-zero livable neighborhood, or eco-village. Studies of global water quantity in the Water unit moved to a regional focus on water quality in watershed, and the local fossil fuel industry was examined during the Carbon unit. Biodiversity and food were discussed on a regional scale through content on invasive species and local food markets, respectively. During this course, students continued utilizing the design process for projects focused on energy use, water use, biodiversity, and food sources in a local, impoverished neighborhood. They conducted research and formulated clear definitions of the existing problem. In this course, they spent more time on the iterative process of exploring solutions, developing a design proposal, and revising their proposed design based on peer and instructor feedback.

The final course in the sequence, Introduction to Design, allowed students to apply the sustainability concepts and design strategies from the prior two courses in the development of an

on-campus project. Students worked in teams with the facilities department to improve aspects of campus sustainability, including energy efficiency, water efficiency, and campus food options. This course provided students with design-based content of validation, review, and reporting on their final design. Students proposed alternative project solutions mid-term and received feedback from course instructors, facilities and their peers. They addressed the feedback to review and revise their proposals and develop a final recommendation. Two design recommendations, a lighting redesign and efficient water fixtures, have been implemented on campus.

Several aligned co-curricular activities included a guest lecture by two faculty members who had worked at the Honduras orphanage during the Energy unit, viewing of the film "Up the Yangtze" when discussing global water issues, a trip to the local farmer's market when covering regional food issues, a trip to a nearby city to visit an eco-village when working on plans for a local net-zero livable neighborhood, and a trip to the local wastewater treatment plant when discussing regional water quality.

Pre- and Post-course Survey Results

Students in the program took a pre-course survey at the start of the Fall Quarter Introduction to Design course and post-course survey at the end of the Spring Quarter Introduction to Design course. Twenty-five students participated in the pre-course survey, while only fifteen participated in the post-course survey due to attrition in the program.

The first part of the survey measured students' perspectives of the interconnection of sustainability and engineering (Table 1). Students rated how well they agreed with the statements on a 1-7 scale (1 = strongly disagree; 7 = strongly agree). Overall, student ratings either increased or remained the same between the start and completion of the program.

Table 1: Mean rating of perspective items (Survey questions from McCormick *et al.* 2013)[1]

Question	Pre (n = 25)	Post (n = 15)
It is important for me to learn how engineers can make the world more sustainable.	6.3	6.3
Engineers play an important role in improving overall quality of life.	6.6	6.7
Learning about sustainable engineering now will be useful for me in my future career.	5.6	6.0
The ability to assess social, economic, and environmental implications of engineering designs is a useful skill that will help me be successful at my job.	6.1	6.1

I would prefer to learn about sustainability engineering applications more than many other engineering concepts.	3.8	4.9
I typically read news stories involving environmental, energy, and economic issues before reading other news stories.	4.0	5.2
If income was not a factor, I would prefer a job related to sustainable development over other types of engineering positions.	4.4	4.9
I have volunteered (or am planning to volunteer) on a project to help a community become more sustainable.	5.1	5.6
I often engage others in conversations and activities to heighten awareness of recycling, environmental protection, or other sustainability principles.	4.3	5.3
Practicing sustainability is a behavior that is a part of my everyday life.	5.0	5.9
My future career will likely involve solving local or global problems that may involve social, economic, and environmental issues.	5.4	5.1

The second part of the survey measured students' confidence in their ability and knowledge of applying sustainability in engineering projects. Students rated how well they agreed with the statements on a scale of 0 to 100 (0 = no confidence; 50 = moderately confident; 100 = fully confident). Student ratings of their abilities increased through the duration of the program.

Table 2: Mean rating of ability items (Survey questions from McCormick *et al.* 2013)[1]

Question	Pre (n = 25)	Post (n = 15)
Identify the environmental elements of an engineering project	56	68
Understand environmental risks associated with engineering projects	61	73
Identify the economic elements of an engineering project	54	73
Understand the economic risks associated with engineering projects	53	67
Identify the social elements of an engineering project	58	73
Understand the social risks associated with engineering projects	53	69
Recognize the social and economic impacts in engineering design	58	75
Understand the interdependency among environmental, social, and economic aspects of engineering	60	80
Assess the practicality of engineering design, including the potential impacts on community and economy	63	76
Understand the meaning and application of sustainable engineering	65	84

The next part of the survey included multiple choice questions of basic knowledge items relating to sustainability and environmental science principles covered throughout the course sequence. More students provided the correct answer after completing the program on most items.

Table 3: Percent of content items correct

Question	Pre (n = 25)	Post (n = 15)
What is the most common cause of pollution of streams, rivers and oceans? [Surface water running off yards, city streets, paved lots and farm fields]	32%	47%
What do you think is the main cause of global climate change? [More carbon emissions from autos, homes and industry]	82%	87%
Which of the following power sources for automobiles releases the least amount of carbon dioxide? [Hybrid Gas-Electric]	55%	67%
_____% of the food we consume comes from _____ crop species. [90; 15]	59%	73%
The greatest cause of the worldwide loss of species is _____. [habitat destruction]	91%	87%
Worldwide, the most widely used renewable energy resource is _____. [Hydropower]	23%	40%
One of the problems with finding new fossil fuel deposits in developing countries is that _____. [International companies move in to harvest the new deposit, and very little money or resource remains in the country]	45%	53%

The same qualitative questions were posed to the students in the pre- and post-surveys to explore their responses for any changes in substantive explanations of the topics at hand (Table 4). The sampling represents a student who earned above-average marks, average marks, and below-average marks throughout the course sequence to provide a more complete spectrum of representation. Most responses show an increased comprehension of the topics shown.

Table 4: Sampling of responses to qualitative questions

Question	Pre-Survey Responses	Post-Survey Responses
In a sentence or two, please define triple bottom-line as best you can.	1. *No response* 2. I don't know 3. A triple bottom line is when waste is piled up.	1. The impact a design has on the economy, environment and society. 2. A way of evaluating the sustainability of something by looking at the way it effects people, the environment, and the economy. 3. The triple bottom-line is the three factors that you must consider when designing -- economic, social, and environmental.

In a sentence or two, please define life-cycle analysis as best you can.	1. The analysis of the stages of an object from birth to its death (where it becomes obsolete or breaks down). 2. Analyzing how the project will affect the surrounding area and communities for its duration. 3. A life-cycle analysis analyzes how energy is transferred in life.	1. Life cycle analysis is looking at a product's complete life cycle, from raw materials to final disposal of the product. 2. An analysis of a product or design that looks at the impact it will have in manufacturing, transport, use and disposal 3. In a life-cycle analysis, you observe every stage of an item's life (production, use, and disposal).
Differentiate between the cradle-to-cradle and cradle-to-grave.	*1. No response* 2. Cradle-to-cradle is going from one environment to another, while cradle to grave is going to a death *3. No response*	1. I am not sure 2. Cradle-to-cradle is something that progresses while cradle-to-grave is something that dies. 3. Cradle to cradle describe the creation of something that is eventually turned into something new. Cradle to grave describes something that is created then thrown away when it is no longer needed.
Differentiate between the open systems and closed systems.	*1. No response* 2. Uses outside resources to help the cycle vs. reusing resources for the cycle 3. An open system is probably a system that affects and be affected by changes of outside conditions, while a closed system does not.	1. When there are things coming in and out of a system, e.g. Earth is a closed system and the moon is an open system 2. An open system interacts with the outside system while a closed system only needs to interact within its own system. 3. Open system can be affected by the outside factors, and mass crosses the boundary. Close system is only affected by factors within the system, while no mass crosses the boundary.

Please write one developed, cohesive, organized paragraph to explain how you would define and describe sustainability for another freshman.	1. Sustainability is the act of lowering the usage/wasting energy. 2. Sustainability is the act in which a species in an environment or ecosystem can support and maintain itself in a positive productive manner; without causing any detrimental short term or long term effects to the environment. To be sustainable one must be able to support oneself off the materials present without having any net waste, such as Sweden example of importing waste to use for fuel. 3. Sustainability is making mindful choices in order to preserve the environment. Sustainability is just what it is defined as, continuous and long-lasting. Sustainability is aimed at practicing activities and trades so that they will be able to continue to be practiced in the future.	1. Sustainability is a way to reduce the usage of a material or reuse another material. Ultimately, it is using the least amount of a material with the same amount of effectiveness or even better than the original. 2. The Brundtland Commission. Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs. 3. Sustainability is using resources wisely. Sustainability means not causing climate change. Sustainability is stopping global warming so there is still snow. Sustainability is functioning in the present while preparing for the future.

Assessment of Program Learning Outcomes

Students used the following rubric (Table 5) to perform a self-reflection at the beginning, middle, and end of each quarter to identify their level of learning for each outcome. They used the description of Bloom's Taxonomy (Anderson and Krathwohl 2001)[2] to determine where they felt they fell for each outcome. They also reflected on how they met each outcome at the level they had reached (i.e. through course content, professional development activities, or project work). We also asked students to identify in which outcome they had seen the most improvement and which outcome they may not be achieving. Table 5 shows values that are a ratio of the percentage of responses at a level for each outcome at the end of the program (n = 16) to the percentage of responses at that level for each outcome at the beginning of the program (n = 22). Higher values greater than 1.0 show that more students reached that level at the end of the program than at the beginning, based on their own self-assessment.

Table 5: Student self-assessment of program learning outcomes shown as %Post/%Pre for responses at each level of Bloom's Taxonomy (Anderson and Krathwohl 2001)[2]

	A. Recognize	B. Understand	C. Apply	D. Analyze	E. Evaluate	F. Create
	Exhibit memory of previously learned material by recalling facts, terms, basic concepts, and answers	Demonstrate understanding of facts and ideas by organizing, comparing, interpreting, giving descriptions, and stating main ideas	Translate acquired knowledge, facts, techniques, and rules in a different way to solve problems	Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations	Present and defend opinions by making judgments about information and validity of ideas or work based on a set of criteria	Compile information together in different way by combing elements in a new pattern or proposing alternative solutions
Related to personal and community values:						
1. implications of my personal habits and growth, as well as others'	0.0	0.7	0.0	0.3	2.0	1.4
2. implications of my personal values and feelings, as well as others'	0.0	0.3	0.0	0.9	1.4	3.4
3. cultural attitudes about human relationship with the built and natural world	1.2	0.0	0.5	0.7	1.7	1.8
4. basic politics of sustainability	0.0	0.4	0.0	1.4	1.4	0.0
5. principles of sustainable living	0.0	0.7	0.2	3.8	1.6	1.1
6. different definitions of sustainability in historical, political, professional, and personal contexts	0.0	0.4	0.3	1.7	1.2	1.4
Applied to design process:						
7. basic concepts of environmental science and economics	0.0	1.2	1.1	0.7	1.1	2.1
8. basic sustainability organizational concepts, including policies and practices	0.0	0.0	0.1	1.7	1.6	1.4
9. sustainable design principles, tools, and metrics	0.0	0.3	0.3	0.6	2.1	4.2
10. problem definition and solution in an environmental, social, and economic context	0.0	0.3	0.4	0.2	1.4	4.9
11. impacts of decision-making in environmental, social and economic contexts	0.0	2.6	0.0	0.2	2.2	3.4
12. life-cycle assessment of products and processes	0.0	0.3	0.0	1.4	3.5	0.7
13. written and oral communication throughout the design process	0.0	0.0	0.2	1.4	1.3	8.8

Conclusions

According to the pre- and post-course survey results, the students exhibited an increased knowledge of sustainability content through the program. Students also grew in confidence of their ability and knowledge of applying sustainability in engineering projects. We have continued to use this framework of the design process integrated through the three-course sequence, and we feel this is an effective approach of teaching sustainability to future scientists and engineers, as they are researching and developing problem solutions or strategies for improvement of real-world issues. With the intent of this program being to set a foundation upon which students can build in their understanding of the complexity of sustainability, we are currently working to grow this into a four-year program. We plan to continue using the case studies and design process for the core Introduction to Sustainability course because we have demonstrated its effectiveness. By continuing to perform pre- and post-course surveys and collecting student feedback, we can continue to assess our program to motivate students through real-world issues and creativity in developing relevant and innovative solutions through the design process.

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