AC 2011-1917: FIRST-YEAR ENGINEERING STUDENTS' ENVIRONMENTAL AWARENESS AND CONCEPTUAL UNDERSTANDING THROUGH A PILOT SUSTAINABLE DEVELOPMENT MODULE

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First-Year Engineering Students' Environmental Awareness and Conceptual Understanding through a Pilot Sustainable Development Module

Introduction:

There are several compelling reasons to investigate first-year engineering students' awareness of environmental issues and to examine how students' understanding of environmental issues changed after a sustainable development module was integrated into their first engineering course:

First, the National Academy of Engineering (NAE) recently reported that many high school students do not perceive engineering as a field of study where they can make a difference in the world and help solve major societal problems[1]. Making explicit the connections of engineering to sustainability and the responsibility of all engineers to understand sustainability concepts as a core characteristic of engineering ("normalized sustainability"[2]) could serve to make STEM fields significantly more appealing to high school and university students. For example, research found women enter science or other fields in order to help people and improve the quality of people's lives[3], in addition research found that women tend to leave engineering for majors that are more likely to deal with the social good[4]. With this negative impact on the national engineering workforce where "only 40 to 60 percent of entering engineering students persist to an engineering degree, and women and minorities are at the low end of that range"[5](p.40), it is crucial that we find ways of stemming the engineering attrition. One area that bears exploration is that engineering fields that are thought to have helping- or caring-oriented attributes (e.g., biomedical and environmental engineering) seem to draw students who may not have considered an engineering degree or career. Environmental engineering in particular shows many helping attributes and has the highest percentage of female students nationally[6]: 43%, almost two and a half times the 18% figure for women in engineering as a whole[6]. The connection of Environmental and Ecological Engineering (EEE) to solving problems that matter to people may be one reason for this high representation[1].

Finally, the research team is addressing an area of national need. The increased need for engineers who are skilled in addressing *a broad range of engineering issues with environmental implications* has been identified in some of the National Academy of Engineering's "Grand Challenges of Engineering[1]". As the world becomes more integrated culturally and environmentally, engineers have to adapt to the challenges with responsible innovations that embrace the ethical and ecological contexts. Traditional engineering has mostly focused on a set of technical skills, such as problem solving, design, and modeling; while these skills are still core and important, the target attributes for future engineering graduates include specific character qualities and affective dispositions as well. Recognizing the changing roles and functions of engineers, organizations like the National Academy of Engineering have emphasized the need to promote engineering "habits of mind", which include systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations[7]. These "habits of mind" qualities would shift perceptions of engineers from individuals who are object-oriented workers to individuals who have a strong work ethic (in collaborations and communications), are ethically responsible (globally, socially, intellectually, and technologically), are able to adapt, and are innovative and entrepreneurial[7,8]. This would also shift the target attributes for the "engineer of 2020" to include being ethical and inclusive of all segments of society, being creative and flexible, being able to work effectively with multicultural teams, having strong communication skills, and *considering sustainability issues in all aspects of the engineering process*[5]. The next decade (and possibly beyond) offers unprecedented opportunity for increasing underrepresented populations in the engineering workforce.

Thus, this research project addresses the serious issues of training students to develop "habits of mind" with a focus on sustainability issues in engineering, which is becoming an area of national need. For this goal, we developed a "game for learning" or "serious game", which supports "critical" and "sustainable thinking" of students' within their own personal choices, by providing situations which require decision-making based on the environmental footprint and highlight the impact of environmental engineering on the entire product life-cycle. Students were active participants in the game design process. Through this "participatory design" [9], we aimed to research and change the attitudes and threshold concepts (key concepts or gate keeper concepts) of first-year engineering students towards the relationship between environment/ecology and engineering.

This project was guided by the following research questions: (1) What is the knowledge and attitude level of first-year engineering students in regards to environmental and ecological issues, in particular pertaining to environmental issues and their relation to engineering? (2) What are the baseline threshold or gatekeeper concepts of first-year students and how will a sustainable engineering module affect these baseline concepts, concepts that help students to transform existing knowledge of the relationship between environmental issues and engineering into deeper conceptual understanding?

Literature Review: Sustainable Engineering

Currently, the Accreditation Board of Engineering and Technology (ABET), as well as several engineering professional societies (e.g., American Society of Civil Engineers)[10], American Society of Mechanical Engineers[11], American Institute of Chemical Engineers[12], and National Society of Professional Engineers[13] have identified sustainability as a key attribute or ethical responsibility of the educated engineer.

"Sustainable engineering" refers to system and process design that recognizes the impacts of engineering on natural resources and systems, and enforces an explicit requirement to protect the rights and resources of the future. As an organizing theme, it is a powerfully inspiring and motivating concept for current and potential students of engineering, because it embodies engineering that matters: to people, to the earth, to society, to urban systems, and to environmental justice. As technical content, it is no simple matter; design (and redesign) of complex systems in order to meet interconnected goals requires large-scale analytical thinking and an explicit recognition of the interaction between the technical, ecological, and social realms.

Ecological literacy consists of three interrelated components: knowledge, affect, and behavior[14]. That is, one must know about ecology, show concern for the natural environment, and act in a way that is consistent with this knowledge and concern. It follows then, that for students to have sustainable engineering literacy they must have knowledge about the subject, show concern for the natural environment, and show behavior consistent with this knowledge and concern, for example by developing technology with the ecological footprint in mind. Several studies on environmental behavior have found links between knowledge, attitudes, and behavior or behavioral intentions, suggesting that as knowledge about an issue increases, so will subsequent attitudes or behaviors[15].

Previous studies have examined how knowledge about the environment affects environmental attitudes or behaviors: An undergraduate course in environmental science can increase students' sense of concern for the environment and their willingness to engage in behaviors that can have an impact on the betterment of the environment [16]. For example, following lessons in environmental education, undergraduates' attitudes towards environmental sustainability became more positive and many of their behaviors affecting sustainability of the environment also became more frequent[14]. Therefore, the sustainability aspect of solving environmental problems will encourage students, who may not have considered engineering to be a "caring" discipline, to pursue engineering to solve world challenges from a sustainable perspective.

For the 21st century engineering students, solving an engineering problem with environmental constraints in mind should be a strength or even second nature. However, research (also by this research team) has shown a lack of environmental awareness and knowledge among engineering students[17,18,19]. With this in mind, the goal of this project is to change the attitudes of first-year engineering students towards the environment and demonstrate that engineering is a career that can have a large impact (potentially positive) on the environment.

Threshold Concepts and Misconceptions

Threshold concepts are perceptions can be thought of as a "portal" to new knowledge that transforms the learner's understanding or way of thinking[20] (p. 1). Threshold concepts are often resistant to conceptual change often due to their counter intuitive or "troublesome" nature[21]. Once a threshold concept is understood, a transformative shift in understanding or worldview takes place and new understandings of other concepts are available to the learner [22]. Meyer and Land[21] describe five characteristics of a threshold concept: a) transformative, b) irreversible, c) integrative, d) bounded, and e) troublesome. That is, once a person understands a threshold concept, it transforms the way they perceive and understand, once the concept is understood it cannot be unlearned, the concept clarifies interconnections between concepts, the concept is bounded as a distinct concept, and the concept is troublesome because individuals have trouble learning or understanding the concept[21].

Students often ignore or reject concepts that do not fit with their existing beliefs or attitudes[23], which indicates that threshold concepts may be particularly resistant to change. For example, Bishop and Anderson[24] found that biology undergraduate students who had misconceptions about the concept of natural selection did not change according to the number of years of high school and biology nor in a biology course that directly addressed the misconceptions. In order to design the most effective educational curricula for students that will enable conceptual change, it is valuable to know and assess students' threshold concepts.

Some threshold concepts may also be misconceptions. Misconceptions can be described as "pre-conceptions" or "students' prior knowledge" about a concept[25] (p. 1). Misconceptions have also been referred to as "alternative understandings" because they are understandings that a student forms based on prior knowledge or experience[26] (p. 604). For example, in the field of ecology, ecological adaptation is a fundamental concept for which students commonly have misconceptions[27].

Similar to threshold concepts, students' misconceptions are often resistant to change[26] and as such often require a paradigm shift, or conceptual change, in a students' mind to overcome the misconception[25]. Posner, Strike, Hewson, and Gertzog[28] posit that in order to overcome misconceptions, several conditions must be met, including: a) dissatisfaction with the existing concept, b) the concept should be intelligible, c) the concept must initially seem plausible, and d) the concept should suggest the potential for extension or opening of new areas of inquiry.

Intervention - Sustainable Development Module

With threshold concepts and misconceptions of environmental sustainability in mind, a four-week module was developed and incorporated within an introductory class for first-year students enrolled within engineering at X University. The module consisted of four hours per week and used various teaching methods including hands-on activities, guest lecturers, participatory exercises, lecture sessions, one overall project, a presentation, and several online activities. Goals of this four week module included: 1) assisting in the development or strengthening students' introductory level competency in researching and analyzing environmental impacts of everyday products; 2) introducing students to the topic of Life Cycle Analysis (LCA) in theory and practice; 3) outlining the use of Excel and databases to demonstrate the environmental impacts of everyday products; 4) introducing students to the principles of engineering and game design; and 5) the facilitation of team-based experiences through LCA based activities and game design.

The first teaching aspect of the module was to educate first-year engineering students about various issues for which they may have none to very limited knowledge. Environmental issues that were discussed ranged from topics including carbon footprint and natural resource depletion to nano-pollution and the scarcity of water in many parts of the world. The students were presented the topics and participation with the lecturer was encouraged to determine the amount of knowledge the students had on the various issues. The students were introduced to many of these environmental impacts and issues and provided examples of what leads to these environmental problems (i.e. anthropogenic pollution or natural occurrences). The module was intended to provide students an arena to think through these issues and determine what they could do as an engineer and as a consumer to further improve and lessen their negative environmental impact on the environment.

Second, in addition to introducing various environmental issues felt throughout the world, the four week module had an overarching topic: Life Cycle Analysis (LCA). The topic of LCA was carried throughout the four-week module because it tied in the various environmental topics and took them to a more advance level. The students were introduced to LCA and the many steps involved in performing a LCA study. Various examples were shown to the students that included previously performed LCAs of hybrid vehicles, light bulbs, and washing machines.

Each example shown to the students outlined each step of the LCA, from goal and scope definition to interpretation of the results, and eventually ended with either a recommendation of which product is more environmentally friendly or which part of a product's life cycle could be improved. This portion of the module was used to highlight how the students' future career as engineers would be impacted. They were introduced to the idea that an engineer can take a part of a product's life cycle (i.e. material acquisition, production, recycling, etc.) and can re-design that portion to make the product more environmentally friendly, use less materials or more environmentally conscious materials, or use less energy. The four-week module was aimed to show students that no matter what field of engineering they ultimately decide to pursue (i.e. chemical, civil, mechanical, etc.), LCA would be a great tool in their careers to optimize products and processes.

Third, LCA was used as a vehicle to understand the various environmental topics and offered students that opportunity to learn about the concept through several methods, underlying each with the use of Excel and databases. Since the module had the students in the classroom/lab for four hours a week, there was sufficient time for students to collaborate in teams as well as work through LCA based hands-on activities. The two hands-on activities had the students taking apart a desktop computer (not including the monitor) and smaller electronics (including calculators, telephones, and compact disc players). The students were supplied with the tools necessary to disassemble the components. The students then completed a LCA on the products by examining the components within their products and the materials used to create them. Students had access to a computer to research the components and look at the production process involved with each component. These hands-on activities allowed the students to get a view of the numerous components required to make one product, the multitude of materials (i.e. plastic, metal, etc.) required, and analyze those materials' environmental impact.

Lastly, to further strengthen the students' understanding of LCA, game design was introduced to the students by connecting and re-introducing the principles of engineering. By designing a game with LCA components, the activity was to provide an introduction to LCA to someone who had very little experience with the method, while reinforcing the engineering principles they have been using throughout the semester. The goal of this activity was for students to look at what they learned about LCA and environmental issues and apply that to game design. Students were shown previously designed games and a current computer-based game being designed for inspiration. This tool has been shown effective in a previous study, using a shorter formatted four session (1 hour each) workshop series, however students did not fully incorporate their understanding of LCA into their game design, and more time to develop the game itself was recommended[18]. Here in this segment of the module, the students were tasked with creating a game during four (2 hour) class periods that would teach the player about LCA. This activity was intended to provide a facilitation of team-based experiences and a overall project conclusion of the module, by making the student the teacher/designer of the topics taught during the module and thereby strengthening their understanding of LCA and environmental issues.

Methodology

A sequential explanatory mixed-method design[29] was utilized to investigate the first-year engineering students' environmental awareness and assess their changes in threshold concepts and misconceptions of environmental sustainability after the implementation of a sustainable development module in their course. In this study, the initial phase of quantitative data collection and analysis was followed by qualitative data collection and analysis. The quantitative phase had the priority and results were used to depict trends related to research questions and to guide the qualitative data collection and analysis; while the results from the qualitative phase was used to "assist in explaining and interpreting the findings of " the quantitative phase[29] (p. 227). At the quantitative phase, two surveys were separately conducted at the beginning of semester among all first-year engineering students (n=1,643) and prior to /at the end of the intervention of the sustainable development module among selected sample students. The quantitative data were analyzed for better understanding of student baseline knowledge of environmental issues and changes in environmental knowledge after the implementation of the sustainable module. At the qualitative phase, qualitative data including project artifacts, were collected during the module and analyzed to strengthen or explain the claims made at the quantitative phase. The results from both phases were combined ultimately for final interpretation.

Participants

All of the first-year engineering students are required to be enrolled in a first-year experience course, which, as addressed in the syllabus, was aimed at helping them develop professional skills including skills of problem-solving, design and team working. Participants on this study were 1,643 first-year engineering students that were enrolled in this first-year-engineering course and completed and returned the baseline survey, eliciting their baseline understanding of ecological and environmental engineering. The survey was administered in September 2010 and encompassed student demographic information, as well as students' initial understanding of ecological and environmental engineering. The sample consisted of 1,287 males (79%), 344 females, and 12 who did not report their sex. A majority of the students were Caucasian (68%), with 28% of Asian, 5% of Hispanic or Latino, 3% of African American and 1% of Native American or Native Alaska students. The majority of the students were at the age of 18 (55.5%) or 19 (33.3%).

Two of the sixteen sections then went on to incorporate the specifically designed sustainability module into their class instruction, with a total of 240 students. The target population participated in the sustainable development module for 4 weeks of the 16-week instruction. A pre and post Environmental Inventory Survey was used to assess changes in their threshold concepts and misconceptions surrounding sustainability, and 140 students completed the pre and post Environmental Inventory Survey. In addition, wiki responses to module activities, game design artifacts, peer assessments, and student interviews were utilized.

Instruments

Baseline Survey: Used in previous work[17], the baseline survey included demographic information, environmental awareness and understanding of sustainable development[16] in four subscales *(issues, policy, tools, development),* perceived importance of sustainable development (developed by the research team), and environmental knowledge[30]. For more information on the baseline instrument, see the full survey in previous research[31].

Environmental Inventory Survey: The Environmental Inventory survey was developed to measure students' threshold concepts and misconceptions about sustainability, environmental issues, and life cycle assessment (see Appendix A). The survey consisted of environmental measures in attitude, knowledge, and threshold concepts for a first-year undergraduate engineering student population.

In the first section, environmental attitude was measured on both general and more specific engineering issues. Nine items measuring environmental attitudes were taken from an environmental survey developed by Holl, Daily, Ehrlich, and Bassin[32] to measure undergraduates' knowledge and attitudes on environmental and human population issues. Students were asked to rate their level of agreement on a scale from 1 to 5 (1 = strongly disagree, 5 = strongly agree). Ten additional items were added to specifically measure students' attitudes and levels of responsibility from the perspective of a future engineer towards the environment (e.g., As an engineer, I would be willing to design more environmentally friendly products).

The next section of the survey measures students' knowledge of life cycle assessment concepts; members of the research team developed these items with expertise in environmental engineering, environmental biology, and educational assessment. The question format is a mix of multiple choice and true-false items, with each asking the respondent to indicate how certain they are of their response (0%, 25%, 50%, 75%, or 100%) in order to eliminate respondents who guessed at the correct answer, as used by Holl et al. [32].

Finally, section 3 of the survey was developed by the research team to measure students' threshold concepts on environmental issues and sustainability (Table 1). The content of the questions was developed through a literature review of common student misconceptions and fundamental concepts in biology, ecology, and environmental issues (e.g., [27,33, 34 & 35]). Items range from more general environmental content (e.g., *Which of the following is NOT a green house gas?*) to specific to the engineering field (e.g., *A group of engineers are brainstorming ideas for a more eco-friendly cell phone. What are some concerns they should keep in mind?*) for a total of 11 items. The items were developed as multiple-choice format and students were again asked to select their level of certainty for their answer.

Table 1. Threshold Concepts *(with examples of questions developed here)*

Concept	Question
1) Students don't understand that engineering is broader (they think LCA is unrelated to engineering design). [19]	*Conducting a LCA is part of the engineering design process*
2) Results of LCAs are surprising and troublesome.[19]	*LCA results are easy to understand and implement*
3) Compromising functionality for environmental concerns.[19]	*Designing a product to have a lower impact on the environment always means a compromise in functionality*
4) Cradle to grave aspects.[19]	*The focus of analyzing the environmental impacts of a product is on…*
5) Uncertainty and complexity of LCA.[19]	*When designing a product, by analyzing the environmental impacts of a product first, there will be a clear direction on how to proceed with the design.*

Artifacts: During the sustainable module, students were assigned to teams of four to design an educational game prototype. All the artifacts, such as storyboard and sketching paper regarding the game prototype design and development were collected. Each game design was presented and scored based on an established rubric[34]. There were a total of three overarching areas for scoring the game, where each criterion was based on the level of achievement (baseline, effective and exemplary) defined by the rubric. The first area focused on the organization and design criteria for the game was based on a) layout/design, and b) navigation. The second area looked at the instructional design and delivery of the game, including three criteria: a) objectives for learning, b) different learning styles, and c) higher level learning skills. The last area was related to the game-based learning criteria, which included: a) rule clarity, b) goal defined, c) feedback incorporation, d) interactions are clear (student-student/ student-computer), and e) subject is clearly stated.

Data Analysis

Both quantitative and qualitative methods were used for data analysis in this mixed-method study. For quantitative data (surveys), statistical strategies of descriptive and inferential analyses including means, standard deviations, Pearson correlation, and statistical t-test comparisons were applied to analyze the data in order to generate responses to each quantitative question. The Quantitative data analysis process was conducted using Statistical Package for the Social Sciences (SPSS). The statistical analysis was the main focus of this study and guided the further investigation of qualitative analysis.

Results

First we examined what first-year engineering students' knowledge and attitude level was in regards to environmental and ecological issues, in particular pertaining to environmental issues and their relation to engineering. The initial results in the baseline survey in students' self-assessment of their awareness revealed that students show a lack of awareness about several aspects of environmental issues. Students reported the *greatest awareness about general environmental issues* on a 1 to 4 scale *(mean = 2.86)*, while students reported the *lowest awareness about environmental legislation and policy issues (mean = 1.36).* Students also lacked some awareness about environmental tools, technologies, and approaches *(mean = 2.23)* as well as sustainable development issues *(mean = 2.17).* Water pollution, air pollution and waste were mentioned as some of the top environmental issues within the area. The majority of students responded that they did not receive previous environmental education in school (64.5%). Finally, while most students rated the role of engineering in environmental sustainability as important or very important for future generations (93.1%), they rated the role of engineering in environmental sustainability for them personally as important or very important as only 74.2%.

Over the course of the sustainability module there was a statistically significant increase in students' LCA knowledge scores from pretest (M=3.16, SD=1.27) to posttest (M=3.63, SD=.91), $t(137)=-3.57$, $p < .001$, using a paired-samples t-test. Within the environmental survey, 13 questions true/false and multiple-choice items were analyzed to determine students' awareness of LCA (Table 2), sustainable engineering concepts, and engineering design to highlight any gaps in knowledge that may need further attention within the curriculum. Student responses on the assessment indicate that there are still some important sustainable engineering and design concepts that students find challenging, in particular general estimates and research components *(see questions 3,4,7,and 8).* There were no significant changes found in students' general attitudes regarding the environment, engineering specific environmental attitudes, and general environmental knowledge.

Table 2: Percentage of students responding correctly for each item

Item	***Correct Response***	**Pre (%)**	**Post (%)**
1. LCA stands for?	*Life Cycle Assessment*	66.4	98.6
2. An LCA should include all of the following except;	*Product data cost*	59.3	74.3
3. LCA helps to calculate the amount of carbon dioxide released during the manufacturing and use of a particular product. What is the approximate amount of CO2 emitted by one year of driving in the US while driving an average passenger car.	*6 tons*	**39.1**	**33.6**
4. How many tons of material was kept out of landfills by the use of recycling and composting practices?	*64 million tons*	**44.2**	**41.4**
5. Conducting a LCA is a part of the engineering design process?	*True*	90.0	90.7
6. A baseline environmental impact profile across the full life cycle of a product is most important for...	*Engineers who design the product*	48.6	58.6
7. A packaging engineer must design a package for a product and she wishes to incorporate an environmental impact assessment. At which stage of the process would incorporating this be most useful for the engineer?	*In research the impacts of the types of materials used to design the package*	**58.6**	**53.6**
8. LCA results are easy to understand and implement.	*False*	**47.8**	**32.1**
9. Designing a product to have a lower impact on the environment always means a compromise in functionality	*False*	70.6	78.6
10. When designing a product, by analyzing the environmental impacts of a product first, there will be a clear direction on how to proceed with the design.	*False*	37.6	38.6
11. The letters in the IPAT equation stand for...	*Impact, population, affluence, technology*	38.6	42.1
12. How much of the United States' energy comes from renewable resources?	*7%*	33.1	37.9
13. Ecosystems in general have limitless resources that can always replenish, to support the current rate of population growth.	*False*	64.7	70

Second, we looked at what the baseline threshold concepts were for the first-year engineering students, and how they shifted as a result of the sustainable engineering module. Four of the five targeted threshold concepts shifted as a result of the sustainable engineering module, using a one-tailed paired-samples t-test.

In the first concept we explored students' understanding of the expansiveness of the engineering field. Specifically, we investigated whether or not students thought LCA was related to engineering design. There was a statistically significant change in student's understanding relating to the integration of LCA in engineering design pretest (M=3.46, SD=.55) to posttest (M=3.63, SD=.49), t(139)=-3.32, *p< .001*) following their participation in the sustainable design module.

In the second threshold concept we explored students' comprehension of LCA, where students responded to a True/False question on the survey in which they were asked whether or not "*LCA results are easy to understand and implement*," which was *False*. Nevertheless, 52% of the students selected *True* as correct answer during the pretest; an even higher number of students 67% selected *True* on the posttest. When asked how certain they were of their answers, there was a statistically significant change in the students' level of confidence from the pretest (M=3.14, SD=1.162) to the posttest (M=3.71, SD=1.12), t(136)=3.09, *p < .001.*

For our third concept, there was a statistically significant change in the students' belief regarding whether or not product redesign would have lower functionality from the pretest (M=.71, SD=.457) to posttest (M=.78, SD=.416), t(136)=-1.782, *p=.035*. More students indicated that they believed functionality would be compromised following their participation in the sustainability module. At the time of the pretest approximately 51% of the students believed functionality would be compromised; at the posttest this number grew to approximately 68%.

In the fourth threshold concept we explored students' understanding of cradle to grave aspects of sustainable engineering. Here students were asked to choose up to five applicable focus areas where environmental impact could take place; all five were correct. By the end of the module there was a statistically significant increase in the number of areas that students choose, prior to the module (M=3.96, SD=1.48) and following their participation (M=4.33, SD=1.24), t(133)=-2.89, *p = .003*. There was also a statistically significant increase in students' level of confidence from the pretest (M=3.62, SD=1.22) to the posttest (M=4.19, SD=.994), t(132)=-5.543, *p < .001*. Lastly, we explored student perceptions regarding the complexity of LCA, where there was no significant difference.

As a final component of the sustainable development module, the game design artifacts were incorporated into a final presentation to share with the class. The presentation was aimed at showing the teams' game design as it incorporated the LCA components to other class members. Within each class, the room was divided into four sections, and winners were chosen for that group. Here are some examples of two winning teams' game design ideas, including: the "Skate n' Scrape" (Figure 1) and "Green Force" (Figure 2). In the first, *Skate n' Scrape*, competitive skateboarding was used to teach LCA, with the ultimate goal of accomplishing level objectives and beat the computer in races. In the second, *Green Force*, they are using the LCA Process in the creation and design of products, to create environmentally friendly products that are practical for the user. Each level takes you through a series of selections and earns a score at the end of each product, and products become progressively more advanced in each level, where players can interact via their scores/rankings posted online.

Figure 1. Skate n' Scrape

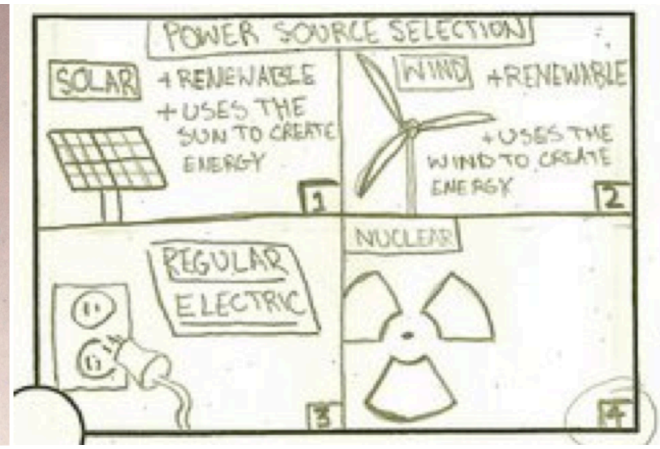

Figure 2. Green Force

Discussion

The purpose of this study was to better understand where first-year engineering students' knowledge and attitude level is in regards to environmental issues, and in particular environmental issues and their relation to engineering. The initial results revealed that students show a lack of awareness about several aspects of environmental issues, especially within environmental legislation and policy issues, which may be related to the fact that the majority of students did not receive environmental education previously. Regardless of past experience, most of the first-year engineering students rated environmental sustainability as an important issue, for engineers in general and for them personally.

Surrounding the implementation of a sustainable engineering module, students' overall knowledge of LCA increased, although the majority of students still had issues with the role of research and the general estimates presented in the questions. However, at the end of the module, several project artifacts revealed that students were able to teach the LCA concept to classmates as well, showing that they understand baseline LCA concepts.

The second component of this research was to determine the baseline threshold or gatekeeper concepts of the first-year students, and see how a sustainable engineering module will affect these baseline concepts. Four of the five targeted threshold concepts shifted positively as a result of this module, showing that student had a better understanding of the threshold concepts provided in the module. All threshold concepts were directly addressed and expected to shift as a result of the module. The shifts included concepts about the broader impact of engineering, the surprising and troublesome results of LCA, compromising functionality for environmental concern, and aspects of "cradle to grave". Lastly, we explored student perceptions regarding the overall complexity of LCA, here there was no change. As a result, more emphasis will be placed here when redesigning the existing LCA Module.

These results help to shed light on the first-year engineering education research, in both instructional design and conceptual understanding focused on environmental concerns. Due to the importance of environmentally sustainable designs, as young engineers, environmental legislation and policy will become crucial in their designs, and should become a target of future instructional modules. In addition, creating module components that challenge the students further could help them move beyond their newly understood threshold concepts, to achieve a deeper conceptual understanding of the relationship of environmental issues and engineering. This may be a result of time, and a four-week module may be just the first step.

Implications

A nationwide study of graduation rates for students in engineering fields showed that the average semester that most students leave engineering is the fall of sophomore year[4]. Research indicates that non-academic factors may have more importance than academic ones[36], especially for underrepresented groups in engineering such as women. For example, in regards to the academic achievement of students who leave engineering, females leave with higher grade point averages (G.P.A.s) than males, which indicates that other factors besides academic achievement are involved in females' retention in engineering[4]. There is strong evidence that most women in the sciences are concentrated in disciplines related to helping others or improving the human condition[3], and that women tend to leave engineering for majors that are perceived to be more likely contributors to social good[4]. With this in mind, future work will look at a comparison at the end of the year to see if a four week sustainable development module will have an impact on retention of those that participated when compared against the other sections.

In addition, a redesign of the introductory engineering curriculum at a Purdue University for the academic year 2011-12 will be initiated, incorporating more sustainable development content as well as more defined linkages about the role of engineers in sustainability.

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Appendix A. ENVIRONMENTAL INVENTORY

ENVIRONMENTAL ATTITUDES	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
1. Agriculture is not important to the U.S. economy because it contributes only 3% of the nation's GNP.	❍	❍	❍	❍	❍
2. Deforestation is easily remedied because it's always possible to plant more trees.	❍	❍	❍	❍	❍
3. Population growth is important to stimulate the U.S. economy.	❍	❍	❍	❍	❍
4. The U.S. population has nearly doubled since the Second World War.	❍	❍	❍	❍	❍
5. There is a lot of vacant land in the U.S. that is suitable for agriculture or urbanization.	❍	❍	❍	❍	❍
6. The population should continue growing so there are sufficient young people to support old people.	❍	❍	❍	❍	❍
7. Population growth is a principal cause of environmental deterioration.	❍	❍	❍	❍	❍
8. Couples in the U.S. should have no more than 2 children to help preserve the environment.	❍	❍	❍	❍	❍
9. Improving the state of the economy is more important than improving the state of the environment.	❍	❍	❍	❍	❍
10. I would be willing to stop buying products from companies cited of polluting the environment, even though it might be inconvenient for me.	❍	❍	❍	❍	❍
11. As an engineer, I can contribute to sustainable development through the engineered design of a product.	❍	❍	❍	❍	❍
12. As an engineer, I would be willing to design more environmentally friendly products.	❍	❍	❍	❍	❍
13. As an engineer, I would be willing to spend more time to redesign existing products to be more recyclable.	❍	❍	❍	❍	❍
14. As an engineer, I can do something about the life cycle of a product in discussing options with the client.	❍	❍	❍	❍	❍

15. Please indicate your level of agreement with the following:

Engineers have a responsibility to:	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
a. take into account the environmental impacts of their designs.	❍	❍	❍	❍	❍
b. improve the state of the economy over the improvement of the environment.	❍	❍	❍	❍	❍
c. take into account how the product will be used.	❍	❍	❍	❍	❍
d. utilize materials that are recyclable or reusable.	❍	❍	❍	❍	❍
e. take into account how the product will be disposed of.	❍	❍	❍	❍	❍

16. What does LCA stand for?	How certain are you of your answer?
a. Life Cycle Assessment b. Leftover Carcinogen Assessment c. Local Consumption Assessment d. Lifecycle Carbon Analysis	0% 25% 50% 75% 100%

17. LCA is the estimation of the environmental impacts during...	How certain are you of your answer?
a. production of the product using raw materials. b. use of the product by the consumer. c. disposal of the product after its use. d. all of the above.	0% 25% 50% 75% 100%

18. An LCA should include the following EXCEPT;	How certain are you of your answer?
a. Resource extraction and material transport (1) b. Product manufacturing and recycles/renewable content (2) c. Maintenance considerations of the product (3) d. Product cost data (4)	0% 25% 50% 75% 100%

19. An example of a comparative LCA is plastic cups versus paper cups. When a LCA is used to compare two or more products, the basis of comparison should be that an equivalent amount of service is delivered to the customers. This equivalent amount is called the Functional Unit. In the example of plastic versus paper cups, what functional unit will you use?	How certain are you of your answer?
a. ONE cup of each type b. ONE paper cup versus FOUR plastic cups c. the number of cups of each type equivalent to 1 kg of plastic/paper d. any of the above	0% 25% 50% 75% 100%

20. LCA helps to calculate the amount of carbon dioxide released during the manufacturing and use of a particular product. What is the approximate amount of CO2 emitted by one year of driving in the US while driving an average passenger car?	How certain are you of your answer?
a. 4 tons b. 6 tons c. 8 tons d. 10 tons	0% 25% 50% 75%

	100%

21. How many tons of material was kept out of landfills by the use of recycling and composting practices?	How certain are you of your answer?
a. 12 million tons b. 64 million tons c. 89 million tons d. 125 million tons	0% 25% 50% 75% 100%

22. Conducting a LCA is a part of the engineering design process?	How certain are you of your answer?
True False	0% 25% 50% 75% 100%

23a. If TRUE, please specify which part of the process.	How certain are you of your answer?
	0% 25% 50% 75% 100%

23a. If FALSE, what process is it more closely connected to?	How certain are you of your answer?
	0% 25% 50% 75% 100%

24. A baseline environmental impact profile across the full life cycle of a product is most important for...	How certain are you of your answer?
a. clients who want to develop a product b. biologists who study a products' environmental impact c. engineers who design the product d. none of the above	0% 25% 50% 75% 100%

25. A packaging engineer must design a package for a product and she wishes to incorporate an environmental impact assessment. At which stage of the process would incorporating this be most useful for the engineer?	How certain are you of your answer?
a. in reviewing how the client will use the package b. in researching the impacts of the types of material used to design the package c. in assessing of how the package is disposed of d. none of the above	0% 25% 50% 75% 100%

26. Analyzing the environmental impacts of a product is important for which engineering field/s? (please check all that apply)	How certain are you of your answer?
Packaging Engineers (1) Environmental Engineers (2)	0% 25%

Mechanical Engineers (3) Biomedical Engineers (4) None of the above (5)	50% 75% 100%

27. LCA results are easy to understand and implement.	How certain are you of your answer?
True (1) False (2)	0% 25% 50% 75% 100%

28. Designing a product to have a lower impact on the environment always means a compromise in functionality.	How certain are you of your answer?
True (1) False (2)	0% 25% 50% 75% 100%

29. What is NOT a limitation of LCA?	How certain are you of your answer?
a. only addresses issues set in the Goal and Scope b. can only be used on products and not processes c. system boundary has to be set d. lack of spatial and temporal dimensions	0% 25% 50% 75% 100%

30. The focus of analyzing the environmental impacts of a product is on (please check all that apply)	How certain are you of your answer?
a. where the materials originate. b. how a product is disposed of. c. how a product is used. d. the use of environmentally friendly materials. e. how a product is designed.	0% 25% 50% 75% 100%

31. When designing a product, by analyzing the environmental impacts of a product first, there will be a clear direction on how to proceed with the design.	How certain are you of your answer?
True (1) False (2)	0% 25% 50% 75% 100%

32. Greenwashing can be defined as...	How certain are you of your answer?
a. the government providing incentives to replace non-sustainable products with more environmentally friendly products. b. the act of improving poorly designed products with engineered products aimed at improving environmental performance. c. the act of companies producing “green” products to compete with traditional products and raise awareness for their environmental benefits. d. the act of misleading consumers regarding the environmental practices of a company or the environmental benefits of a product of service.	0% 25% 50% 75% 100%

33. The letters in the IPAT equation stand for...	How certain are you of your answer?

a. Impact, population, affluence, technology b. Improvement, pollution, academics, training c. Impact, pollution, affluence, toxicity d. Improvement, poisonous, arsenic, toxicity	0% 25% 50% 75% 100%

34. Which of the following terms correctly defines a mixture of pollutants that includes particulates, nitrogen oxides, ozone, aldeyes, peroxyethanoyl nitrate, un-reacted hydrocarbons, and is known for being an eye irritant and damaging $2 to $3 billion in crops annually:	How certain are you of your answer?
a. Photochemical smog b. Toxicity smog c. Eutrophication d. Ecotoxicity	0% 25% 50% 75% 100%

35. What is Global Warming Potential?	How certain are you of your answer?
a. it is the peak temperature the world is expected to reach due to green house gases b. an equation to predict the quantity of green house gases in the atmosphere in the following decade c. a measure of how much a mass of a green house gas is estimated to contribute to global warming d. a measure of the toxicity of green house gases in the environment and their potential impact to ecosystems and human health	0% 25% 50% 75% 100%

36. Which of the following is NOT a green house gas?	How certain are you of your answer?
a. Carbon dioxide b. Chlorofluorocarbons c. Ozone d. All of the above are green house gases	0% 25% 50% 75% 100%

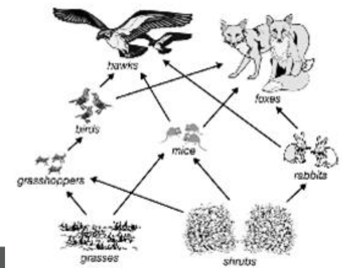
37. How much of the United States' energy comes from renewable resources?	How certain are you of your answer?
a. 3% b. 7% c. 9% d. 12%	0% 25% 50% 75% 100%

38. Ecosystems in general have limitless resources that can always replenish, to support the current rate of population growth.	How certain are you of your answer?
True (1) False (2)	0% 25% 50% 75% 100%

39. An engineer is designing a hydroelectrical technology that closes off the Seca river to produce energy. This will subsequently inhibit the yearly upstream river migration of one species of fish, which the local bear population depends on. Over the next year, once the engineering project is put in place it will affect... (please check all that apply)	How certain are you of your answer?
a. the fish population dependent on the Seca river for migration b. the redtoed frog population upstream in the Seca river that feeds on the same food source as the fish population c. the aggression noted in the bear population (related to territory size while feeding) d. the redtoed frog population upstream in the Fria river, that is located 15 miles north of the Seca river e. none of the above	0% 25% 50% 75% 100%

40. A team of engineers is redesigning a wind farm where avian (bird) mortality is a concern. Researchers estimate that 576 raptors (hawks, eagles and kestrels) may have died in a two-year period due to collision with wind turbines.

41. Look at the picture and answer the following question; If the wind farm is left unaltered, this wind farm could effect:
a. the hawk, eagle and kestrel populations. b. a decrease in the food source of the raptors. c. an decrease in the fox population. d. less mice and rabbits, with taller shrubs. e. the entire ecosystem will be affected.



42. A group of engineers are brainstorming ideas for a more eco-friendly cell phone. What are some concerns they should keep in mind? (please check all that apply)	your answer?
Materials (1)	0%
Manufacturing (2)	25%
Packaging (3)	50%
End-of life (4)	75%
none of the above (5)	100%