AC 2009-157: THE IMPACT OF EXPOSURE TO BIOLOGICALLY INSPIRED DESIGN ON THE ENVIRONMENTAL ETHICS OF UNDERGRADUATE ENGINEERING STUDENTS

Brent Nelson, Northern Arizona University

Brent Nelson received the B.S. degree in mechanical engineering from the University of California at Berkeley in 2002, and the M.S. and Ph.D. degrees in mechanical engineering from the Georgia Institute of Technology in 2004 and 2007, where he held NDSEG, GeorgiaTech Presidential, and Woodruff Fellowships. After finishing his PhD, he held a National Academy of Engineering CASEE Postdoctoral Fellowship, during which he worked with the Center for Biologically-Inspired Design at the Georgia Institute of Technology to study the use of Biologically-Inspired Design as a context for studying innovative design, student design behavior, and multidisciplinary collaboration. In August 2008 he joined the faculty of the Mechanical Engineering Department at Northern Arizona University as an Assistant Prfoessor, where his research interests span across applications of atomic force microscopy, thermal transport in micro/nanoscale devices, renewable energy, energy conservation, biomimetic design, and engineering education.

The Impact of Exposure to Biologically-Inspired Design on Environmental Ethics of Undergraduate Engineering Students

Abstract

Many natural organisms have developed and adapted solutions to technical challenges that are similar to those encountered in the engineering world, including developing hard and tough materials, optimizing the division of labor and resources, maintaining constant temperature, and generating efficient propulsion in air and water. Biologically-inspired design (BID) refers to applying such natural solutions to generate innovative design solutions for human-encountered technical challenges. BID exposure allows ecological principles to be taught within an engineering context, potentially enhancing environmental appreciation among engineers. This study evaluates results from a survey instrument that evaluated environmental attitudes among engineering students in a BID course taught at our institution and was administered both at the beginning and end of the semester. The survey produced mixed results, with a statistically significant increase occurring in the number of students freely listing environmental impact as a design consideration, but a small decrease occurring in the relative rank of environmental impact when students were prompted to rank it against other design considerations. Such a disconnect between attitudes and actions has previously been observed and could be attributed to a number of factors, including environmental discussions in the students' other external activities, media coverage, political debates, and a drought crisis that occurred in our region during the semester of the course. The preliminary results demonstrate that BID represents a promising approach for improving environmental ethics of engineering students and recommend further examination of the subject.

Introduction

Concerns over climate change, energy production, and the impact of waste have caused many scientists and engineers to recognize the often negative impact of humans on their environment. ABET accreditation criteria now account for environmental responsibility with criterion 3c, which lists the "ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" as a required engineering program outcome. Many scientists and engineers, however, have a limited awareness of the environmental impact of the technology they create and use, and they often do not investigate new design concepts and paradigms that might mitigate negative environmental effects. Ideally, engineers would proactively work on developing new engineering solutions that would help to mitigate the environmental effects of humans. Short of this ideal, even an engineer with only marginal concern about ecological health might design a product or process to use less toxic or recyclable materials, which would still be of significant benefit to the environment in general.

The question of how to strengthen the environmental ethics of engineering students remains the subject of much active study. Some studies have called for increased intervention from oversight bodies such as ABET and the UN,[1,2] others have called for intervention from industry,[3] while many others have described creation and development of environmental awareness and sustainability courses at specific institutions,[4-7] or proposed courses to develop.[8] A review of such programs can be found elsewhere.[9] One review in particular identified the need to implement an ethic of caring into environmental education to develop deeper senses of environmental responsibility among students,[9] although the correlation between caring and action is imperfect.[10] One effort to close the gap between attitude and practice was the development of a general environmental science course specifically focused on generating a sense of individual empowerment regarding environmental challenges.[11]

One of the most common correlative factors affecting environmental sensitivity or caring is personal experiences of natural areas, especially those during childhood.[12,13] While childhood experiences in natural areas are the most influential in affecting environmental sensitivity, experiences as adults can increase sensitivity as well.[13] Studies specifically in the university setting have shown that general science education can improve environmental attitudes among students.[11,14]

Biologically-inspired design (BID), or biomimetics, is the design technique of learning from the adaptations of biological organisms to develop new solutions to technical challenges. Exposure to BID could enhance environmental attitudes in several different ways. First, evolutionary adaptation represents millions of years of proven design concept testing, with the added constraint that all adaptations must utilize environmentally-friendly materials and processes.[15,16] Thus BID exposure could increase the hope and expectation among engineers and designers that more environmentally-benign technologies are possible since nature was able to do so. Second, learning about the delicate balance of ecosystems may make engineers more sensitive to the impacts of their designs on the ecosystem. Third, learning about the adaptations that different species have developed to solve engineering problems may convince engineers to protect those species even if only because of what can be learned from them. Fourth, learning about the diversity within nature can develop an inherent appreciation for nature, in the same manner that childhood experiences in natural areas can affect environmental ethics. Because BID exposure allows ecological principles to be taught within an engineering context, such environmental appreciation may be enhanced because of the apparent utility of the principles to the engineer.

This article reports on the impact of BID education on the environmental attitudes among undergraduate engineers enrolled in a course specifically focused on BID.

Methods

The BID class used in this study was an undergraduate multidisciplinary special topics course, cross-listed in biology, polymer textile and fiber engineering, industrial and systems engineering, materials science and engineering, and mechanical engineering. The distribution of engineering students in the class was 1 electrical, 13 biomedical, 8 industrial and systems, 13 mechanical, and 3 materials science. There were also 7 biology students, but they were not part of the study described here.

The beginning portion of the course consisted of general introductory lectures on BID, design methodology, and tools and techniques specific to BID, as well as class discussions of 'found objects,' which were biological objects and organisms identified and researched by the students. The remainder of the course alternated between guest lectures on various technical topics within

BID, such as locomotion and materials design, and continued discussion of found objects or student design projects. Guest lecturers were faculty members from various departments who were actively researching the BID topics on which they lectured.

Outside of class, the primary assignment was a design project in which the students chose a biological system to mimic and translate into a manufacturable conceptual design. Students were allowed to freely define their own project topic, with the only requirement being that their project had to utilize principles taken from a biological source. The final product produced by the design teams was not to be a prototype, but rather a presentation and report that could be given to hypothetical investors or project managers requesting funding to move forward on the project. The final report was to describe the proposed design, explain how it could be made or implemented, compare it to existing solutions, and provide relevant quantitative analysis that assessed the feasibility and claimed advantages of the design. The purpose of this project format was to force students to consider economic and practical feasibility in their designs. There were abundant challenges associated with assigning students with a semester-long design project focused on analogical design utilizing cross-disciplinary information. For this reason, correlating student experience on the design project with environmental ethics was not feasible. The encountered challenges pertaining to student design behavior are not the focus of this article, but they will be described elsewhere.

There was no explicit emphasis within the class on environmental issues. The reason for this was that the intention of this initial study was to establish whether BID education by itself could impact environmental ethics through the aforementioned mechanisms. Adding an explicit emphasis on sustainability in future iterations of the course will be the subject of future studies. One lecture discussed mimicking ecosystems in systems design, which included some discussion of sustainability, but the lecture was presented from an industrial perspective rather than an environmentalist perspective. The lecture focused on identifying principles of ecosystems that could be applied to large systems like cities or industrial plants, and then understanding the industrial and practical challenges that may prevent utilizing these principles, such as cost or reliability.

Even though the correlation between environmental attitudes and actions is inconclusive, improving environmental attitudes can only help and is a place to start in examining changes to environmental ethics. This study used a survey instrument to evaluate environmental attitudes among the engineering students in the BID course. Administering the survey at the beginning and end of the course allowed monitoring changes in environmental attitudes over the period of the course. Survey responses were anonymous, limiting the results to generalizations about the shifts in the aggregate environmental attitudes among the engineers in the class.

The survey instrument used in the study had three components and is shown in the appendix. The first component was free response and asked students to list the factors they take into consideration when designing a system or device. Students were instructed to complete this portion of the survey before moving on to the subsequent portions. The second component of the survey listed the factors form, function, cost, environmental impact, and novelty, and asked students to rate the importance of each on a scale from 0-5. The third component of the survey asked the students to rank the aforementioned factors in order of relative importance.

The goal of the first component of the survey was to assess whether students were proactively concerned with environmental factors. The goal of the second component was to assess the degree of perceived importance they allocated to environmental factors, and the goal of the third component was to assess the actual degree of relative importance placed on environmental factors when potentially in competition with other design constraints and considerations.

The instrument asked about considerations within a design setting in order to frame the survey questions within the context of future behaviors.[17] Although such survey questions are not subject to true economic, feasibility, and time constraints, the majority of engineering students at our institution participate in an industrial internship program and have enough industrial experience to have a reasonable grasp of how these factors might influence design methodology.

Results and Discussion

Because survey results were anonymous, the results are presented for the class as a whole. Due to several students dropping the class during the semester, the number of respondents decreased from 39 in the initial survey to 31 in the final.

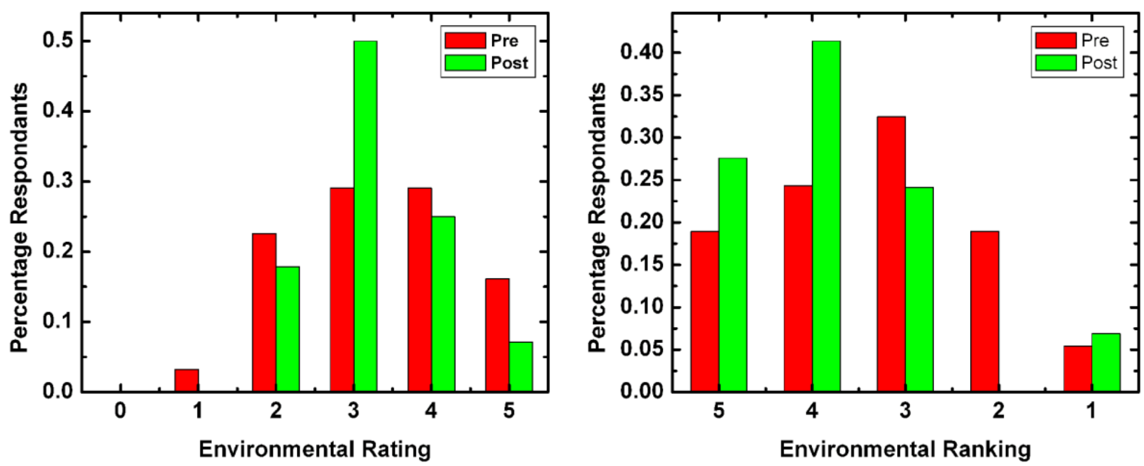

Figure 1. Percentage distribution of student ratings (left) and rankings (right) for environmental factors, showing no statistical difference. For the ranking, '1' corresponds to the highest ranking.

Figure 1 shows the distribution of the student ratings (left) and rankings (right) of environmental factors, taken from the responses to components 2 and 3 of the survey, respectively. The graphs are arranged such that for both graphs, low environmental priorities are on the left while high environmental priorities are on the right. The mean environmental ratings for the pre- and post-tests were 3.3 and 3.2, respectively, and the mean rankings were 3.4 and 3.9, respectively. Thus a small decrease occurred in the priority given to environmental considerations for both metrics, as the increased number for the ranking corresponds to a lower relative priority. The pre- and post-test distributions are relatively similar, with a chi-squared test showing no statistical significance between the two.

Despite the lack of a statistically significant difference between the pre- and post-tests on components 2 and 3 of the survey, the number of students listing environmental considerations as a design factor in the first component of the survey increased from 13% (5 respondents) to

45% (14 respondents), an increase of nearly 250%. A chi-squared test showed this change to be statistically significant.

The increase in the number of students listing environmental factors in the free response portion of the survey implies that the students were more intrinsically concerned with environmental consequences at the end of the class than at the beginning. However, the decrease in the ranking of environmental factors, although not statistically significant, implies that a heightened awareness of environmental considerations would not affect the actions of the students in their design activities. The disconnect between attitudes and actions is also apparent in the distributions for the rankings and ratings in Figure 1. The ratings distribution (left) skews towards higher ratings for environmental considerations, while the rankings distribution (right) skews towards lower rankings, again implying that while students hold environmental considerations in high regard, the value disappears when placed in competition with other criteria. Such a disconnect between attitudes and actions has previously been observed in the literature.[10] A survey targeted more specifically to determining the degree to which an individual would accept tradeoffs for environmental benefits would be more effective than the simple ranking system used in this study, and should be used as a follow-up study.[18]

Several factors limit the strength of the conclusions drawn from the results of this survey. Heightened awareness of environmental factors could come from myriad external factors unrelated to the BID class, including environmental discussions in the students' other external activities, media coverage, political debates, and a drought crisis that occurred in our region during the semester of the course. Additionally, the students may have remembered the factors listed in the survey from the pre-test, affecting their responses in the post-test, causing more students to list environmental considerations as a factor affecting their designs. However, students were never told that the purpose of the survey was to evaluate environmental ethics, and no similar increases were observed in the number of students listing the other design factors from components 2 and 3.

Conclusions

This article reports on the effect of BID education on the environmental attitudes of undergraduate engineering students. Survey responses demonstrated that students had an increased awareness of environmental considerations, but that such awareness may not translate into behavioral changes. Potential external factors limit the conclusions of the study, and follow-up studies that are more specifically targeted to assessing potential for behavioral change were recommended. In future expansions of this study, results will be tracked for individual students, and will extend beyond the semester of the course to allow monitoring of attrition. This will allow examining for differences according to age, gender, industrial experience, and academic discipline. Additional, more advanced environmental surveys will be used to increase statistical significance of the results. While the long term goal is to incorporate explicit discussion of sustainability and environmental impacts, the preliminary results described here demonstrate that BID holds promise as an approach for improving environmental ethics of engineering students, and further examination of the subject is recommended.

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Appendix

Please list your priorities and considerations when designing a system or device. Please do not modify your answers after you have turned to the next page.

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As a designer, rate each of the following aspects of a device design from 0-5, where 0 means not at all important, and 5 means very important. Please rate both the main category and the subcategories.

1. **FORM** of a device _____ _____
   a. Ergonomics _____ _____
   b. Visual appeal _____ _____
2. **FUNCTION** of a device _____ _____
   a. Ability to do intended job _____ _____
   b. Efficiency/simplicity with which it functions_____ _____
3. **COST** of a device _____ _____
   a. Manufacturing cost _____ _____
   b. Device cost _____ _____
   c. Continuing usage cost (e.g. electricity) _____ _____
4. **ENVIRONMENTAL IMPACT** of a device _____ _____
   a. Environmental impact of manufacturing _____ _____
   b. Environmental impact of use (e.g. energy) _____ _____
   c. Environmental impact of disposal _____ _____
5. **NOVELTY** of a device _____ _____
6. **OTHER**______________________ _____ _____

Rank the main categories in the preceding list of device design considerations (Form, Function, Cost, Environmental impact, Novelty, Other) from most important to least important.

__________ __________ __________ __________ __________ __________

Most impt least impt

Would your answers above change if you were to answer as a consumer? If so, please write those answers on the right-hand side, and re-rank below.

__________ __________ __________ __________ __________ __________

Most impt least impt