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Educational Opportunities of a Designed-Based Project that Challenges Freshman Students to Build a Miniature Racing Car

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Executive Summary

This paper introduces a semester long team-oriented, hands-on engineering project to design a miniature racing car that will compete in a series of challenges. Each team, consisting of three to four members, will be given a battery and a motor by the beginning of the semester, and by the end of the semester, must come up with their own unique design, manufacture their design, present it to the class and engineering faculty and staff, and compete in a series of racing challenges. The miniature racing car project awakes a desire of learning about engineering while acquiring useful skills such as problem solving, machining, time management, leadership, teamwork, etc. In addition, the students learn how to utilize engineering software such as MATLAB, SolidWorks, AutoCAD, and others in a creative manner to benefit in the project. The project is centered on the Conceive, Design, Implement, and Operate (CDIO) process, which is an innovative educational technique based on the principle that product, process, and system development are a key context for an engineering education. This project enhances students' learning experience through three categories: knowledge, skills, and competitiveness. This project accomplishes these three categories by helping each individual acquire technical and analytical skills and allowing them to experience what it is like to work on an engineering design using the proper software and hardware tools. First-year engineering students tend to question if they will be able to come up with creative designs and develop innovative devices within a relatively short period of time. Implementing a system engineering and freshman design course in the engineering core that challenges students to build a miniature racing car is beneficial for the students. Educational benefits that have been discovered are that students realize what they are interested in, discover what their roles are as a part of a team, gain soft and technical skills, and enjoy the project overall. The effectiveness of the project was quantitively measured through surveys that exposed the students to different aspects of the course. This showed that although most students thought they did not have the skills to successfully complete the project, at the end, they were able to succeed and learn from the experience.

Keywords: Educational opportunities, miniature racing car, engineering, skills, competitiveness, knowledge

Introduction

The improvement of the students' learning in the undergraduate engineering education system can be accomplished through numerous elements. The System Engineering and Freshman Design course at the University of Southern Indiana is intended to help students develop qualities needed to prepare them for the remainder of their collegiate courses and for their career. In addition, freshman students gain exposure to engineering design early in their college education which is essential to continuing in the engineering courses. Researchers suggest that the learner-learner interaction can enrich learning outcomes [1]. Thus, peer-oriented educational activities such as the creation of a functioning miniature racing car are critical in the learning journey of engineering students. Additionally, it introduces the needed skills and implements the Conceive, Design, Implement, and Operate (CDIO) process that stresses engineering fundamentals set in the context of breaking down complex processes into the four CDIO concise steps. When such a design project was first introduced in engineering education, it seemed to be unattainable and overwhelming for first-year engineering students. Despite this, studies have found that project-based learning contributes to the development of skills that are needed in every-day life such as time management, delegation of responsibilities, and others [2].

The implementation of a design-based project of a miniature racing car provides educational opportunities into three main categories:

1. Knowledge
2. Skills
3. Competitiveness

For each of the three categories, a rationale is presented to support selection of the theme and offer categories to organize learning outcomes and how it benefits directly to their future careers as engineers. It is expected that these categories will inspire engineering instructors to pursue ideas for improving assessment in their classrooms through the implementation of a design-based project.

Objectives

The overarching objective of this research paper has been to enhance the learning experience in engineering education by producing a designed-based miniature racing car project that point out needed future skills in their careers. In doing this, three key areas for Engineering Education are taken into consideration:

1. *Knowledge.* It is necessary to understand why one technique works where another fails. In the engineering field, theory prepares one to set a direction through the experience of others. Moreover, the theory helps one make predictions that are valuable in the production of goods and needs. A case study of engineering graduates' states that it is the engagement with knowledge the central to the development of capabilities [3]. This suggest that the knowledge acquired through their undergraduate coursework leads to the acquisition of skills that are needed in the engineering field.

2. *Skills.* Hands-on experiences help students increase their interdisciplinary knowledge. It helps students learn the practical implementation of theoretical knowledge in any discipline and enables a deeper learning experience. Additionally, students get to know how the industry operates and what standard procedures must be followed in the real working environment. These skills are important to any engineering student because according to the Institution of Mechanical Engineers, employers are searching for candidates that acquire soft skills, hard skills, and good character [4].

3. *Competitiveness.* Challenges, and coming up with solutions to perform better and be the most effective team will lead to a successful career path in engineering. Competition is essential because it leads to one very important thing, innovation. In the job market, products with more features and capabilities, products that cost less but can do more, and products that just plain solve their needs/wants better than any other product can are always wanted. Employers clearly look forward to candidates who are focused and are passionate about the profession they aspire to enter.

These three key areas for Engineering Education are critical and can be achieved through the implementation of a designed-based miniature racing car project because:

1. Being exposed to such a project will require the students to utilize previous knowledge that they have acquired in physics, mathematics and engineering courses as well as investigate and examine new opportunities of learning for the adequate performance of the project.

2. The building of a miniature racing car will promote the interest in developing and confining new technical skills in order to contribute to the team and perform successfully in the competition. Similarly, the desire for learning and the acquired technical skills will lead to an effective teamwork-based project that will enhance their overall performance in the competition.

3. This project challenges students to work in teams to be more successful than the other teams. The possession of a strong desire to be more successful than others will encourage students to become more competitive, which can ultimately help them in the competitive engineering world.

The aim of this project is to create a miniature racing car that will provide students with the ability to apply engineering design to produce solutions that meet specific needs with consideration of multiple factors. Ultimately, having the ability to function effectively on a team whose members together provide leadership, create a collaborative environment, establish goals, plan tasks, and meet objectives is crucial to completing a project efficiently.

A significant part of this project is to examine how every mechanical change that can be done from race to race can be implemented to the miniature racing car in order to make it powerful enough to successfully finish the competition. In addition to identifying how each mechanical change will improve the car, students must also recognize how these changes will benefit the car before each race. For example, smaller gear ratios will assist each race by increasing the speed. However, lower gear ratios will add more power for inclines. Therefore, having the mechanical knowledge of what benefits the car in different scenarios will affect how the races go significantly.

Background

The course that implements this project is the second in a two-course design sequence for first-year engineering students. It introduces students to systems engineering and design and complies to ABET learning outcomes. Research proposes that students are lacking in projects that enhance their communication and teamwork skills [5]. This course focuses on team-oriented, hands-on engineering project using both reverse and forward design that enhances the students' communication and teamwork skills. Students will learn to perform design calculations, use computer methods to aid in design, manage projects, and present project results by the end of each project phase.

Researchers suggest that the CDIO process prepares engineering graduates to solve more convoluted engineering activities [6]. A formal view to the progress of the project was taken and resulted in a systematic development of the required components which correlates to the CDIO process. In order to meet the stated aims, the following steps must be undertaken:

1. Conceive Phase – The phase includes brainstorming potential designs for the miniature racing car and abandoning the unrealistic ideas. As a team, the group creates several ideas that will hypothetically accomplish the goal. Speed, obstacles, power, materials and details are taken into consideration while finalizing designs.

2. Design Phase – During the Design Phase physics, 3D modeling, knowledge of systems, and research is needed to begin the process of the development of the car. Each member of each team should play an active role in order to receive all the benefits from the project. Free body diagrams are very useful in this phase. Majority of this phase incorporates the use of computer-aided design and drafting software applications such as AutoCAD and Solid Works. In addition, MATLAB is utilized as a design tool as students must run calculations such as the potential velocity of the vehicle and potential time in which the vehicle will complete each race so that it becomes feasible to optimize the design. Students will support their decision mathematically and with scientific foundation. When a final design is chosen and is designed on software, the missing parts to build the car should be ordered.

3. Implementation Phase – This phase combines the design and concept phase. The parts of the miniature car are now in the process of being constructed as well as assembling premanufactured parts with machined parts into a final product. Machines that students were trained on are utilized in this phase to cut materials. A waterjet and 3D printing are mandatory since a 3D printer piece must be added to the vehicle, which promotes creativity. Each member of the team will perform work adequately on the car and its parts. As problems arise, minor adjustments to the original design may have to be implemented as well.

4. Operation Phase – The four races, that are described below, will put the vehicle design to the test through the four races. The mechanical changes will be implemented between each race. This phase is to test the car and potentially make more minor changes to the design before race day. The sole purpose of this phase is to perfect the car and ensure it is operating at its full potential.

As mentioned above, the first step of the CDIO process consists of sketches and brainstorming. Next, in the design phase, students must bring their thoughts and ideas into visual representations by creating SolidWorks models of the vehicle as shown in Figure 1. Then, the pieces and materials that are not already available are ordered and the implementation of the miniature racing car starts. In this phase, they actually put together a functioning car utilizing the design that has been already created. In Figure 2, the chassis of the vehicle of one of the teams of the University of Southern Indiana was made with a Water Jet. Similarly, the same team 3D printed a motor mount that was then implemented in the vehicle, which you can examine in Figure 3. Finally, by the end of the implementation phase, the operation phase begins and a final functioning vehicle must be finalized, as Figure 4 shows. Minor adjustments may be made in order to have a successful performance in the competition day.

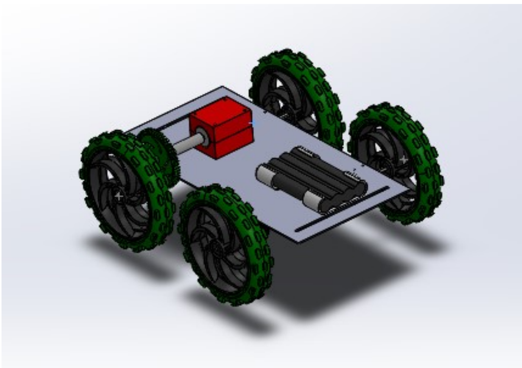

Figure 1: Product of the Design Phase

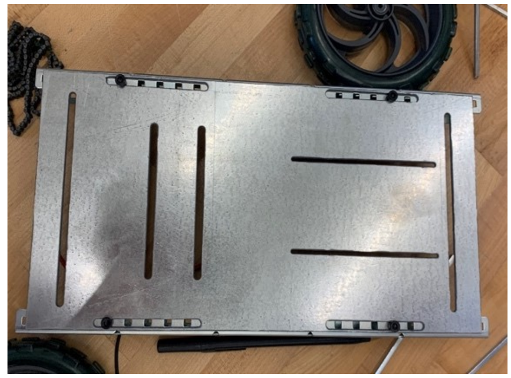

Figure 2: Chassis made with Water Jet in Implementation Phase

Figure 3: 3D-Printed Motor Mount

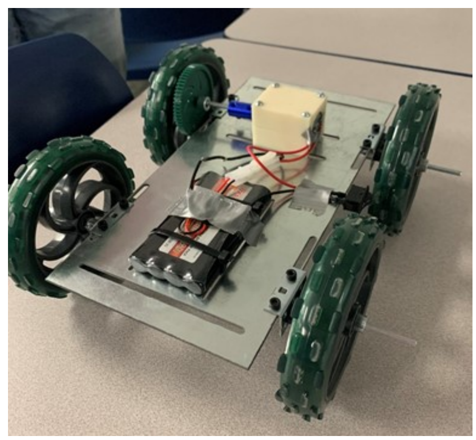

Figure 4: Final Product

The development and use of hands-on technological tools enhance courses that involve difficult-to-grasp concepts in a learning environment [7]. The establishment of a design-based project that challenges students to build a miniature racing car will contribute to the well-understanding of intricate material by students, and consequently, increase their interest in STEM fields. Hands-on experiences have demonstrated to give the opportunity to work in teams, with the purpose of creating and designing objects that can address concepts in other classes [8].

Methodology

The competition is essentially a test of the understanding of varying mechanical tools such as torque, gears, traction, four-wheel drive, etc. Therefore, the project is an exceptional attempt to design and create a Miniature Racing Car so that the car can be tested through four races:

- "Speed Demon": During the Speed Demon race, the car will start from rest and will complete a 30-meter distance. The goal of this race is to cover the required distance as fast as possible.

- "Traction and Stability": This race involves starting from rest and going up a 30-degree incline that is 2 meters long. The goal is to reach the top of the incline in the least amount of time possible.

- "Tug-of-War": Starting from rest, the car will pull one another with a connected rope within a predefined distance.

- "Obstacle Course": The vehicle will start from rest and will have to pass a certain number of obstacles. The goal is to pass all obstacles as fast as possible.

This project also allows the students to gain new skills that will be beneficial in the rest of a student's undergraduate degree and in professional fields in the future. Researchers have found that students are not aware of the employability skills so they describe some of the most important employability skills [9]. These employability skills are displayed in Table 1 and are expected to be developed through the designed-based project of a miniature racing car and can be utilized when working with future clients and coworkers when trying to finish projects efficiently with superior quality.

Table 1: Employability skills acquired through the miniature racing car project

	Expected outcomes	Miniature Racing Car Project Learning Opportunities
1.	Time management skills	The project consists of reports and presentations for each part of the CDIO process. Each phase will have multiple deadlines that will help students get comfortable with managing the time range available.
2.	Teamwork skills	There are multiple teams of three or four members each. Each member plays a different role and has different interests. However, they all have the same goal, which is to win the races that the car is going to be exposed to. They are going to learn to work together and face challenges as a team.
3.	Communication skills	Students write reports and create a formal presentation for each phase of the CDIO process. This will help them become more proficient in effectively addressing their thoughts.
4.	Problem-solving skills	Each race represents a whole different challenge. Only one mechanical change can be made between the races. This is one of the first problems they are going to work on as a team, in addition to the other challenges that will come up their way along the process.
5.	Planning and Organizing	Students will be encouraged to meet in teams and organize a rough schedule in order to get the materials necessary for their unique design on time.
6.	Managerial skills	Students will motivate their teammates, assign and delegate work according to the capability of each member.

7.	Interpersonal skills	The large amount of time spent together as a team will develop their ability to relate to one another and learn to cooperate and motivate each other.
8.	Adaptability	Some of the ideas that the students may come up with will sound reasonable but will not work out well. The ability to adapt to their environment and the new circumstances of their miniature racing car is crucial.
9.	Creativity and Innovation	Students must come up with their own design. This encourages creativity and innovation.
10.	Technical skills	Utilizing software and gaining design experience through MATLAB, SolidWorks, AutoCAD, etc. is an extremely important part of the project. Additionally, machining in an applied engineering center with equipment that can be found in real-world industries should be taught through this course

The main difficulty with the creation of such miniature car is that the battery and a motor are the only components of the car that are given from the beginning. This condition challenges each team to develop with a design from scratch that allows the set battery and motor to work properly.

The need for such vehicle in the creation of new engineers is justifiable. The use of mechanical knowledge as well as working in team-oriented projects are a common part of the everyday life of most of the people in the engineering world. Studies suggests that there are needs in the engineering learning process in regard to the acquisition of modern knowledge and practical skills for the STEM field [10]. Moreover, it is likely that the usage of the Conceive, Design, Implement, and Operate (CDIO) process in the creation of miniature racing cars will increase in the future, particularly with the introduction of such vehicles that are efficient and made by undergraduate students.

Table 2 decomposes the classes at the University of Southern Indiana that helps each student build their design and experimental skills. A class in a student's first year as an engineering student is needed to help the learning process flow smoothly. The educational opportunities of a designed-based project miniature racing car are numerous, in addition to the opportunity for engineering students to find their passions and their role in a team early on in their college journey.

Table 2: Design path for engineering students within the student's undergraduate experience

ENGR 108 - System Engineering and Freshman Design	**ENGR 291 - Experimental Design and Technical Writing**	**ENGR 355 - Strength of Materials**	**ENGR 491 - Senior Design**
This course uses team-oriented projects to teach students the design process and technical communication.	This course is designed to improve a student's experimenting, analyzing, and presenting skills. Writing technical reports is a significant component of this course, as is technical reading related to lifelong learning and ethical responsibility.	A study of stress-strain relationship for axial, torsion, shearing, and bending loads; deflection of beams; connections; combined loadings; statically indeterminate members; and plane stress. The laboratory experience will include material testing, analyzing, and troubleshooting.	Design problems provided by industrial sponsors are studied by small teams of students to develop solutions using engineering design, while considering realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

How Design Courses Progress

Survey Method

In order to quantitively measure the success and achievements of the implementation of a designed-based project that challenges freshman students to build a miniature racing car, twenty-one students that were taking the system engineering and freshman design course in 2017 at the University of Southern Indiana were surveyed. They were asked certain questions regarding the project at the beginning and at the end of the semester by a rating scale paper survey.

Survey Results

This survey of twenty-one students at the university of Southern Indiana asked engineering students questions on their attitudes toward the design-based miniature racing car project. This section provides a summary of key analytical points of the survey.

Table 3: Knowledge/Skills Question as a Scoring System from -2 to 2

Counts respondents	Total	Very poor (-2)	Poor (-1)	OK (0)	Good (1)	Very good (2)	Mean
Beginning of the Semester	21	4	4	6	7	0	-0.24
End of the Semester	21	0	6	6	6	3	0.29

1. **Engineering students do not think that they have the necessary knowledge/skills to develop a miniature racing car.** When asked about whether they had the necessary knowledge and skills to complete the project at the beginning of the semester, they seemed to have an overall negative response toward the question. On the other hand, by the end of the semester they thought they had the skills and knowledge necessary to develop the miniature racing car project. This demonstrates the effectiveness of the project and impact on the students' learning.

Table 4: Difficulty of the Project Question as percentage

Counts Analysis % respondents	Total	Very easy (-2)	Easy (-1)	OK (0)	Hard (1)	Very hard (2)	Negative	Neutral	Positive
Beginning of the Semester	21	1	3	11	6	0	19%	52%	29%
End of the Semester	21	1	0	5	15	1	5%	24%	76%

2. **Engineering students think that the project is challenging.** The project was introduced to the focus group at the beginning of the semester. When asked about the difficulty of the project at the beginning of the semester and having a basic understanding of what the project was going to consist of, most people thought that the difficulty of the course was neutral, neither hard nor easy. By the end of the semester, most people thought that the project was difficult and harder than what they thought. This data suggests that this project exposes them to a challenging engineering experience that is meaningful in their professional careers. The fact that they gained the knowledge and skills to overcome this challenge means that although it was an intricate and challenging project, they have the ability to break down complicated processes in order to smoothly come up with a solution.

Conclusion

In brief, the educational opportunities of a designed-based project that challenges freshman students to build a miniature racing car can be summed up into three categories, which are knowledge, skills, and competitiveness. These three categories play an essential role as they move on to their real engineering world. The creation of a miniature racing car exposes engineering students to the CDIO process that prepares them to face more complex engineering activities at all stages of the life cycle of technical objects, processes and systems. The success of the project has been quantitatively measured through surveys that were resented to students from the University of Southern Indiana. The data shows that the project overall is challenging and that they do not think that they have the necessary knowledge and skills to develop a miniature racing car at the beginning of the semester.

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