Participation in a Fuel Efficiency Competition for the Mechanical Engineering Capstone Design Experience

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The Shell Eco-marathon is an international event that challenges students to design, build and test vehicles that use the least amount of fuel to travel the farthest distance. Undergraduate mechanical engineering students at Loyola Marymount University (LMU) have participated in this competition during the past three years within their capstone design course sequence. Data was collected and tracked over the past two years that examined the students': 1) goals after completion of their undergraduate degree, 2) perceived competency in various project activities, and 3) perception of including various topics in the course sequence. It was found that: 1) the students had an increased desire to pursue an engineering career, 2) the students significantly improved in various design and engineering related skills and 3) that the vast majority of the students felt that participating in a design competition against other schools was extremely important.

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Background

Significance

It is clear that the undergraduate science, technology, engineering and mathematics (STEM) educational system within the United States is archaic and not evolving fast enough to address major global concerns and keep pace with current innovative technological advances. It has been reported that the number of engineering undergraduates has declined by 18% between 1983 and 1999[1]. More disheartening is that a 3% decrease in engineering graduates occurred between 1986 and 2006, at a time when the number of students receiving bachelor's degrees in the United States has increased more than 50%[2]. For the past 20 years, the National Academy of Engineering (NAE), the National Science Foundation (NSF) and the engineering community in general have been warning academicians of this problem[3]. In particular, these agencies have been calling for systemic changes in engineering education, including more emphasis on implementing hands-on, real-world engineering practice and design throughout the curriculum.

As a response, professional organizations and corporations (i.e., the American Society of Mechanical Engineers (ASME), the Society of Automotive Engineers (SAE) and Shell) organize design competitions that serve as arenas for students to directly apply the engineering fundamentals and skills they learn within their courses to real-world problems. Unfortunately, the vast majority of the student teams participating in these competitions do so in an extra-curricular manner. These competitions act as perfect forums for the students to practice engineering and can easily be integrated into STEM curricula resulting in numerous benefits.

This presents a very exciting, yet challenging opportunity for the STEM academic community. Because a main function of large research universities offering Ph.D.'s in mechanical engineering is to do research related to real-world problems, smaller Master's universities that do not offer Ph.D.'s most typically teach lecture-style undergraduate courses that do not directly engage the students in real-world engineering applications. Since this project was conducted at a Master's-granting institution, the challenge of teaching undergraduate engineering courses in a manner that excites the students and engages them in actually solving real-world problems using a hands-on, practical approach is the subject of this work.

Related Literature

The project mode of instruction in engineering education in the US was discussed by Lutz and Schachterie, who conducted a survey of engineering educators in the US to ascertain actual practice regarding the delivery of engineering projects in the curriculum[4]. Similarly, Da Rocha Brito et al. discussed the benefits of including projects in engineering education[5]. The projects provide opportunities for the students to develop additional abilities that will eventually make them professionally competent. In particular, they discuss their efforts of requiring the students to develop projects at the beginning of a course, work closely with a professor and/or project advisor and showcase their project results. In addition, the projects are coupled with laboratory experiences and the students participate in at least five of these projects during their undergraduate education. Their methods have increased the development of research skills, student self-confidence and leadership abilities. Finally, their approaches have given the students a more generalist view of the global marketplace.

However, a clear distinction exists between collaborative, multidisciplinary design projects and international design competition projects[6]. Lee specifically discussed the benefits of design competitions on engineering education. In particular, he discusses the enhanced undergraduate engineering educational experience as a result of participation in the International Walking Machine Decathlon. This competition was established to serve as a catalyst to motivate engineering students to learn more about the practical aspects of engineering, to solve a design problem from concept to implementation and testing, and to increase multidisciplinary exposure for the students.

Abdul-Wahab also discussed the benefits of international design competitions on the educational experience of engineering students[7]. This paper discussed a cooperative effort between industry, governmental agencies and academia to solve real environmental problems facing industry through student environmental design competitions. It was observed that all competing teams agreed that this competition was the best part of their engineering education. This approach is one solution to the missing bridge between fundamentals of engineering and appropriate design training that is a basic issue in engineering education.

Although research has been conducted on the benefits of including projects and international design competitions on engineering education, the author is not aware of any study that goes into such depth to quantify changes in the students' abilities while participating in such a project. The purpose of this study was to provide clear evidence illustrating the direct, measurable benefits on student learning through the participation in an international design competition that focuses on vehicle efficiency.

Shell Eco-marathon Competition

The Shell Eco-marathon competition:

1. Is an international event that challenges students to design, build and test vehicles that use the least amount of fuel to travel the farthest distance, and
2. Serves as an educational platform that encourages innovation, reinforces conservation and fosters the development of leading technology for greater energy efficiency.

The fundamental engineering principles to improve vehicle efficiency are to reduce the vehicle mass, reduce the rolling resistance, and to improve the aerodynamics. The ETH Zurich PAC-Car II obtained the Guinness World Record for the most fuel-efficient vehicle at the 2005 Shell Eco-marathon Europe, with a fuel efficiency of 12,665.5 mpg (5,385 km/l)[8]. The PAC-Car II is an excellent example of the passion, quality and technological potential involved in these design competitions.

Loyola Marymount University (LMU) entered its first Shell Eco-marathon Americas competition in 2007, but failed to complete the vehicle, as it was organized as an extra-curricular project. The Eco-marathon vehicle project was then incorporated into the mechanical engineering capstone design course in the spring of 2008, and then incorporated into a yearlong senior-level mechanical engineering design course sequence during the 2008/2009 academic year. The performance results of the various LMU vehicles, including the 2009 Gen3 vehicle shown in **Figure 1**, at the Eco-marathon Americas are listed in **Table 1**. The major reason for the improvements from 2008 to 2009 is attributed to the increased level of integrating this design project into the mechanical engineering curriculum.

Figure 1. 2009 LMU Gen3 Shell Eco-marathon Americas prototype class combustion vehicle and team.

Year	Vehicle	Weight (lb)	Place	Efficiency (mpg)
2008	Gen1	202	15 / 29	313.4
2009	Gen2	111	15 / 43	531.1
2009	Gen3	93	9 / 43	858.4

Table 1. LMU Eco-marathon Americas results and weights for the prototype combustion class vehicles.

These fuel efficiency competitions are propitious environments for technical innovation[8] and are therefore relevant platforms for implementing into an undergraduate engineering curriculum. Unfortunately, the majority of the teams do not have strong enough connections to the worlds of research and industry, have very limited financial support and participate in these competitions in an extra-curricular manner. These are the primary obstacles to the development of true technical innovations. The goal of this project was to develop and study a model pedagogy and curriculum for these obstacles to be overcome.

The project also introduces students to two of the primary topical concerns of the automotive industry: safety and environmental sustainability[8]. By implementing and studying the impacts of a pedagogy that directly engages undergraduate engineering in solving a real-world problem involving environmental sustainability, numerous direct impacts potentially arise, including:

1. An increased number of students would be interested in pursuing a career in engineering,
2. The students will become highly excited and passionate about the importance that they, as engineers, play in solving the problems facing society,
3. The students would have a better practical understanding of engineering fundamental topics, and
4. Establishing quantitative evidence proving the efficacy of implementing this pedagogy into an undergraduate engineering curriculum, thereby creating a potential model for other institutions to follow and further improve upon.

Research Methods

Research Questions

Data was collected during the past two academic years in order to evaluate the benefits of incorporating the Shell Eco-marathon competition vehicle project into a yearlong senior-level mechanical engineering design course sequence. The students had no prior experience working on this particular project or a similar engineering project. A survey and filled out by each student prior to working on the project, midway through the project and after the project conclusion. The survey asked the students to evaluate and indicate:

1. Their goals after completion of their undergraduate degree;
2. Their current perceived level of ability and competency with various design project aspects, including computer aided design (CAD) modeling, design for manufacturing and assembly (DFMA) and geometric dimensioning and tolerancing (GD&T) practices, teamwork, manufacturing experience and communication skills, all ranked as either no, low, moderate, high or extraordinary ability; and
3. The importance of including various topics in the course sequence, including CAD modeling, creating physical prototypes, group-based and independent design projects and participating in a design competition, all ranked as either not, somewhat, moderately, very or extremely important.

Survey Participants

27 senior mechanical engineering students were enrolled in MECH 483 (Elements of Design) and MECH 441 (Mechanical Engineering Laboratory III) during the fall semester of 2008. The objectives of MECH 483 is for the students to learn how to design mechanical components and systems and to create an entire CAD assembly model of their vehicle design. The purpose of MECH 441 is for the students to gain hands-on experience in common design testing procedures and various manufacturing operations.

These students were split into two teams, with one team of 13 students and one team of 14 students. Each of these two teams worked on the design and testing of a prototype vehicle for the Shell Eco-marathon competition during the fall semester. The two teams were each organized into component-specific design group (drivetrain, shell, frame and engine/electrical), with about 3 students in each design group. A similar approach occurred during the fall of 2009, with a total of 20 students working on the design of one vehicle.

Continuing from the fall semester, the students worked on the fabrication and vehicle testing during the spring semester, with the competition occurring in mid April. During the spring semester, a total of 26 students were enrolled in MECH 484 (Mechanical Engineering Design) and both teams consisted of 13 students. The main purpose of MECH 484 is to have the students gain experience in manufacturing, assembling and testing a functional final prototype based on their 3D CAD models.

Findings

Student surveys were distributed to all of the students at the beginning and end of the fall semester in MECH 483 course and at the end of the spring semester in the MECH 484 course. Therefore, the students completed this survey a total of three times: at the beginning of the project, midway through the project and at the conclusion of the project. The data was analyzed using statistical techniques and average values for all of the questions were obtained from the students' responses.

In terms of the students' goals after completion of their undergraduate degrees, some changes occurred while the students worked on this project. Initially, 67% of the students planned to go to graduate school for a degree in an engineering-related field, while 26% of the students intended to obtain an engineering-related job position. After the project, 50% of the students planned to go to graduate school, while 38% planned to obtain an engineering job.

Statistically significant changes were observed in the students' perceived level of ability and competency with various design project aspects as they progressed through this project. In particular, **Figure 2** shows significant increases in various design, engineering and project skills by the time of the project completion. The most statistically significant changes occurred in the students' skills in design for manufacturing (DFM) practices (+50% change) and in the proper selection of standardized components (+40%).

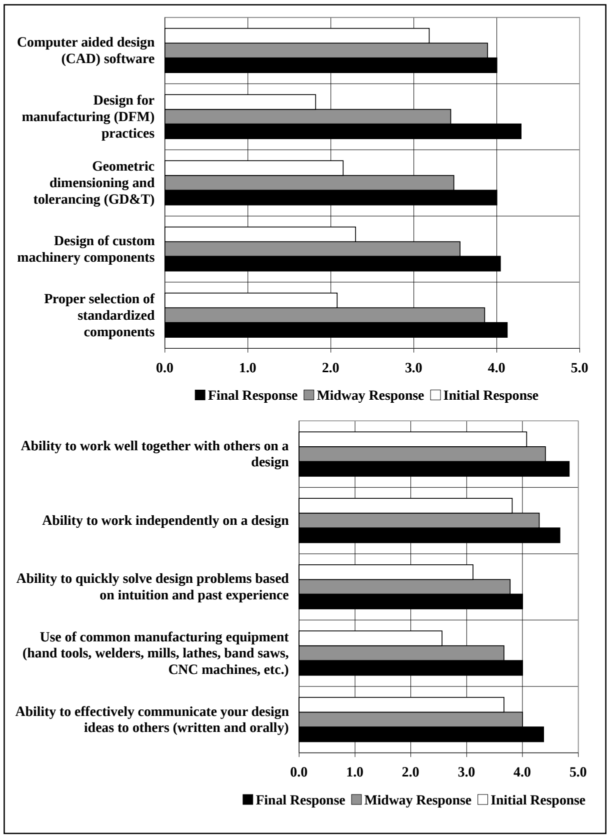

Figure 2. Survey results used to track changes in the students' perceived ability levels in performing various design and engineering related tasks (1.0 = no ability, 2.0 = some ability, 3.0 = moderate ability, 4.0 = high ability and 5.0 = extraordinary ability).

Finally, the data indicating student feedback about the course content and inclusion of various topics remained relatively unchanged during the duration of the project. However, some slight changes were observed in terms of the importance of participating in a design competition against other universities (+8%), the importance of working on independent project aspects (+8%), and the importance of applying knowledge from previous engineering courses to a comprehensive project (+8%). At the conclusion of the project, the average student ranking of the importance of participating in a design competition against other universities as 4.7 out of 5.0, indicating that they felt it was extremely important.

Conclusions

A study was conducted to evaluate the impact of incorporating a fuel efficiency competition into a senior-level mechanical engineering capstone design sequence. The following key conclusions were drawn:

- The students' interest in attending graduate school decreased by 17%, while an increase of 12% occurred in their desire to obtain an engineering job position,
- A significant increase was observed in the students' perceived ability levels in performing various design and engineering related tasks, and
- The vast majority of the students felt that participating in a design competition against other universities was extremely important.
- Additional outside factors not examined in this study could have also influenced the results.

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