AC 2012-5591: CHANGING STUDENTS' KNOWLEDGE AND ATTITUDES ABOUT SUSTAINABLE DEVELOPMENT AND SUSTAINABLE ENGINEERING IN AN INTRODUCTORY SCIENCE AND ENGINEERING CLASS

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Abstract

Numerous professional organizations call for engineering graduates to appreciate the importance of sustainable development and its relationship to sustainable engineering. Methods for integrating sustainable engineering into existing courses and curricula are needed in order for students to develop these skills. In this study, students in an introductory science and engineering course were introduced to the concepts of sustainable development and sustainable engineering through assigned reading, class lectures, and group activities. Comparison of the results of a survey administered before and after these activities suggests that they led to increased familiarity with basic concepts of sustainable engineering such as life cycle assessment, as well as an increased in the value placed by students on sustainability and environmental issues.

Introduction

The "Bodies of Knowledge" (BOKs) of the American Academy of Environmental Engineers (AAEE) and the American Society of Civil Engineers (ASCE) identify the skill sets needed to practice environmental and civil engineering at various points in an engineer's career, including after completing the B.S. degree. Outcome 8 of the AAEE BOK calls for the ability to recognize life cycle principles, to identify non sustainable components in engineered systems, to explain how and why to integrate sustainability into engineering projects, and to quantify emissions and resource consumption associated with engineering processes (paraphrased from AAEE (2009)[1]). Outcome 10 in the ASCE BOK also calls for an appreciation of sustainable development and the environmental impacts of engineering projects. Specifically, the commentary for ASCE BOK Outcome 10 states "To be effective, professional civil engineers should appreciate the relationship of engineering to critical contemporary issues such as … raising the quality of life around the globe … and the … environmental …implications of engineering projects"[2]. The National Society of Professional Engineers (NSPE) Code of Ethics for Engineers also encourages engineers "to adhere to the principles of sustainable development in order to protect the environment for future generations"[3].

A survey of college engineering students from 21 universities on five continents found that while most students stated that they had at least some knowledge of basic environmental issues related to sustainable development and sustainable engineering (acid rain, air pollution, deforestation, global warming, ozone depletion, and water pollution) they reported relatively low knowledge of other environmental issues, including design for the environment, life cycle assessment, waste minimization, and components of sustainable development.[4] In another survey, a majority of students studying science and technology at the University of Plymouth in England rated themselves as "familiar" or "very familiar" with the terms "sustainability" and "sustainable development", yet did not demonstrate a multifaceted understanding of the environmental, economic, and social aspects that make up these concepts.[5]

The objective of this work was to develop a learning module for a sophomore class populated by majors in civil engineering, environmental engineering, and environmental science that would: (1) introduce the concept of sustainable development, (2) require students to identify links between sustainable development and sustainable engineering, and (3) introduce the concepts of life cycle stages and life cycle assessment. The goal was to increase students' knowledge by a change in values[6]—specifically a change in students' assessment of the importance of sustainable engineering in their own careers. The desired outcomes, defined using Fink's "Taxonomy of Significant Learning"[6], were for students to (1) understand the definition of sustainable development, the concept of life cycle stages, and the steps and environmental processes commonly included in life cycle assessments (Fink's "foundational knowledge"); (2) identify relationships between sustainable development and sustainable engineering (Fink's "integration"); and (3) believe, at the end of the learning activities, that sustainability is an important facet of science and engineering education and practice (Fink's "human dimension").

Methods

First, students' prior knowledge and attitudes were assessed using a survey, with some questions adapted from prior published surveys[4, 5, 7] and additional questions based on the AAEE and ASCE BOKs. The survey and results are given in the Appendix. Then, students completed several assignments and activities, both outside of and in class. After these activities, the survey was re-administered and changes in students' knowledge and attitudes assessed by comparing the before and after survey responses.

After the initial survey, approximately one week (two 75-minute class periods) were focused on the topics of sustainable development and sustainable engineering. First, students were assigned two documents to read at home that would introduce the concepts of sustainable development[8] and sustainable engineering[9], along with a list of eight possible short answer quiz questions to help focus their reading. This was followed by a quiz approximately two weeks later. A short amount of time was spent on introductory discussion of the concepts of sustainable development (e.g., the Brundtland Commission definition[10]). Students then worked in small groups of 3-4 to understand the concepts of sustainable engineering by examining consumer products they carried with them to class (things like calculators, coffee cups, pens, or notebooks) to determine if they were made from recycled or recycle-able materials, whether they could be disassembled into their component parts (required prior to recycling), and if their component materials were made from renewable or nonrenewable resources. Then, the concepts of life cycle stages and design for the life cycle were introduced via a small group activity in which students considered a consumer product in their backpack (such as one of those listed above), or some process they engaged in that morning (e.g., taking a shower, brushing their teeth, or driving to class), then sketched a process flow diagram of that product or process showing all stages of the life cycle, including raw materials extraction, refining, product manufacture, transportation, use, and disposal). Then, students were asked to identify the stages in the life cycle of their chosen product/process that they believed had the greatest adverse impact on the environment, and to propose how those adverse impacts could be mitigated through product/process redesign. Finally, as recommended by Vanasupa et al.[11], students considered the NSPE Code of Ethics for Engineers[3], then discussed in their small groups how the NSPE charge to "hold paramount the safety, health, and welfare of the public" could relate to both environment-related issues (such as use of toxic chemicals in manufacturing a product) as well as non-environment-related issues (such as the potential for catastrophic failure of structures based on poor design).

These activities were followed by a brief lecture introduction to the life cycle assessment process using the International Organization for Standardization (ISO) protocols[12], including an overview of the steps in the life cycle assessment process and discussion of public databases for conducting the life cycle inventory step of the life cycle assessment (e.g., the National Renewable Energy Laboratory Life Cycle Inventory database[13]). An overview of the life cycle impact assessment process was also given, including a discussion of the following impact categories: global climate change, acid precipitation, eutrophication, ozone layer depletion, and smog formation.

Finally, students performed a limited life cycle assessment using the public domain software "Building for Environmental and Economic Sustainability" (BEES)[14]. Students worked in small groups of 3-4 to compare the environmental and economic (i.e., cost) impacts of building products. The software BEES was chosen for this life cycle assessment activity both because it is very easy to use, and also in the hope that it would capture the interest of a class consisting largely of civil engineering majors who are sometimes more enthusiastic about construction projects than environmental issues. To complete the exercise, student teams selected a building product category (e.g., floor coverings) from the BEES database and choose at least two alternatives in that category to compare (e.g., vinyl flooring versus carpeting). Then, they identified the appropriate functional unit for comparison for that building product category (e.g., in BEES, the functional unit for comparison of floor coverings is material adequate to cover 1 ft^2 of flooring for 50 years). Finally, students used BEES to compare the chosen alternatives in terms of both cost (in present value dollars for one functional unit), and "environmental performance" in terms of five impact categories (global warming, acidification, eutrophication, ozone depletion, and smog) and five life cycle stages (raw materials acquisition, manufacturing, transportation, use, and end of life). Specifically, for each alternative, students compared the emissions in each impact category for each step in the life cycle. When there were significant differences in impacts between products (e.g., CO_2 emissions per functional unit for vinyl flooring versus carpeting), students read the product information included in the BEES database to try to identify the reasons for the differences. A common observation was that the greatest environmental impacts for numerous building products occurred in the materials acquisition, manufacturing, and transportation life cycle stages. This makes sense considering that most building products do not consume energy or emit wastes during the use phase of the life cycle, and are relatively inert in the end of life or disposal stage, but can be energy and waste intensive during the phases of the life cycle involving raw materials acquisition, manufacturing, and transportation to the point of use.

Results and Discussion

The survey (Appendix) asked students to pick the best responses to a series of statements. Open ended answers were not solicited. The resulting distributions of answers were not normally distributed, either before or after the in class activities (i.e., responses of "yes" and "agree" were more common than responses of "no" or "disagree"), so analysis of variance or a t-test of statistical significance was not appropriate. Application of a ranking method such as the Mann Wilkinson test to survey results having answers (e.g., yes, not sure, or no) that could be assigned only discrete numerical values (e.g., 3, 2, or 1), rather than a continuum of possible answers, was not appropriate either. Therefore, data are analyzed qualitatively, and the use of the term "significant" in the discussion below is not meant to indicate the results of a statistical test of significance.

The first desired outcome was for students to understand the definition of sustainable development, the concept of life cycle stages, and the steps and environmental processes included in life cycle assessments (Fink's "foundational knowledge"[6]). Comparison of the before and after survey results (Figure 1, Appendix question 1) indicates a significant increase in

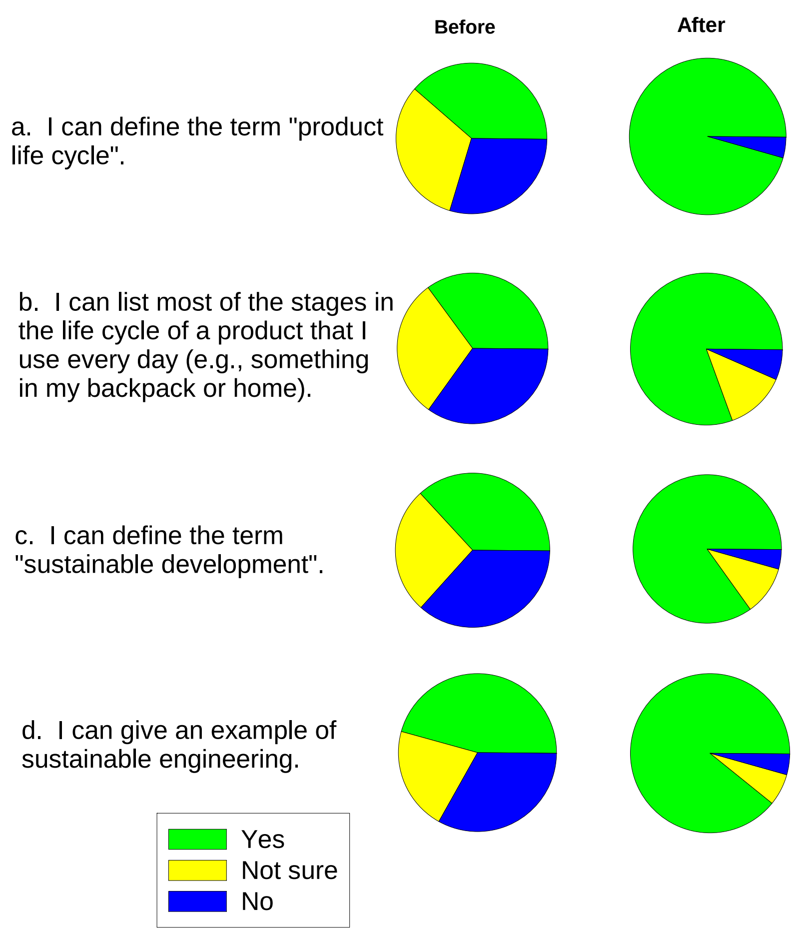

Figure 1. Please choose the best response to the following statements.

many "foundational knowledge" areas. Specifically, there was a significant increase in the number of students responding "yes", and a decrease in the number of students responding "not sure" or "no" to questions affirming their familiarity with the concepts of product life cycle, life cycle stages, sustainable development, and sustainable engineering. In terms of critical environmental problems, there was not much change in students' self-assessed ability to describe global climate change and acid precipitation, a moderate increase their ability to describe ozone layer depletion and smog formation, and a significant increase in their ability to describe eutrophication (Figures 2, Appendix question 2). These results suggest that sophomore college students have some awareness of many environmental problems, with the notable exception of eutrophication. Their self-assessed ability to list the major types and sources of pollutants that cause these environmental problems, on the other hand, showed a more significant increase (Figure 3, Appendix question 3).

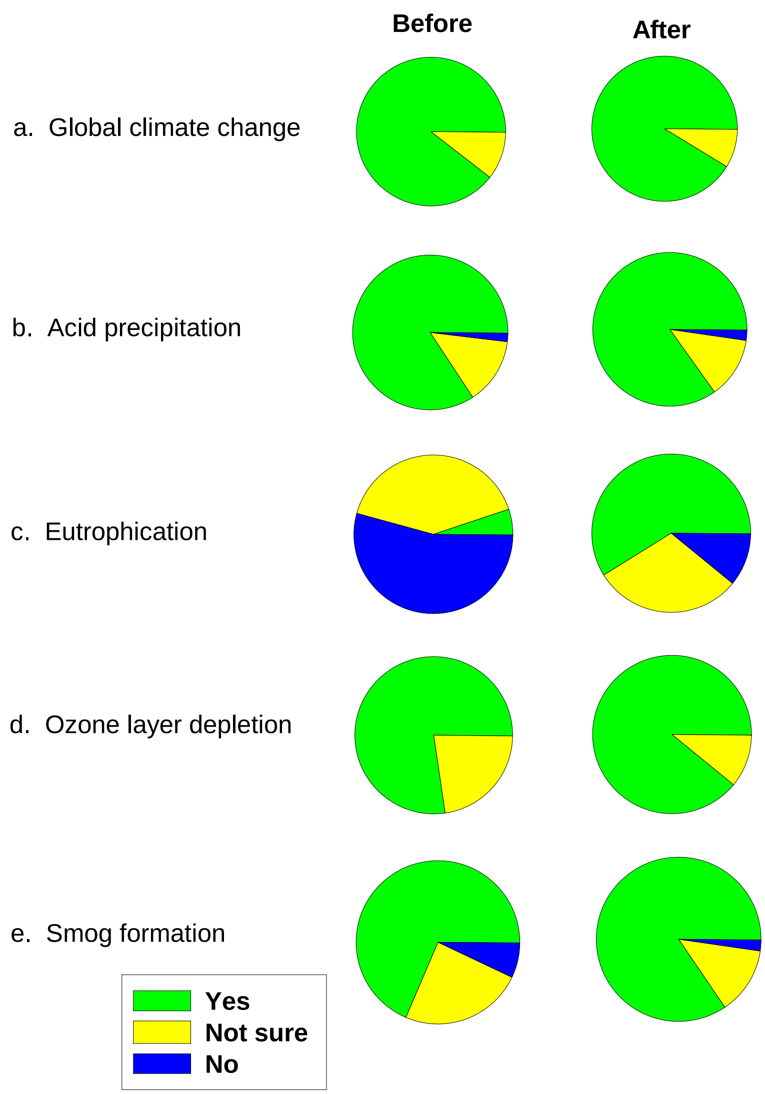

Figure 2. Please choose the best responses to the following statement. I can describe what the following environmental problems are (not necessarily what causes them, just what they are).

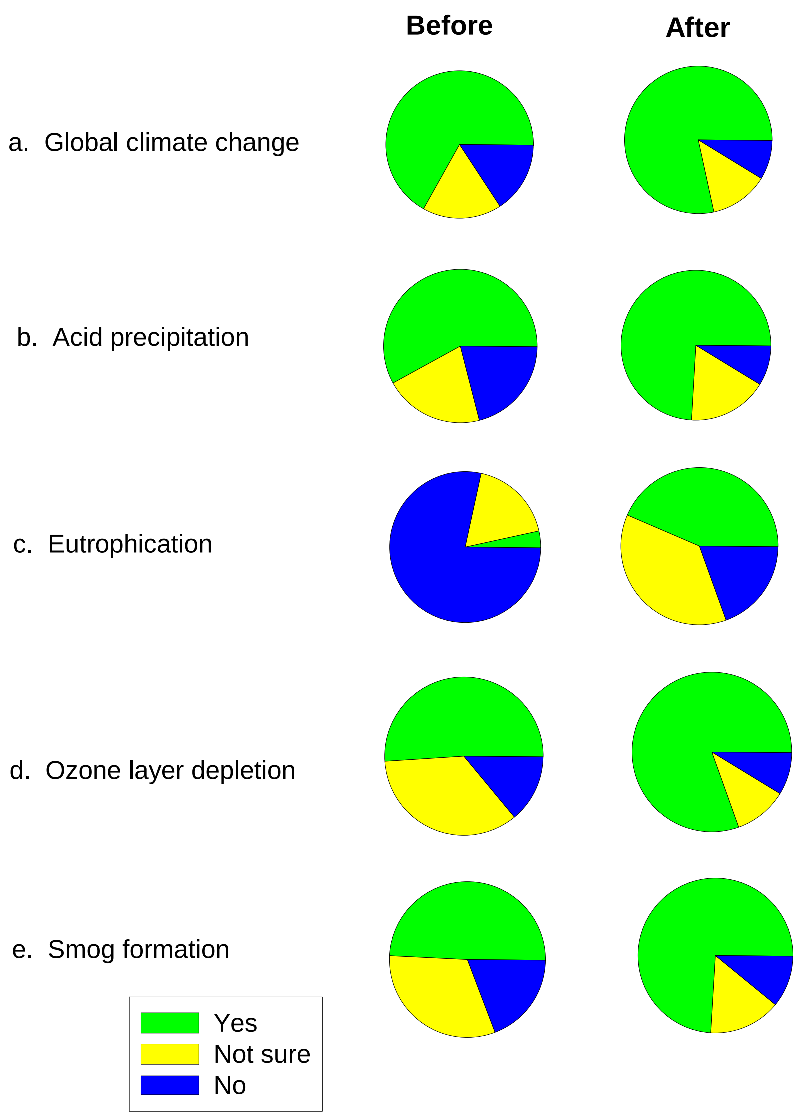

Figure 3. Please choose the best responses to the following statement. I can list the major types and sources of pollutants that cause the following environmental problems.

The software BEES was used as a hands-on exercise to increase students' familiarity with the steps in the life cycle assessment process. The expectation was not that students would gain expertise in the challenging process of life cycle assessment, nor that they be able to expertly apply BEES as a result of the brief class activity—instead, the goal was "foundational knowledge"[6]. Given this caveat, there was a dramatic increase in students' self-assessed ability to carry out the steps of life cycle assessments—identifying wastes emitted and resources consumed in a product life cycle—between the before and after surveys (Figures 4a and 4b, Appendix questions 4a and 4b). This is not surprising since it is unlikely that introductory

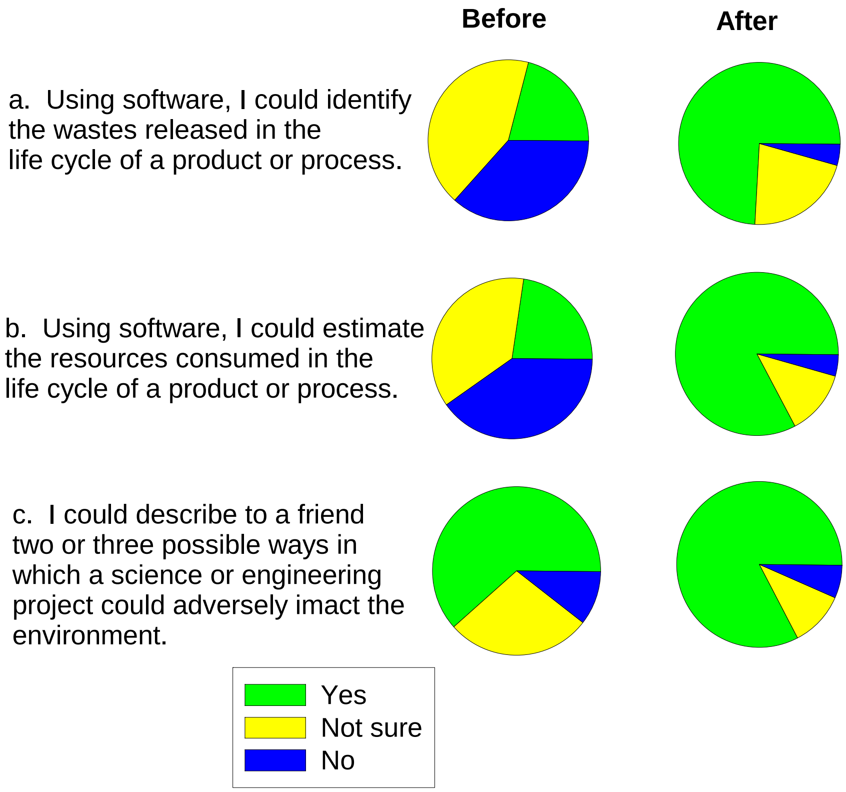

Figure 4. Please choose the best response to the following statements.

science and engineering students have had significant exposure to the procedures for life cycle assessment in their prior studies.

In terms of the second desired outcome—the ability to identify relationships between sustainable development and sustainable engineering (Fink's "integration"[6])—there was a significant increase in students' self-assessed ability to describe how a science or engineering project could adversely impact the environment (Figure 4c, Appendix question 4c), and in students' responses to the statement "I can give some examples of how scientists and engineers could integrate sustainability into their professional activities (Figure 5b, Appendix question 5b).

In terms of the final desired outcome—for students to develop the value or belief that sustainability is an important facet of science and engineering education and practice (Fink's "human dimension"[6]), the survey results indicate some change as a result of the class activities. For example, there was a small increase in the number of students that chose "agree" or "strongly agree" in response to the statements "I think that sustainability needs to be integrated into all science and engineering disciplines (Figure 5a, Appendix question 5a), and "Scientists and engineers should consider environmental impacts over the life cycle in designing products and processes" (Figure 5c, Appendix question 5c). But there was no significant change between the before and after survey responses to the statement "I think that, through their work, scientists

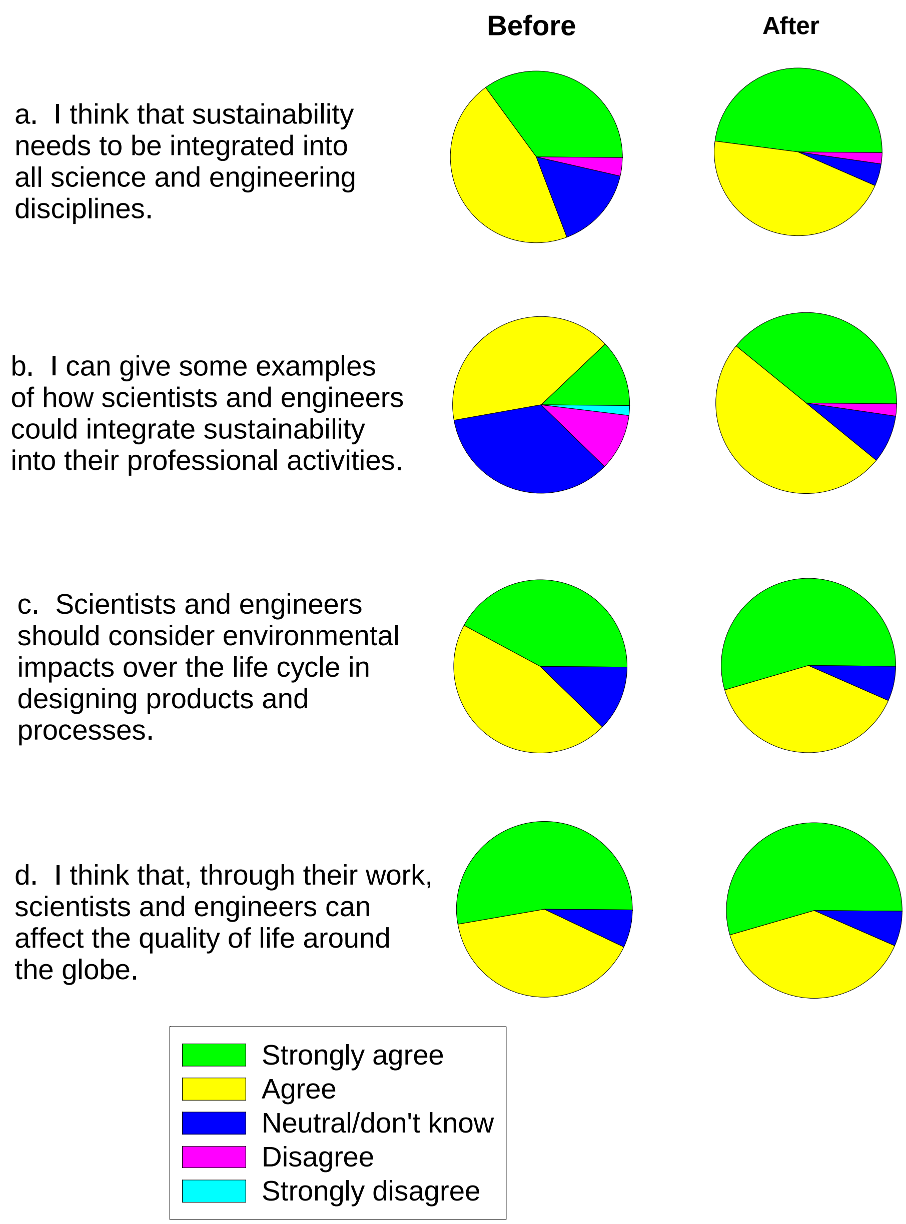

Figure 5. Please choose the best response to the following statements.

and engineers can affect the quality of life around the globe" (Figure 5d, Appendix question 5d). This is because most students (93%) chose "strongly agree" or "agree" in response to this question both before and after the module on sustainable engineering, indicating a prior appreciation of the role of scientists and engineers in improving the quality of life around the globe, as called for by ASCE BOK Outcome 10[2]. This may reflect, in part, students' motivations for choosing civil and environmental engineering and environmental science as career paths.

Conclusions and Recommendations

The concepts of sustainable development, sustainable engineering, the life cycles of products and processes, and life cycle assessment were introduced in an introductory science and engineering course via team activities and public domain software. It is the hope that such "foundational knowledge"[6] will allow students to apply the principles of sustainable engineering in future courses or their careers. These activities also may have resulted in some increase in students' appreciation of the importance of sustainability in science and engineering education and practice. Whether these changes are lasting must be assessed in the future.

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Appendix—Survey and Responses

The survey was administered anonymously using the online software Survey Monkey. An identical survey was administered both before and after class instruction on sustainable development and engineering. Ten to fifteen minutes of class time were given to complete the survey each time; students could also complete the survey outside class for a brief window of time if, for some reason, they could not complete it in class.

There were 57 responses for each question in the "before" survey and 46 responses for each question in the "after" survey, except for question 2e, for which there were 45 responses. Sixty five students were enrolled in the class. The survey below was preceded by an informed consent form. Students had to consent to participate in the study before proceeding to the survey. Percentages below may not sum to 100% due to rounding error.

1. Please choose the best response to the following statements.

		Responses (before/after) as %		
		Yes	**Not sure**	**No**
1a	I can define the term "product life cycle".	39/96	32/0	30/4
1b	I could list most of the stages in the life cycle of a product that I use every day (e.g., something in my backpack or home).	35/80	30/13	35/6
1c	I can define the term "sustainable development".	37/85	26/11	37/4
1d	I can give an example of sustainable engineering.	46/89	21/6	33/4

2. Please choose the best response to the following statement. I can describe what the following environmental problems are (not necessarily what causes them, just what they are).

		Responses (before/after) as %		
		Yes	**Not sure**	**No**
2a	Global climate change	90/91	10/9	0/0
2b	Acid precipitation	84/85	14/13	2/2
2c	Eutrophication	5/59	40/30	54/11
2d	Ozone layer depletion	77/89	23/11	0/0
2e	Smog formation	68/84	25/13	7/2

3. Please choose the best responses to the following statement. I can list the major types and sources of pollutants that cause the following environmental problems.

		Responses (before/after) as %		
		Yes	**Not sure**	**No**
3a	Global climate change	67/78	18/13	16/9
3b	Acid precipitation	58/74	21/17	21/9
3c	Eutrophication	4/44	18/37	78/20
3d	Ozone layer depletion	51/80	35/11	14/9
3e	Smog formation	49/74	32/15	19/11

4. Please choose the best response to the following statements.

		Responses (before/after) as %		
		Yes	**Not sure**	**No**
4a	Using software, I could identify the wastes released in the life cycle of a product or process.	21/74	42/22	37/4
4b	Using software, I could estimate the resources consumed in the life cycle of a product or process.	23/83	37/13	40/4
4c	I could describe to a friend two or three possible ways in which a science or engineering project could adversely impact the environment.	61/83	28/11	10/6

5. Please choose the best response to the following statements.

		Responses (before/after) as %				
		Strongly agree	**Agree**	**Neutral/ don't know**	**Disagree**	**Strongly disagree**
5a	I think that sustainability needs to be integrated into all science and engineering disciplines.	35/48	46/46	16/4	4/2	0/0
5b	I can give some examples of how scientists and engineers could integrate sustainability into their professional activities.	12/39	40/50	35/9	10/2	2/0
5c	Scientists and engineers should consider environmental impacts over the life cycle in designing products and processes.	42/54	46/39	12/6	0/0	0/0
5d	I think that, through their work, scientist and engineers can affect the quality of life around the globe.	53/54	40/39	7/6	0/0	0/0