Incorporating a Sustainability Module into an Introduction to Engineering Course

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Abstract

Sustainability has become an increasingly central topic for the engineering profession. The sustainability concept requires all of us, as engineers and citizens, to consider much more widely than before the impact of our own lives and of the products and services engineers design. Through a Department of Education funded grant, our university has initiated a long term effort to incorporate the sustainability concept into the engineering courses.

Initially, freshman engineering students at our university were introduced to sustainability through the completion of an additional module added to their required introduction to engineering course. This traditional course includes study skills in engineering, the engineering profession, the engineering design process, and ethics in engineering among others. From this additional module, students should be able to define sustainability, to assess the sustainability of their individual lifestyles, and become aware of sustainability efforts on their community.

We found strong evidence that the inclusion of the sustainability module increased the awareness of the sustainability concept among first-year engineering students. Additionally, the positive attitude toward sustainability and the willingness to incorporate sustainability in the engineering design process were increased. These results indicate that early emphasis in first-year introductory courses may affect students' attitudes and knowledge of sustainability concepts.

Justification

All engineers should be familiar with the concept of sustainability. ABET (ABET website at http://abet.org/DisplayTemplates/DocsHandbook.aspx?id=3149 visited on January 7, 2013) has listed sustainability as one of the constraints for engineering designs under general criteria 3 program outcome c. The Engineer of 2020 report presented by the National Academy of Engineering, NAE (NAE website at http://www.nae.edu/File.aspx?id=10368 visited on January 7, 2013) has noted as well the importance of sustainability. In a study Allen et al. (2008)[1] attempted to benchmark sustainable engineering education. In this survey of engineering department heads, with more than 270 respondents, about 80% reported teaching sustainable engineering-focused courses or the integration of sustainable engineering material into existing courses. Increased attention to teaching engineering students about sustainability, sustainable development, and sustainable design is also evident on the basis of the number of papers presented at the American Society for Engineering Education (ASEE) annual conference that included these keywords in their titles, which increased from 1 to 3 papers in the 1998–2002 period to 27 papers in 2009 to 36 in 2012.

Additionally, the Code of Ethics for the National Society of Professional Engineers (NSPE) states that engineers have an ethical obligation to hold paramount the health, safety and welfare

of the public in the performance of their professional duties (NSPE website at www. http://www.nspe.org/Ethics/CodeofEthics/index.html visited on January 7, 2013). The Code also addresses sustainability: "Engineers shall strive to adhere to the principles of sustainable development in order to protect the environment for future generations" in the section about Professional Obligations (NSPE website at www. http://www.nspe.org/Ethics/CodeofEthics/index.html visited on January 7, 2013). But how do we include the concepts of public service and sustainability into engineering education?

Many universities have available courses mainly focused on sustainability, with 64 civil/architectural/environmental engineering courses identified in a recent benchmarking survey by Allen et al. (2008)[1]. These courses are most often electives targeted to upper-division students, such as the Green Engineering and Sustainability course at Michigan Technological University and Yale University referenced by Zhang et al. (2008)[2] and the seminar course at Lamar University mentioned by Koehn et al. (2009)[3]. An alternative approach to teaching sustainability in upper-level elective courses is to introduce sustainability at the beginning of the curriculum, during the first and second-year courses. The expectation is that introducing sustainability to first-year students will reinforce the knowledge that all engineers need to consider sustainability on all their design projects.

At our university, first-year engineering students are preparing for the future by understanding sustainability and incorporating it into their overall design process. Through a Department of Education funded grant, our university has initiated a long term effort to incorporate the sustainability concept into the engineering courses. Initially, the first-year course Introduction to Engineering was used to implement an additional module on sustainability.

Curricular Context

The Introduction to Engineering (EN 101) is a two-credit required first-year course for all students pursuing a major on engineering at our university. This course meets for 50 minutes twice a week over the 15 weeks of the semester. This course not only presents the students with study skills in engineering, the engineering profession, the engineering design process, and ethics in engineering but also motivates the students to learn about current issues such as sustainability. Therefore, one of the most important outcomes of this course is to encourage students to understand the challenges when designing product and services while considering sustainability into their designs.

Sustainability Module

During the fall semester of 2012 two sections of the introduction to engineering course were taught. The first section, the experimental group, with 23 students was exposed to the sustainability concept, sustainability in the engineering design process, and the strategic sustainability plan for the local County through presentations, hands-on exercises, and conferences where County officials presented their strategic sustainability plan for the County.

The exposure to sustainability for the second section, the control group, also with 23 students was mainly accomplished through lectures and homework assignments. Students were free to register on either the control or the experimental group and they were unaware about the experiment.

For the experimental group, a sustainability module encompassing the eighth and ninth lectures in the course, two written homework assignments worth 6% of the total course grade, and a design project presentation in class was added. The eighth lecture introduced a range of topics, including definitions of sustainability, the triple bottom line definition according to scientists and economists, the Impact, Population, Affluence, Technology also known as the IPAT equation used to measure the environmental impact of human activities, the unique challenges of international sustainable development, the limits of growth, the concept of carrying capacity, and ecological footprint analysis. The ninth lecture included a presentation from the County officials about the strategic sustainability plan for the County.

The students in the experimental group were supplied with the lectures slides, the county strategic sustainability plan, and associated references to learn more on their own. At the end of the eighth lecture, these same students were asked to define the specifications, considering a sustainable design, of a portable toilet that could be used anywhere and to prepare a two-minute elevator speech to present their design to their classmates during the eleventh lecture. Table 1 presents all the topics and educational materials used in the sustainability module added to the experimental group.

Table 1. Topics and educational materials used in the added sustainability module

Topic	Educational Material
Introduction to Sustainability	Presentations and discussions
Triple bottom Line	Presentations and discussions
The IPAT equation	Presentations and discussions
Limits of growth and the concept of carrying capacity	Presentations and discussions
Assessing the foot print	Presentations, discussions, and homework assignments
Introducing sustainability into the design process	Students' presentations
Sustainability efforts in the community	Community leaders presentation
Evaluating the foot print	Posters

Evaluation of Sustainability Attitudes and Knowledge

To measure students' understanding of sustainability before the lectures, it was desirable to use an instrument already developed, such as a "sustainability literacy" test. Instead, a 10-item

written survey was developed to measure students' self rated attitudes and knowledge about sustainability. The first 5 questions were intended to measure students' attitudes toward sustainability by rating their level of agreement with 5 statements about sustainability. The survey is presented in Appendix 1. The last 5 questions measured their basic knowledge about sustainability by using a multiple selection format. At the beginning of the course, before the lectures on sustainability, a pre survey was applied to both the control and the experimental group. For the control group, the response rate was 87% and for the experimental group the rate was 91%. The same survey was applied to the experimental group at the end of the course, during the last week of the semester, with a response rate of 91% as well.

The questions intended to measure students' attitudes toward sustainability were modified from the Association for the Advancement of Sustainability in Higher Education (AASHE website at www. http://www.aashe.org/Resources visited on August 20, 2012). Question 1 "The earth is like a spaceship with only limited room and resources" intended to measure students self perception on limits of growth and the concept of carrying capacity. The students' attitude toward this question in both groups using a 1 to 5 scale as shown in Figure 1 did not present a statistical difference (Student's t test with 39 degrees of freedom and a p-value = 0.923). Figure 1 shows the answers to the first question from both groups.

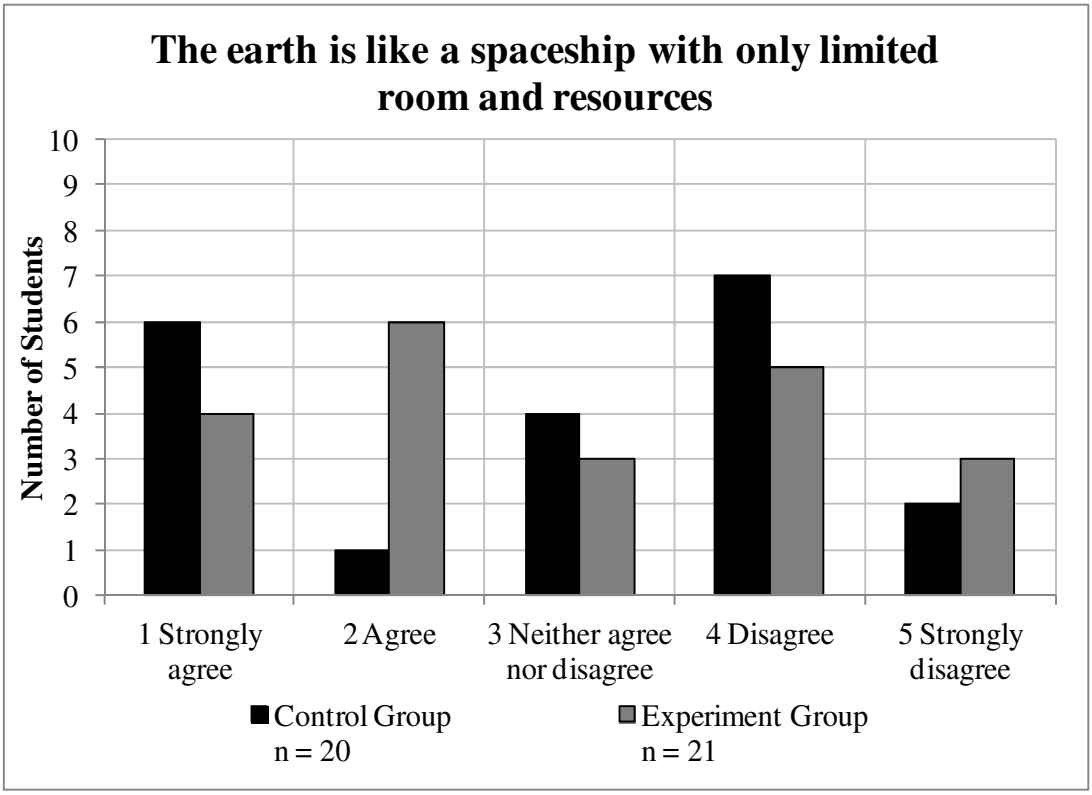

Figure 1. Students' answers to attitude question 1 in the pre-survey

Similarly, for the remaining 4 attitude questions there is no statistical difference between the two groups. It is important to note that 9 out of 20 students (45%) in the control group disagree or strongly disagree with the statements "People should be willing to make economic choices for a better environment" and "My career choices should be influenced by my concerns about the environment and the society and their economic development" on questions 2 and 3 respectively. Figure 2 shows the comparison for the remaining 4 attitude questions between the control and the experimental group.

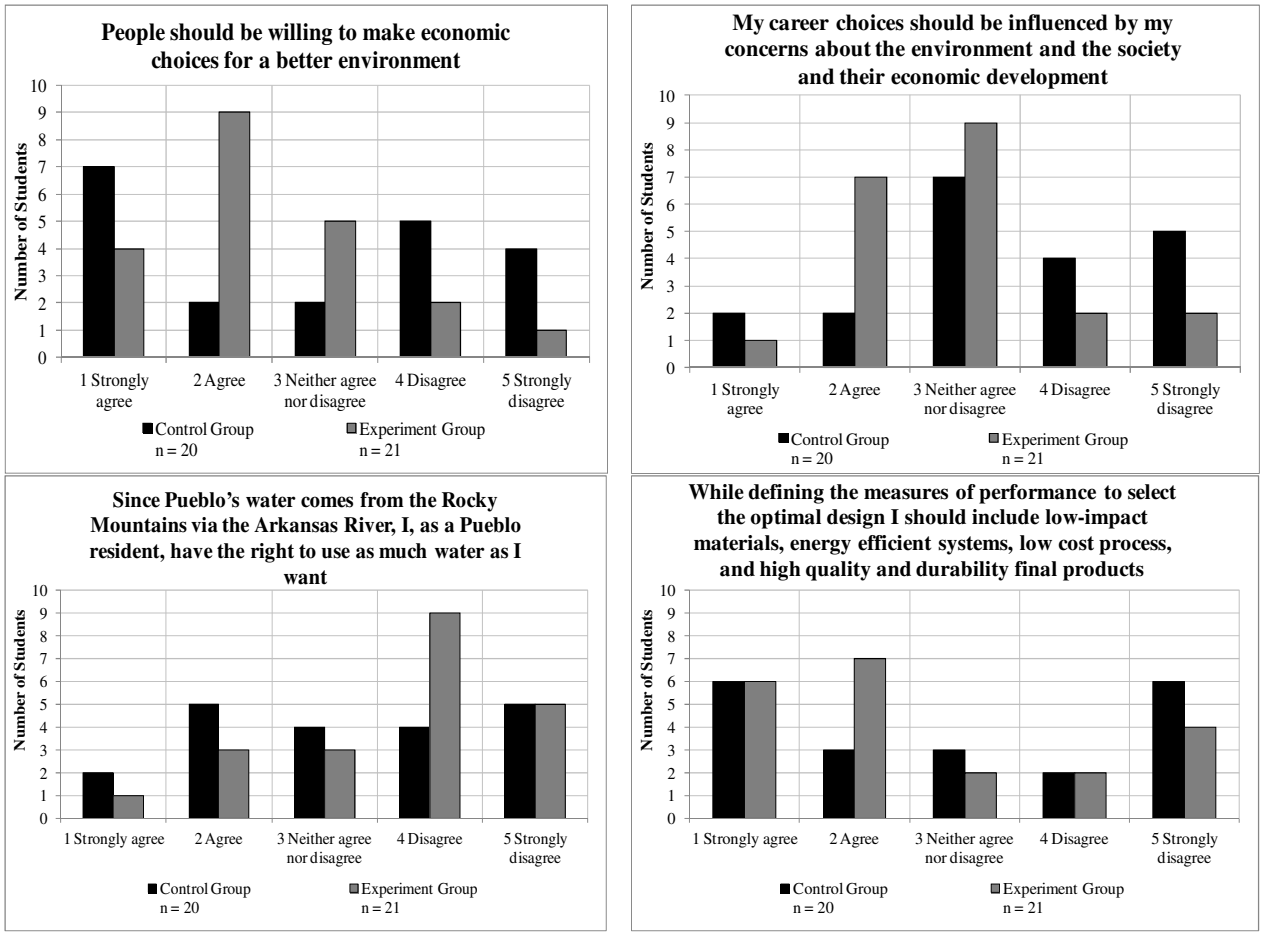

Figure 2. Summary of students' answers to attitude questions 2 to 5 in the pre-survey

For knowledge questions, 70% of the students in the control group and 57% of the students in the experimental group were knowledgeable about the average foot print in the United States. On both groups 5% of the students said recycling is not important to them, 65% of the students in the control group and 71% of the students in the experimental group were able to identify the three components used in the triple bottom line definition of sustainability, 75% of the students in the control group and 76% of the students in the experimental group were able identify the components of the IPAT equation. It is important to note that on both groups a majority of the students (75% in the control group and 86% in the experimental group) were not aware of the share of energy generated from renewable sources in the County during 2010.

Results

Comparison of attitudes and knowledge for experimental group before and after the added module

Based on the results of the post-survey, it can be concluded that in general students' attitudes toward sustainability were changed after their exposure to the added sustainability module (Student's t test with 40 degrees of freedom and a p-value = 0.034). For Question 1, 71% of the students in the post-survey strongly agree or agree that "The earth is like a spaceship with only limited room and resources" as opposed to 48% of students in the pre-survey. This question shows an increase in the students' awareness about the limits of growth and the concept of carrying capacity. Figure 3 depicts students' answers in the experimental group before and after exposure to the added module.

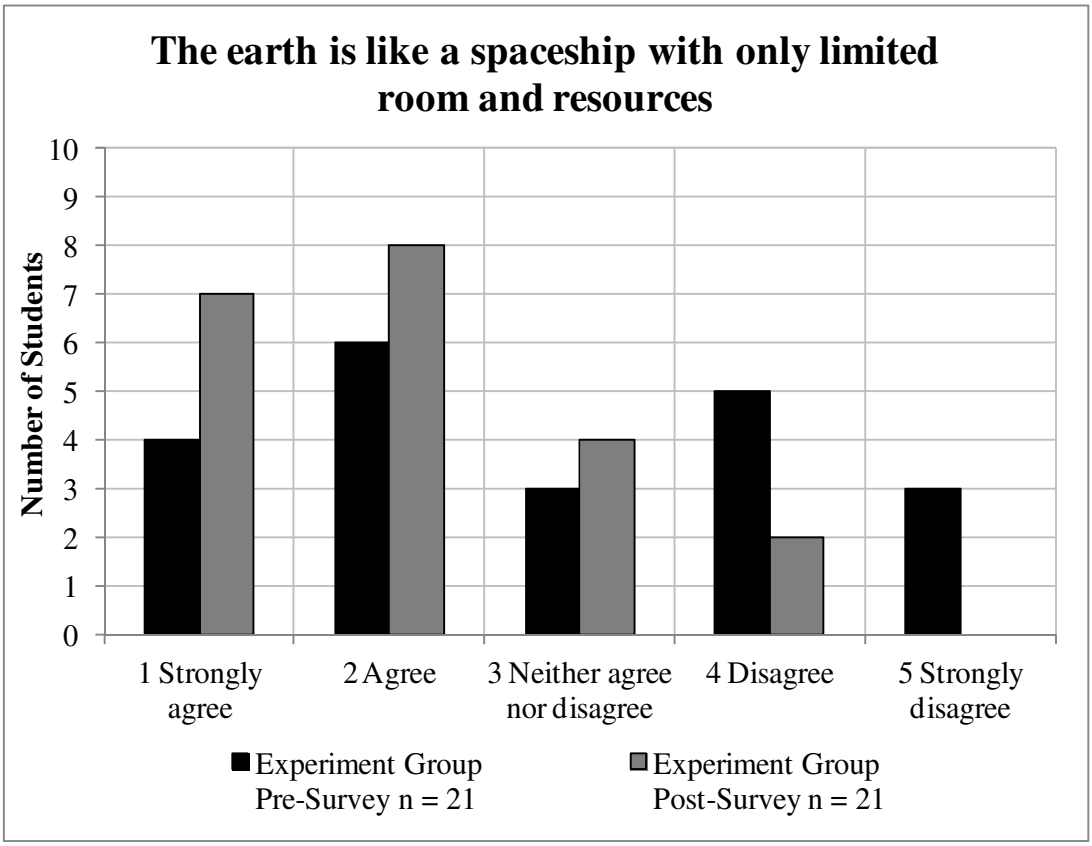

Figure 3. Experimental group students' answers to attitude Question 1 in the pre and post-survey

Similar results were found for attitude questions 3 to 5 (Student's t test with 40 degrees of freedom and p-values of 0.012, 0.00008, and 0.013 respectively). However, it is important to note that in attitude Question 2 "People should be willing to make economic choices for a better environment"; there was not a statistically significant change in students' attitude toward the balance between economic choices and a better environment (Student's t test with 40 degrees of

freedom and a p-value = 0.05). This balance it is still perceived by the students as a trade-off between the two options. In Question 5, an increase in students' willingness to incorporate sustainability to evaluate the performance of the engineering design process was observed.

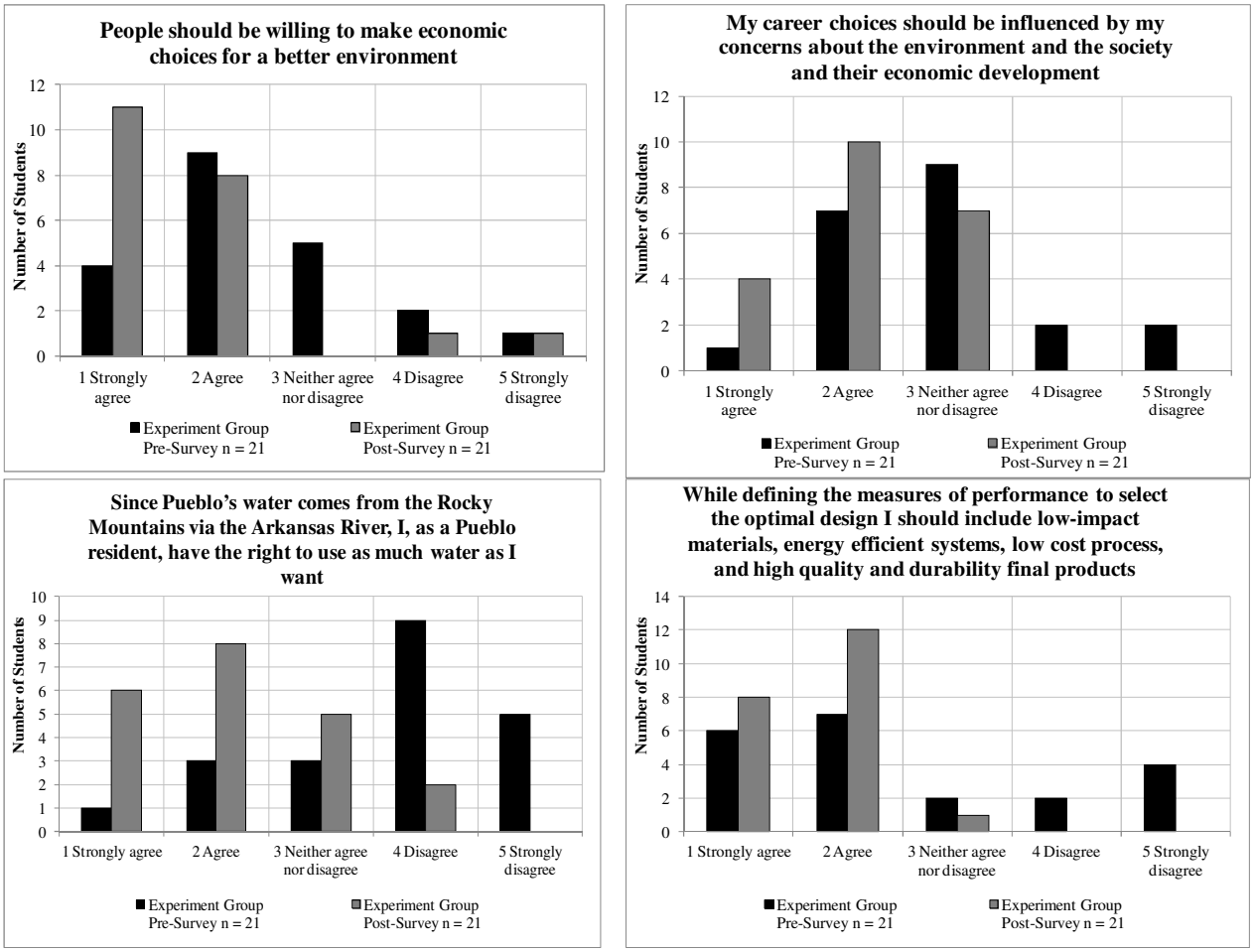

Figure 4. Summary of experimental group students' answers to attitude questions 2 to 5 in the pre and post-survey

For knowledge questions, 81% of the students in the experimental group correctly identified the average foot print in the United States, an increase from 57% in the pre-survey. For both pre and post-survey, 5% of the students said recycling is not important to them. Besides, 91% of the students in the experimental group correctly identified the three components used in the triple bottom line definition of sustainability in the post-survey as opposed to 71% in the pre-survey. Similarly, 95% of the students in the experimental group correctly identified the components of the IPAT equation in the post-survey as opposed to 71% in the pre-survey. It is important to note that after the exposition to the added sustainability module 76% of the students were aware of the small share of energy generated from renewable sources in the County during 2010.

Moreover, a question asking the students in the experimental group the triple bottom line definition was included in the exam 1 (week 5, lecture 10) and in the exam 3 (week 15). The

results in the exam 3 (60% of the students correctly defined sustainability through the triple bottom line) are better than the results in the exam 1 (50% of the students gave a correct definition). It is important to note that before Exam 1, the students were exposed to Lectures 8 and 9, and were assigned the two-minute elevator speech to present their design and the calculation of their individual footprints.

Conclusions

First-year engineering students are receptive and responsive to the addition of topics such as sustainability into their courses whenever instructors are successful in showing them the importance and relevance in today's engineering profession. Initial experiences with sustainability are important to increase students' positive attitude toward sustainability and to increase their willingness to incorporate this concept into their future courses and when dealing with real design problems in their workplace.

The additional sustainability module helped first-year engineering students understand the concept of sustainability and its relationship with the engineering design process as it is applied to solve real-world problems.

Most of the first-year engineering students in the experimental group reported that the additional sustainability module helped them increase their knowledge and positive attitude required to develop a sustainable engineering design.

Results of the survey completed by the experimental group suggested that first-year engineering students were made aware of the definition of sustainability by using the triple bottom line, the IPAT equation used to measure the environmental impact of humans' activities, the limits of growth, the concept of carrying capacity, and ecological footprint analysis.

In the short term, the sustainability module is being improved and incorporated into the spring sessions. In the medium term, two to three years from now, the plan is to offer a minor in sustainability available for all the undergraduate students at our university. Finally, a major on sustainability is in the long term plan, five to seven years from now.

Acknowledgments

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Bibliography

1. Allen, D., et al. (2008). "Benchmarking sustainable engineering education: Final report." Grant X3-83235101-0, U.S. Environmental Protection Agency, Washington, DC.
2. Zhang, Q., Zimmerman, J., Mihelcic, J., and Vanasupa, L. (2008). "Civil and environmental engineering education (CEEE) transformational change: Tools and strategies for sustainability integration and assessment in

engineering education." Proc. ASEE Annual Conf. and Exposition, American Society for Engineering Education, Washington, DC.

3. Koehn, E., Patel, D., and Khonde, S. (2009). "Introduction of sustainability to civil and construction engineering students." Proc. ASEE Annual Conf. and Exposition, American Society for Engineering Education, Washington, DC.

Appendix 1. Survey taken by both the control and the experimental groups.

Attitude Questions

1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree

1. The earth is like a spaceship with only limited room and resources

   1 2 3 4 5

2. People should be willing to make economic choices for a better environment

   1 2 3 4 5

3. My career choices should be influenced by my concerns about the environment and the society and their economic development

   1 2 3 4 5

4. Since Pueblo's water comes from the Rocky Mountains via the Arkansas River, I, as a Pueblo resident, have the right to use as much water as I want

   1 2 3 4 5

5. While defining the measures of performance to select the optimal design I should include low-impact materials, energy efficient systems, low cost process, and high quality and durability final products

   1 2 3 4 5

Multiple Choice Questions

1. If everyone in the world consumed like United States of America then the Ecological Footprint would be? (check one)
    a. About 4.5 planets
    b. About 2 planets
    c. About half of a planet
    d. About 1 planet
2. Which reason to recycle is most important to me? (check all that apply)
    a. It reduces resources and energy use
    b. It saves money
    c. It is the right thing to do
    d. It avoids filling up landfills
    e. It produces economics benefits from job creation
    f. Recycling is not important to me

3. When thinking about sustainability I think about:
    a. Protecting the environment
    b. A fair society
    c. Obtaining profits
    d. All of the above

4. The percentage of electricity generated from renewable sources in Pueblo county during 2010 was:
    a. 5%
    b. 2%
    c. 0.2%
    d. 20%

5. Reducing the environmental impact can be accomplished by:
    a. Decreasing the population
    b. Consuming less things
    c. Implementing greener technologies
    d. All of the above