Integration of Environmental Sustainability with Capstone Experience

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Abstract

Environmental sustainability is one of the most long term challenges facing engineering today. For example, the National Academy of Engineering in the U.S.A. announced a set of "grand challenges" for the engineering profession[1]. In their document, the NAE stated: "As the population grows and its needs and desires expand, the problem of sustaining civilization's continuing advancement, while still improving the quality of life, looms more immediate." As a result, there is an increasing pressure nationally and internationally for strong inclusion of environmental sustainability in undergraduate engineering education.

The integration of sustainability throughout an undergraduate engineering program in addition to the development of a unique inter-disciplinary course in environmentally conscious design have contributed to achieving significant program outcomes. However, significant skill development and outcome validation could be achieved by the careful integration of environmental sustainability in the capstone design experience. This paper describes the integration of environmental sustainability with capstone course topics and activities. In addition, assessment results for the integration impact on the capstone students in addition to achieving program objectives and outcomes are also discussed.

Introduction

In addition to validating program's achievement to students' outcomes[2-6], capstone courses are usually the last phase for students development before graduation[7,8]. This comprehensive view of the capstone course allows for the natural integration of different needed activities to achieve the program educational outcomes and objectives[9]. During course development and implementation, the course activities should be driven to close the gap between the learner state at the beginning of the course and the goal state at the end of the course[10].

One of the top engineering challenges facing the world today is environmental sustainability[11,12]. In response, a set of "grand challenges" for the engineering profession has been declared by the U.S.A. National Academy of Engineering (NAE). The NAE declares[1]: "As the population grows and its needs and desires expand, the problem of sustaining civilization's continuing advancement, while still improving the quality of life, looms more immediate." Consequently, there is an increasing pressure nationally and internationally for strong inclusion of environmental sustainability in engineering education.

In the following, as a step towards facing the environmental challenges in engineering education, the integration of environmental sustainability with an engineering capstone course will be discussed. In this work, environmental sustainability modules developed by a multi-disciplinary group of faculty are integrated with the capstone course activities. Increasing students' awareness of the challenges and the impacts of their design decisions on the environment are the main drivers for the environmental sustainability integration with the capstone experience.

Environmental Sustainability Educational Modules

For addressing environmental sustainability and promoting environmentally conscious engineering practices. a dedicated multi-disciplinary group of faculty have developed the innovative interdisciplinary course materials for ***Environmentally Conscious Design and Manufacturing***[13]**.** The development project was funded in part by a grant from the National Science Foundation. The developed materials are organized in the six topical modules shown in Table 1. These topics are offered through an internet based course open to engineering, science, and management undergraduate and graduate students.

In addition to providing students with the environmentally conscious perspective, the developed materials aims at developing students' economic, managerial, ethical, scientific, and engineering skills for critically examining environmental issues in product design and manufacturing. Emphasis is placed on engineering alternatives for reducing costs and improving environmental performance[13].

Table 1 – Course Modules and Topics

Module #	**Topic Discussed**
Module 1	Technology, the environment and industrial ecology
Module 2	Life cycle concepts and assessment
Module 3	Material Selection
Module 4	Process Design Issues
Module 5	End-of-use strategies
Module 6	Environmentally responsible management

The six topical modules, shown in Table 1, aim at enhancing students' environmental awareness, critical thinking, and problem solving strategies needed for professional practices. By studying the six topical modules[13], "students will be able to:

1. Provide a critical analysis of the historical, ethical, social, philosophical, and regulatory issues underlying the environmental impact of goods and services.
2. Evaluate life cycle analyses of products and/or processes and propose strategies for addressing environmental impact while still meeting design and economic requirements.
3. Conduct a material selection with a goal of reducing the environmental impact of a product and/or process while simultaneously reducing material costs.
4. Use appropriate tools to evaluate the environmental impact of a manufacturing process and recommend actions for reducing this impact and minimize production costs.
5. Propose design changes to a product to enhance recycling, reuse and/or remanufacturing capability with consideration of the economics of these activities.
6. Identify and apply best practices in promoting the environment in a corporate setting."

The six topical modules were introduced and integrated with the capstone course activities. The integration process aimed at enhancing students' environmental awareness and realization of the impacts, of their design decisions, on the environment during the capstone experience.

Environmental Sustainability Integration with Capstone

Capstone courses could play an active role in achieving and validating students' outcomes and program educational objectives. During the course design and development the course structure should be flexible to include a variety of activities in addition to the main design projects. These activities could be designed to address the different educational gaps for each students' team[8.9].

To increase the environmental awareness and close the gap in students' understanding of the impacts of their design decisions on the environment, the discussed environmental sustainability modules were introduced as integrated part of the capstone course activities. For successful implementation of the introduced environmental sustainability activity, the development of accurate performance gaps for each student team were also established.

The capstone course selected shares with educational program the following five Educational Objectives (PEO's), discussed in references[8,9].

PEO 1: Showing leadership in contributing to the success of their teams
PEO 2: Work collaboratively to synthesize information and formulate, analyze and solve problems with creative thinking and effective communication.
PEO 3: Make professional decisions with an understanding of their global, economic, environmental, political and societal implications.
PEO 4: Apply modern tools and methodologies for problem solving, decision making and design.
PEO 5: Commit to professional and ethical practices, continuous improvement and life-long learning.

All course activities are designed to achieve the program educational objectives and students' outcomes based on the needs of each student team, in addition to finishing the capstone project. During implementation, to achieve the Program Educational Objectives, the main drive of the capstone integration is closing the gap between the program's goal and the learners' state at the entry to the course. This gap analysis is formative assessment process[10] starting at the first week of the course.

At the beginning of the course, to assess students' performance gaps on making design decisions with understanding of their environmental implications, students are instructed to discuss the impact of their selected capstone project and design approach on the environment. The initial reports for all the teams are assessed during the second week. The assessment is performed based on the course pre-established performance criteria and rubrics[14,15]. These criteria and rubrics are developed for the performance criterion that relates to the environmental sustainability outcomes and linked to the Program Education Objectives (PEO 3). The gap for each team is then

determined and planned environmental sustainability activities are designed and monitored to the end of the term.

At the end of the course, using the same criteria, targets, and rubrics the final assessments for environmental sustainability performance is conducted. These assessments are performed using direct methods, based on the final project report of each team.

Environmental Topics Integration Assessment and Results

To help in assessing the achievement of the outcomes and objectives a Performance Index relating to environmental sustainability performance is developed for every team in the class. This Performance Index is based on the target established for the environmental sustainability outcomes and educational objectives. Each performance index is developed using the following formula[9].

Performance Index (PI) = [1- (Target Level -Assessed Level)/ Target Level] x100 (1)

Equation 1, is used to develop the course initial and final Performance Indices for every team in the class to assess the achievement level of the environmental sustainability performance.

The course initial and final data assessment data are shown in table 2 and Figure 1. Using these course initial and final assessment data the initial and final Performance Indices, shown in Table 3 and Figure 2, are developed at the beginning and the end of the class.

The initial performance indices are measures for the gap to be closed for each team. These gaps are utilized to guide and monitor the environmental sustainability activities to the end of the course in order to customize the learning for each team. The final performance indices demonstrate each team environmental sustainability performance achieved at the end of the course.

Table 2 - Capstone Initial and Final Assessment Data

Performance level is based on the following scale: 1 2 3 4 5 Low Medium High	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6
Initial - Students understanding of the impacts of their decisions on the environment. (Target Level = 4)	3.1	3.0	3.2	3.1	3.1	3.0
Final - Students understanding of the impacts of their decisions on the environment. (Target Level = 4)	3.7	3.6	3.7	3.6	3.7	3.6

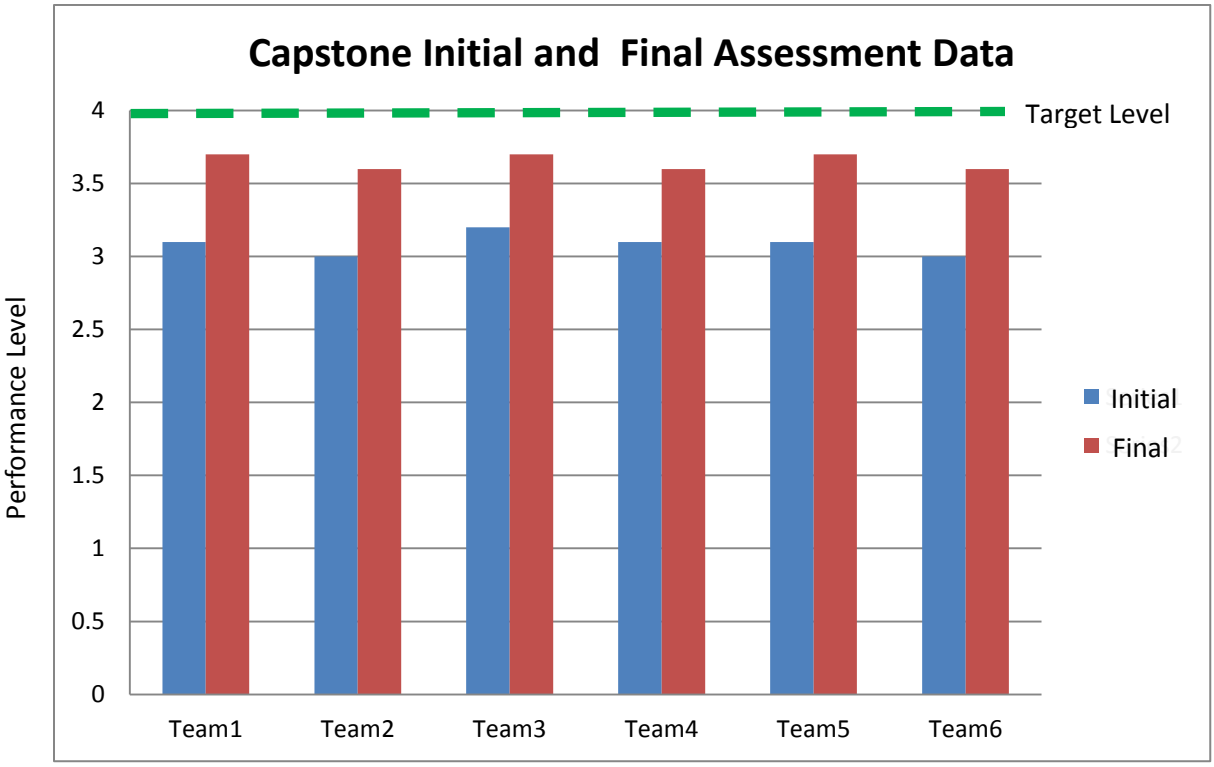

Figure 1 – Students Understanding of the Impacts of Their Decisions on the Environment.

Table 3 - Capstone Initial and Final Performance Indices

Performance Indices	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6
Initial - Students understanding of the impacts of their decisions on the environment. (Out of 100)	77.5	75	80	77.5	77.5	75
Final - Students understanding of the impacts of their decisions on the environment. (Out of 100)	92.5	90	92.5	90	92.5	90

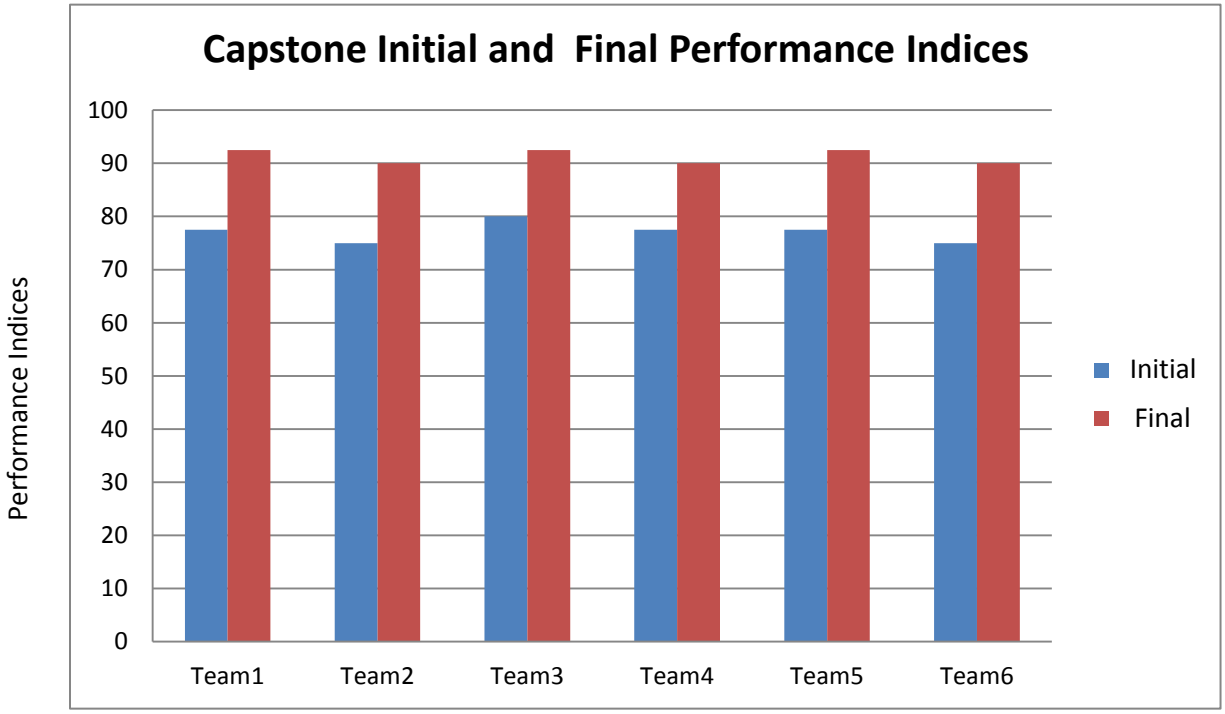

Figure 2 – Students Understanding of the Impacts of Their Decisions on the Environment.

As shown in Figure 2, by identifying the gap, the target improvement and the effort needed can be focused. For the environmental sustainability performance presented in this work it is clear that performance improvement was achieved during the course for each team.

Feedback form Students' Assessment

The following are some feedback from students' assessment to the environmental sustainability materials introduced and integrated with the capstone activities.

1. "These modules would be good for engineers, as most do not think about the environment when they design new products. The main concern when a new product is designed is generally performance and cost. A company generally wants to initially make the product meet specifications. Once the product meets specifications they want to lower the cost of the product. Finally, some companies will look into making the technology green to appeal to a larger demographic. Saying that a product uses green technology/ is recyclable is a strong advertisement method. Therefore, to teach future engineers more about green engineering before they enter the business world will help bring product's impact on the world down potentially at the very first stages of engineering. The less the world is impacted by our products the better. We have been learning over the past 20 -30 years that everything we make has a large impact on our

planet. Since then we have made a strong effort to reduce our impact on the planet from the products we make. This has been very evident in the design of cars as everything we do with cars is to improve fuel economy and improve performance without needing more resources."

2. "The concepts put forward in the module 6 documentation are a good start to creating a process to making companies more green. In this respect, I believe the existing documentation is fairly robust. The use of multiple examples across different disciplines helps to give a broader understanding of the concepts that drive the process."

3. "The work shows a very good way to plan a sustainable product. This kind of analysis is extremely beneficial for an engineer; because beyond the enforcement of the first topic of The Fundamental Principles of ASME Code of Ethics of Engineers, the environmental sustainability practices adds value to the final product."

4. "An important concept to carry into my career is the cradle to cradle approach for engineering. I still would like to know more about it and how it is really done."

5. " If the environment does not survive then neither will we. I feel that the material was strong and explained everything fairly well and got the point across. The material was also well organized."

6. "Good source of information and can show how things used to be and the harm that we are doing to the environment. Really shows how little things have a large impact due to the amount of usage they get, example light bulbs."

Conclusions

Environmental sustainability can be integrated with capstone courses for facing the environmental challenges in engineering education. The integration of environmental sustainability with the activities of an engineering capstone course could enhance students' environmental awareness and understanding of the design decisions impacts on the environment. While environmental sustainability could be addressed through an independent course, or through integration with other courses, final development and/or validation should always be implemented during the capstone experience.

Through successful design, development, and implementation, a capstone course structure should be flexible to include environmental sustainability and other activities in addition to the main design projects. The environmental sustainability activities should be integrated with the capstone based on the performance gap of each project team. Therefore, the development of accurate performance gap, for each student team, is the key for successful integration of environmental sustainability with the capstone experience. The accuracy of the performance gap is mostly dependent on the development of adequate assessment and performance measurement tools. Accordingly, the set of performance indicators and rubrics to be used for assessing and identifying the gaps should be developed in collaboration with all program faculty and

stakeholders. By developing a reliable set of performance indicators, the capstone course environmental sustainability assessment can also be considered as program assessment.

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