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Sustainable engineering: A comparative study of freshman and senior perspectives

Dr. Lynal Albert, Tarleton State University

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Abstract

Most engineering activities draw resources from nature and result in generating some form of end product, waste or emission that either becomes part of the environment or is released into the environment. In recent times, it has become increasingly important that students are taught sustainability principles and practices as part of their engineering curriculum. Sustainability entwined with engineering will prepare today's students to approach problems and develop solutions with a wholesome approach including better management of resources and preventing the need for major future clean-up activities. In order to facilitate the implementation of sustainability concepts as part of engineering design it is essential to create in the freshman mind an awareness of negative outcomes and environmental problems that can result from continued unsustainable practices. In this paper, we present a comparative study of freshman perspective and senior perspective of chief environmental concerns, ways to mitigate them and sustainable practices that can minimize future engineering impact. This study will identify the key areas of knowledge that current engineering education provides and identify differences in the stand point of sustainable engineering between the freshman and senior. The results of this study can aid in design and development of sophomore and upper level undergraduate courses to capture different aspects of sustainable engineering and expand freshman understanding of critical sustainability issues.

Introduction

Many engineering activities utilize resources from the environment in the form of materials or energy. During or upon completion of the engineering process, by products, wastes and emissions are produced that may be discharged into the environment. As such engineering cannot be isolated from the environment and preventing or minimizing its negative impact on the environment is a monumental task that has recently gained momentum. According to the EPA, sustainability is "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations"(1). Sustainable engineering is a process of practicing engineering without compromising on the quality of the environment. Sustainable engineering therefore utilizes a multidisciplinary approach of balancing social, economic, and environmental aspirations combined with good practices of engineering design, thus closing the gap between technology and the community(2). The environment, economy and the society are the pillars of sustainable engineering, with the environment and its protection in the forefront (3). The dependence of social welfare and economic upliftment on clean and safe engineering is highlighted by the 2030 sustainability development goals developed by the United Nations (4). The pursuit of sustainable practices can result in future benefits without compromising economic growth and standard of living. Consequently, sustainability is the end product or goal of sustainable development (2, 5, 6).

Although, industrialization and technological advancement has played a role in causing the urgent need for sustainability today, science and engineering can be pivotal in shaping sustainable practices and strategies(5). One critical element in developing and pursuing sustainable goals is human capital and hence the reform of undergraduate engineering education has received much attention. The motivation for academic institutions to incorporate sustainability principles into engineering education is manifold, including meeting criteria of accreditation boards like Accreditation Board for Engineering and Technology (ABET) across the globe, policies and regulations from government agencies and increase in the standards required by industries that provide employment to engineers(3, 5, 7). According to the National Society of Professional Engineers (NSPE), one of the professional obligations under the NSPE code of ethics, requires engineers to adhere to the principles of sustainable development with the aim of protecting the environment for future generations. Incorporation of sustainable practices into the engineering curriculum and extending engineering education beyond technical training is now recognized as a requirement to producing holistic engineers (2, 8).

Sustainability science has emerged as an academic specialty that is multidisciplinary in nature (5). Figure 1 demonstrates the overlap between the fields. Sustainability requires one to take into consideration economic, societal and social implications so an engineer will design products, systems or processes to maximize benefits accounting for all these areas and not only consider profit(2, 4).

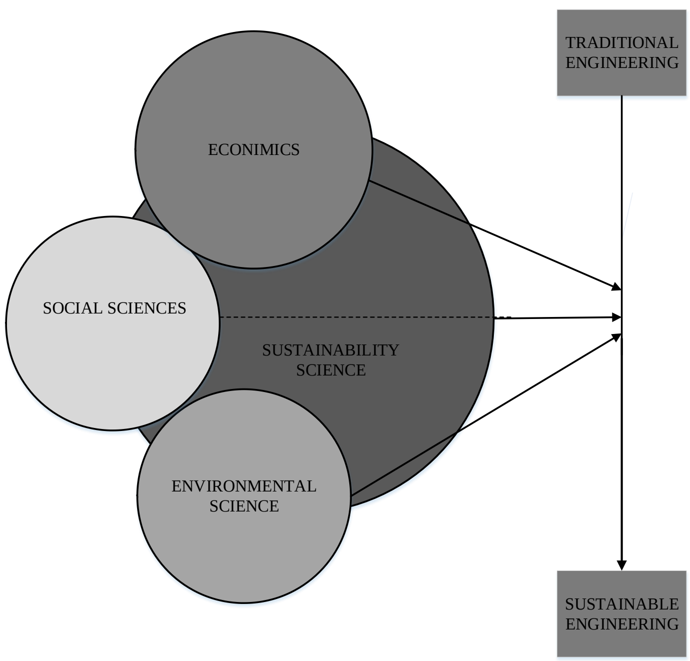

Figure 1: This schematic demonstrates sustainability science as a discipline that draws from multiple fields. Sustainable engineering is the merge of traditional engineering design with sustainability science. The sustainable engineer designs with technical skills while maintaining the theme of sustainability.

To produce engineers that are familiar with sustainable strategies and initiatives, it is extremely useful to identify the existing knowledge of students that are at the start of the engineering education. The primary goal of this study is to understand the freshman perspective of sustainable engineering and compare it to that of senior students. Students are key stakeholders in sustainability based education but studies examining their knowledge and understanding are limited (5). The results of this study will provide fresh insight to tailor courses as necessary to shape the engineering curriculum so as to provide a holistic engineering education.

Methodology

Students enrolled in multidisciplinary freshman engineering courses were provided a survey based on sustainability. They were asked to provide their answers to the following questions:

a) Define sustainability or sustainable engineering

b) What do you think are the critical environmental problems of today (list a maximum of 5)?

c) Identify practices that will enable us to mitigate these concerns (list a maximum of 5).

Students enrolled in multidisciplinary capstone engineering courses were provided the same survey based on sustainability. The survey results were then collected and analyzed for direct comparison. The obtained data facilitates identification of key areas of sustainability that students have been exposed to and retained during their undergraduate engineering education. It also highlights areas that educational interventions need to target to efficiently disseminate fundamental knowledge in the area of sustainability. To fill this gap, the next research stage focused on examining current literature to identify strategies that have been used to address sustainability topics in engineering education. Finally, recommendations are provided to incorporate sustainability concepts in engineering education.

Results and Discussion

Freshman and senior perspective on sustainable engineering: a) Define sustainability or sustainable engineering- when comparing the data obtained for freshman and senior engineering students, not surprisingly, the terms sustainability and sustainable engineering were relatively new to the freshman student. Figure 2 demonstrates our findings that 62% of freshman students were not knowledgeable about factors that contribute to sustainable engineering.

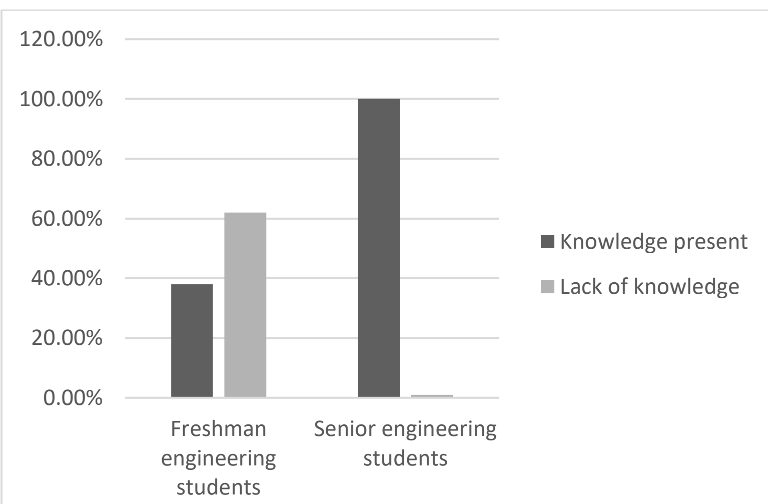

Figure 2: This figure demonstrates that only 38% of freshman engineering students were aware of what sustainable engineering encompasses.

The data clearly highlights the importance of incorporation of sustainability principles and practices as part of the curriculum.

b) What do you think are the critical environmental problems of today? Table 1and 2 below lists the various topics that freshman engineers and senior engineers thought were the most critical environmental concerns currently faced respectively. The data presented in the table demonstrates that freshman students are aware of critical environmental concerns. They generated an average of 4.3 concerns per head when asked for 5. The senior engineering students generated an average response of 4.8 per head when asked for 5. The data demonstrates that senior engineering students are more familiar with environmental issues, however freshman engineering students demonstrated a sound knowledge of common environmental concerns.

Table 1: The table provides the various topics that were raised by freshman engineers as the most critical environmental concerns of the day.

Critical environmental issues	Percentage of students that raised the concern
Pollution	60%
Global warming	38%
Deforestation	33%
Depletion of resources	29%
Wild fires	27%
Polluting the ocean	27%
Killing wild life	18%
Littering	16%
Melting glaciers	13%
Excessive mining	11%
Over population	9%
Non-biodegradable materials	9%
Water scarcity	9%
Ozone layer depletion	9%
Fuel emissions	7%
Excessive water usage	4%
Coral reef destruction	4%
Lack of rigid environmental regulations	4%
Landfill management	2%
Lack of awareness in people	2%
Rising sea levels	2%

Table 2: The table provides the various topics that were raised by freshman engineers as the most critical environmental concerns of the day.

Critical environmental issues	Percentage of students that raised the concern
Non-Renewable Energy	53%
Water quality	40%
Littering	33%
Ecosystem contamination	33%
Solid Waste management	27%
Erosion	27%
Overpopulation	27%
Water demand	20%
Negligence	20%
Toxic spills	20%
Mining	20%
Resource depletion	20%
Landfill management	13%
Plastics in ocean	13%
Erosion	13%
Recycling inefficiency	13%
Air pollution and Emissions	7%
Global warming	7%
Hazardous waste management	7%
Ecological imbalance	7%
Wild Fires	7%

c) Identify practices that will enable us to mitigate these concerns - Freshman and senior engineering students were asked to list strategies that will help combat these environmental concerns, previously listed in a sustainable manner. The question generated 2.04 mitigation strategies per head in the freshman class and 4.13 strategies per head in the senior class. Figure 3 and Figure 4 lay out the mitigation strategies raised by freshman and senior students showing the percentage of students that listed them. The data shows knowledge gap areas in both the freshman and senior engineering class students. In the freshman class, 24% of participants recorded promotion of recycling, 20% recommended using alternate resources that did not cause sustainability issues for engineering, and controlling ocean pollution and deforestation control were also raised by 20% of participants. Emission control and promoting environmental awareness among people were the other two strategies that were popular in the freshman class. In the senior engineering class survey improving current regulations and waste reduction were the most popular strategies identified by 47% of participants to alleviate current environmental problems. Technological advancement was also a popular strategy that was raised by 40% of the students.

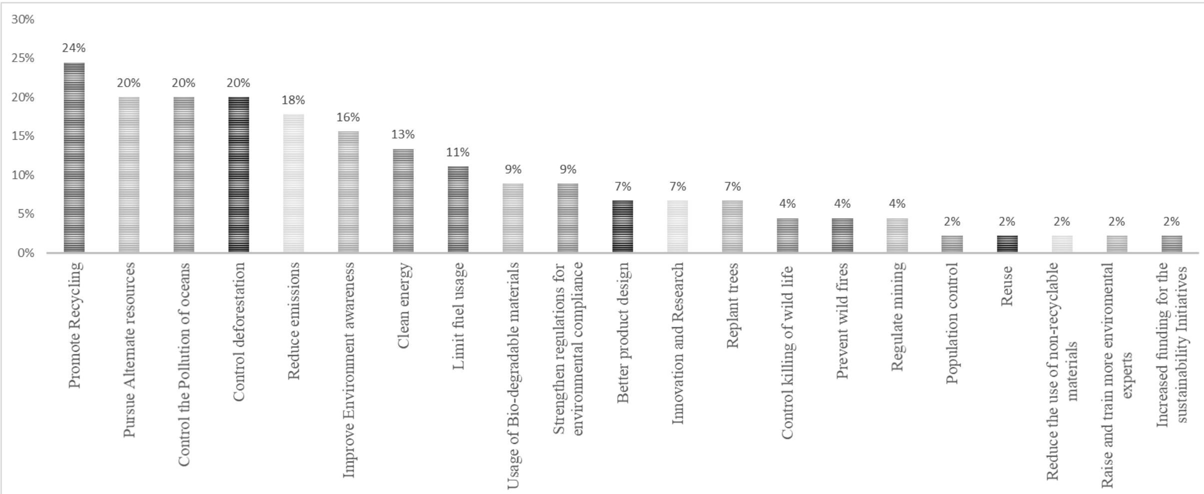

Figure 3: depicts the strategies of dealing with current environmental concerns as listed by freshman engineering students.

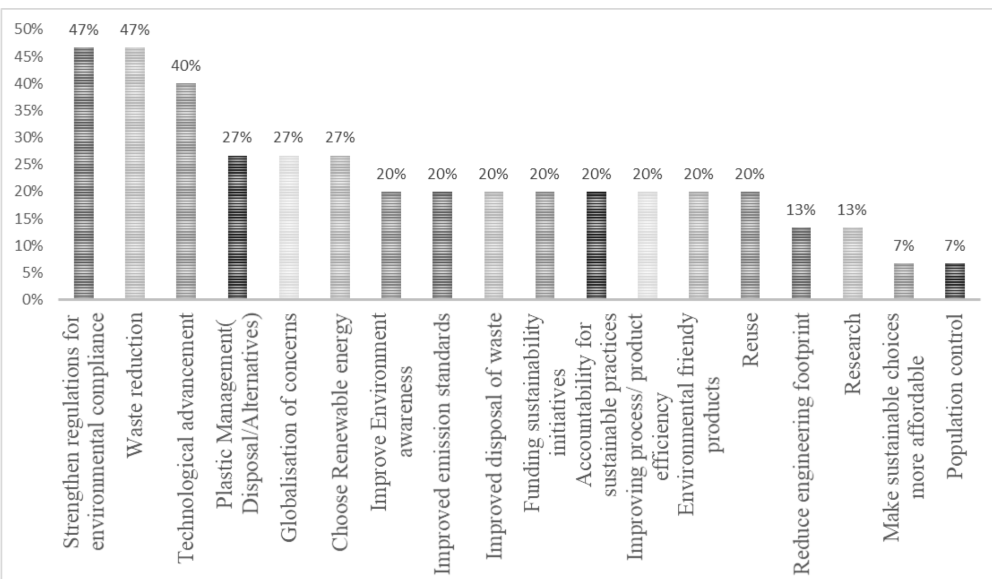

Figure 4: depicts the strategies of dealing with current environmental concerns as listed by senior engineering students.

Strategies currently employed for sustainable engineering education: Some universities require 13 to 15% of credit hours earned as part of an undergraduate engineering degree to provide background in environmental science and sustainability based courses. Some programs offer undergraduate courses with no prerequisites that are multidisciplinary in nature thereby introducing to the young engineer sustainability topics as part of reform courses. Other signature courses cover sustainable engineering topics for a broad range of audience. Apart from developing dedicated sustainability courses, other programs integrate sustainable concepts into traditional engineering courses (3, 4, 7, 9-11). ABET requires all accredited engineering programs to incorporate sustainability primarily to fulfill outcome 4, "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts"(3, 4).

Alternate approaches to incorporating sustainability in the engineering curriculum include providing problem based, service based and project based learning experiences. In problem based learning, a problem is presented to the students depicting real world scenarios and challenges. The students solve the problem taking into account practical constraints and sustainability concepts. In service based learning, students are presented with a problem that a community experiences and they develop solutions as part of service to the community. This method can be incorporated as part of community outreach activities such as those provided by organizations like Engineers without Borders and Habitat for Humanity(10, 12-16). Another common method is to provide design projects where students develop products and designs processes taking into account sustainability measures.

Other Recommendations

Other less commonly practiced methods as of now include virtual environments, augmented reality and serious games as part of courses. Thus sustainability concepts are being integrated as part of the engineering curriculum to equip students with strategies, tools and knowledge so as to provide a holistic engineering education (17-19).

When providing classroom enriching experiences on sustainability, students can be encouraged to use the twelve key principles of green engineering developed by Zimmerman that provide guidelines for engineers to consider sustainability in all aspects of engineering design. This framework is a tool that can aid in the addressing and communication associated with sustainable engineering and design. The principles provide a guideline and are not to be considered a set of rules. Table 3 lists the 12 principles that are key to sustainable engineering (6).

Table 3: The 12 Principles of Green Engineering (Reproduced from Anastas and Zimmerman (6))

Principle 1: Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.
Principle 2: It is better to prevent waste than to treat or clean up waste after it is formed.
Principle 3: Separation and purification operations should be designed to minimize energy consumption and materials use.
Principle 4: Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
Principle 5: Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
Principle 6: Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
Principle 7: Targeted durability, not immortality, should be a design goal.
Principle 8: Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
Principle 9: Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
Principle 10: Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
Principle 11: Products, processes, and systems should be designed for performance in a commercial "afterlife".
Principle 12: Material and energy inputs should be renewable rather than depleting.

A variety of other approaches can also be adopted for fostering sustainability concepts. These includes the use of case studies, debates, simulations, group discussions, multimedia, documentaries, and other approaches. Adopting these techniques can offer students a rich and beneficial learning experience.

Conclusion

Given current environmental concerns, education in the sustainability area has become fundamental. More specifically, engineering educators must provide learning experiences to students that allow them to become stewards of the environment and adopt relevant sustainable practices as part of their profession. Therefore, an understanding of how the current form of education influences the understanding of students is important.

Towards this goal, the current study examined the differences in the perspectives of freshman engineering students and senior engineering students when considering environmental concerns. The results demonstrated that the education and training offered, has been helpful in improving the understanding of students of key environmental issues. Moreover, the educational experience also has been equipping students with knowledge of sustainable practices that if adopted can contribute to the preservation and management of the environment. Further research may need to be performed to develop assessment tools that can identify key areas that need attention and courses and projects can be tailored to improve student learning with emphasis in those knowledge gap areas.

The current article also offers approaches through which sustainable education can be incorporated in the engineering curriculum. These methods include the use of independent sustainability courses, sustainability themes embedded in traditional courses, problem based, service based and project based learning experiences. Other approaches include the use of debates, case studies, documentaries, virtual environments, augmented reality and others. Finally other recommendations to improve the educational experience of students and the outcomes achieved are also discussed based on the principles of green engineering.

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