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Product Development Process and Student Learning in an Engineering Technology Capstone Project: Electrical Go-kart

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ABSTRACT

Project based learning (PBL) is a dynamic classroom approach in which students actively explore, solve real world problems and gain knowledge through developing real products. In our Engineering Technology program, a project based capstone design class is offered that provides graduating seniors a hands-on opportunity to experience team-based design under conditions that closely resemble current industry practice. In this paper, we introduce a capstone project, an electrical go-kart. A group of 20 students spent 15 weeks and around $600 designing and building a working electrical go-kart. This multidisciplinary project allows students to integrate knowledge from across the core curricula, and take a systems approach to product design and problem solving. Student learning outcomes are assessed using a survey and the grades of their final projects. The results are compared with other semesters in which relatively simple projects were assigned. We have observed an overall improvement of student learning outcomes in nearly all aspects. Hence we believe the multidisciplinary projects, such as the electrical go-kart, help students learn valuable knowledge of product development that are usually only acquired through real world working experiences.

Key Word: Capstone Design, Project Based Learning, System Engineering

1. INTRODUCTION

Product design classes teach students how to transfer the information of customer requirements into the knowledge of product, at the same time compromising conflicting customer requirements. It is usually taught in a so-called “three islands” model, including CAD, Design of Components, and Design Methodology (or Capstone Design). Students work in projects under conditions that closely resemble current industry practice, although most undergraduate engineering and technology students lack experience of solving real world problems. We believe Project Based Learning (PBL) is especially effective in preparing students for the challenges in industry.

PBL is a dynamic classroom approach in which students actively explore, solve real world problems, and gain knowledge and skills through developing real products. PBL is a systematic learning and teaching method. It engages students through research assignments, open ended questions and well designed products [1] [2]. In [3], Analytis et al. introduced a paper robot project, in which 76% of students reported gaining more knowledge in programming microcontrollers, and 69% students reported learning more in creating electronic circuits. Mauk et al. presented a point of care lab-on-a-chip system in an undergraduate senior design class, and documented great improvement of student learning [4]. In [5], Cocota et al. report PBL experience in a robotics class, in which a 6-DOF anthropomorphic manipulator robot is designed. The survey shows that 95.3% of students believe the project contributed to the development of their transversal skills. Purdue University initiated the Engineering Projects in Community Service (EPICS) Program at 1995. It combines PBL and community service in the undergraduate extra-curricular projects. The majority of student surveyed cited the program "practical, real world experience in engineering design", with about 84% students claimed positive impact on their engineering education [6].

In this paper, we document a multidisciplinary project recently accomplished in a senior design class, electrical go-kart. The go-kart was developed following Pahl and Beitz's system engineering methodology, which is briefly introduced in Section 2. The product development process, including concept generation and prototyping are introduced in Section 3 and Section 4, respectively. Student learning outcomes are assessed and briefly explained in Section 5. Future improvements to the project are discussed in Section 6.

2. SYSTEMATIC PRODUCT DESIGN PROCESS

Problem statement of the electrical go-kart project is given as:

> *"Design a full size electrical go-kart that is capable of operating safely on paved road at top speed around 25 mph. It should accommodate drivers with different heights (less than 6'5") and weights (less than 300lbs). The part and material cost should be less than $600"*

We choose this project due to its multidisciplinary nature, in which students need to integrate knowledge from mechanical design, manufacturing, electrical and industrial design. It is worth noting that in this project, the instructor did not assign students into specific teams. Instead, students analyzed the design problem and decided their organization structure based on the requirements of the project. In previous semesters, students were assigned into teams which were decided based on product development stages, i.e., marketing team, design team, manufacturing team, and testing team. However, we have observed typical “over the wall” mentality between teams and it caused unnecessary design errors and iterations. For instance, the design team tended to design a product without considering its manufacturability, i.e., rounding off product dimensions into preferred numbers. This caused unnecessary measuring and manufacturing difficulties to the manufacturing team. The design team also tended to design all components from scratch although similar standard ones are readily available on the market. In this go-kart project, students decided the teams structure based on the major functions and subassemblies of the go-kart. Each team was responsible to a sub-assembly from its design to manufacturing to test. This not only helped avoid a lot of “design in-considerations”, but also allowed different teams to work in parallel. Some pictures of students working on the project are show as following, Figure 1.

Figure 1. Students Working on the Senior Design Project

The project is accomplished following Pahl and Beitz’s Systematic Product Development methodology [7], as shown in Figure 2. A product development process is decomposed into four stages: clarification of the task, concept design, embodiment design, and detailed design. At the end of each stage, new information and knowledge are added into the product information models. Activities in the first stage, clarification of task stage, are:

- gather information about the design problem;

- understand the requirements, constraints, laws, codes, etc.;
- arrange the requirements into a clear sequential list; and
- transfer requirements into engineering specifications for the designed product.

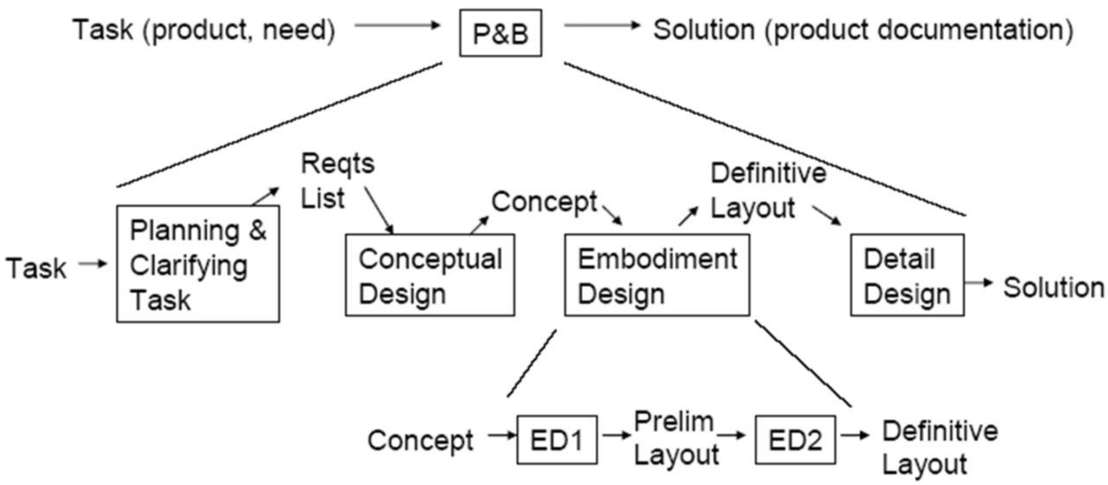


Figure 2. Pahl & Beitz's Systematic Product Development Process

Activities in the second stage, conceptual design, are:

- establish function structure of the product;
- develop solutions to each function/sub-function and combine them into concepts; and
- evaluate and select concepts.

Activities in the third stage, embodiment design, are:

- create product architecture and layout;
- select materials, and develop forms of the product; and
- select components and subassemblies for the definitive layout.

Activities in the fourth stage, final design, are:

- design for production, assembly, operation, etc.;
- create detailed drawings and part list; and
- prepare all documents.

3. PRELIMINARY DESIGN AND CONCEPT GENERATION

The electrical go-kart project started from researching and documenting all design requirements and specifications. Students conducted marketing research that covers the following areas:

- **The intended market** is sports enthusiasts and makers who are comfortable with assembling the go-kart from a kit. Similar karts cost around $1800. This go-kart will offer similar runtime but better performances and cost approximately $600 in parts and materials.
- The **function of the product** is to be able to operate (steering and braking) safely on a paved road at top speed around 25 mph. It has a reliable on-off system and be able to transit between three speeds. It must accommodate drivers with maximum height of 6’5” and maximum weight of 300 lbs.
- The general **physical size** is 6’±6” in length, 3’±3” in width between tires, and 4’±3” in height. The bottom of the driving cabin must be at least 5” off the ground.
- The **safety and environment protection features** include a roll bar and 4 point seat belt that will protect the driver in the event of a rollover, although that should be very rare due to the low center of gravity of the kart. The kart runs on batteries. The batteries do have a chance to spill, hence they will be secured at the back of the kart away from its driver. A protective shell will be placed over the batteries and transmission system.

After finalizing the requirement list, students created a function structure as shown in Figure 3. The product function should be partitioned so that each sub-functions can be provided using one part or component. The purpose of function structure is to decompose such a complex product development problem into simpler sub-problems so that each of them can be solved. Different engineering teams may generate different function structures. As shown in the figure, the go-kart function is decomposed into 5 sub-functions: driver, seat, power, driver safety against possible accidents, and avoid hazardous parts. The “drive” function is further decomposed into moving forward and backward, steering and braking. The power function is decomposed into providing power and transferring the power to the kart.

The next step is to select components and parts as solutions to the sub-functions. This stage requires extensive knowledge and experience from students. Since each sub-function may have multiple solutions, morphological charts are usually used during this stage in order to explore other design concepts. For instance, brake function in Figure 3 can be provided by different designs of the braking mechanism; and the transmission can be either gear or chain mechanisms. Selecting and combining different solutions generate different design concepts. Then, the most promising design concept is selected using decision matrix [8], which is widely used in product concept generation. Students spent a large amount of time googling, reading papers and product manuals in order to develop the most successful design concepts. Figure 3 also helped students form product development teams, and determine each team's responsibilities. In this project, 20 students formed 4 teams: kart team, frame team, powertrain team and body shell team. The kart team designed and built steering and braking systems. Frame team was responsible to the backbone of the kart, including the seat and frame that connects all components together. The powertrain team was mainly responsible to the battery, the control circuit and the chain mechanism that transmits power from the electrical motor to the driving shaft. The shell team was in charge of installing a seat belt, as well as designing and installing a cover shell on the kart.

A concept selection example is shown in Figure 4. The body shell must cover the front of the kart in order to protect the driver from flying objects on the road. It also must cover the batteries and powertrain at the back of the kart to avoid possible acid spill. Students proposed 7 different concepts as shown in the figure. The decision matrix used to select the concepts is shown in

. Decision matrix is a systematic design tool that is capable of compiling a large set of information into a simple value for easy comparison. It is also a good communication tool for students to understand each other's decision. Students considered three criteria for the shell design concept: aesthetic, simple and aerodynamic. The Criteria provide a constant "yardstick" for comparison, so that we do not have to compare concepts to one another. Each concept was evaluated against the criteria, and assigned scores between 1 and 5, with 1 for the least preferred and 5 for the most preferred. The total grade of a concept is simply adding these three scores together. In this project, concept 7 was selected for further development. Similar selection happened throughout the concept design stage, such as selecting electrical motors, control boards, different ways of manufacturing the body shell.

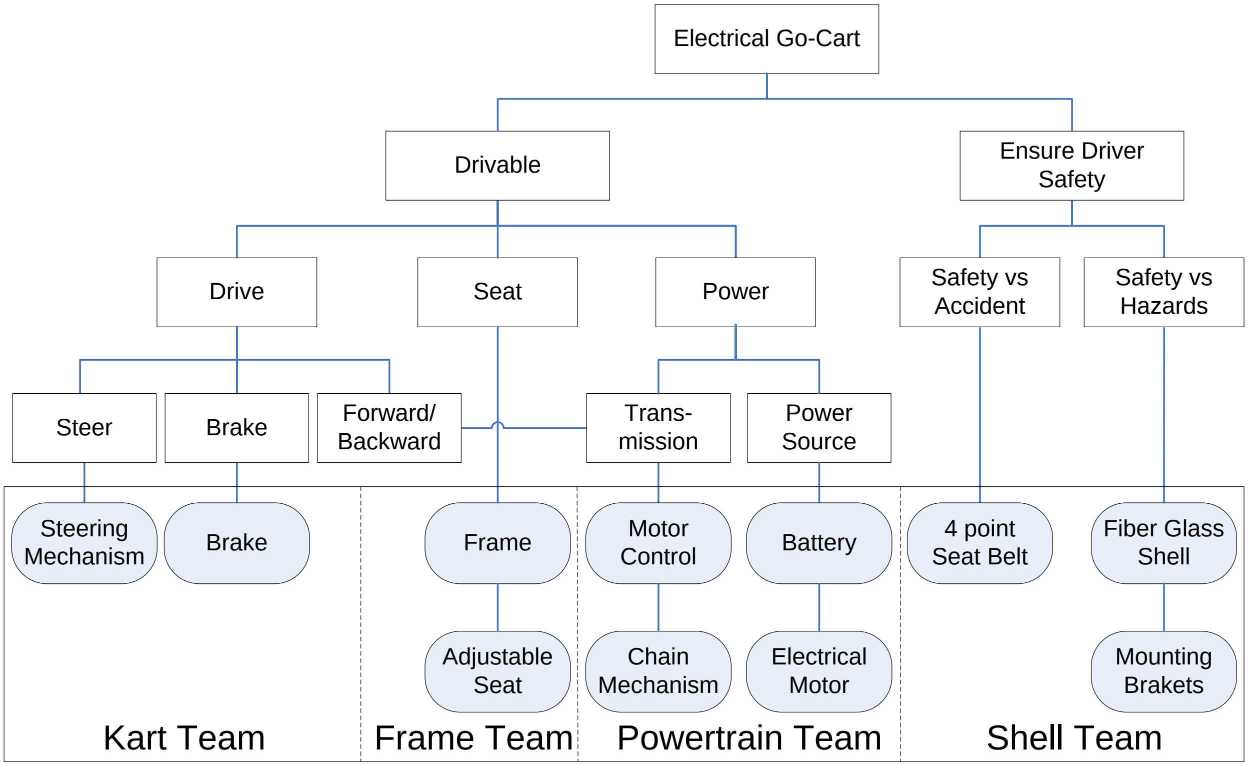
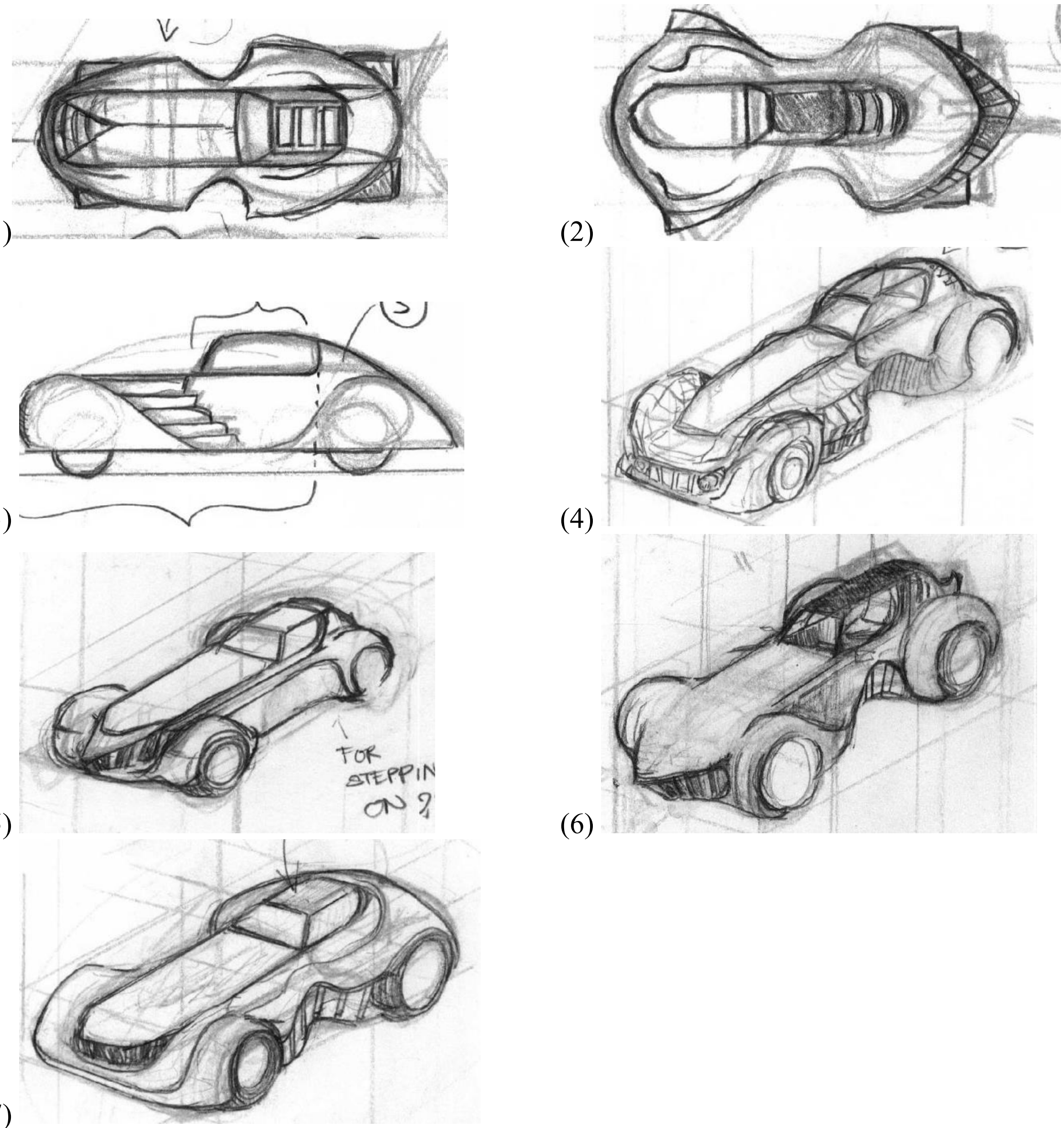


Figure 3. Function Structure of the Go-Kart

Table 1. Decision Matrix for Body Shell Concept Selection

Concepts	Aesthetic	Simple	Aero-dynamic	**Total**
(1)	4	2	3	9
(2)	4	2	3	9
(3)	1	4	1	6
(4)	5	1	3	9
(5)	3	2	3	8
(6)	3	1	3	7
(7)	4	4	3	11



(1) (2) (3) (4) (5) (6) (7)

Figure 4. Body Shell Design Concepts

4. DETAILED GO-KART DESIGN

The following stage is the embodiment design. Students collected and organized parts into "chunks" of the product and connected them into geometric layouts, or product architecture. It requires students to consider not only product varieties, but also the interactions between chunks, such as different ways of connection, how energy, material and signal are transferred. A lot of iterations happened at this stage when a working prototype is made. In this project, the frame team firstly designed a prototype as shown in Figure 5. It can be seen that the over head cage design is safe in case of roll over, but it is too low and could not accommodate taller drivers. Furthermore, batteries are placed at both sides of the seat and it is very dangerous. This architecture was chosen in order to keep the length of the go-kart less than 6’, while keeping the center of gravity low. Since the electrical motor, chain and back wheels are connected with the main frame through only two shock absorbers and a rotating pin, it is too weak to support 4 batteries at the back of the seat. The powertrain team and frame team redesigned the entire kart frame after test driving the first prototype, as shown in Figure 6. The cage design was changed to a roll bar. The power system was relocated to a much lower position. This allows batteries to be installed on top of the chain and electrical motor. This new design is able to accommodate driver as tall as 6’6”. Final design of the go-kart, including the body shell is shown on Figure 8. The shell was made using fiber glass cloth and mat. Resin used is LAM 125 with hardener LAM-229 [9]. In Figure 7, students use plywood and cardboard to make a mold for the fiber glass shell. The completed shell is shown at right of the figure.

Figure 5. First Version Go-Kart Prototype

Figure 6. Second Version Go-Kart Prototype

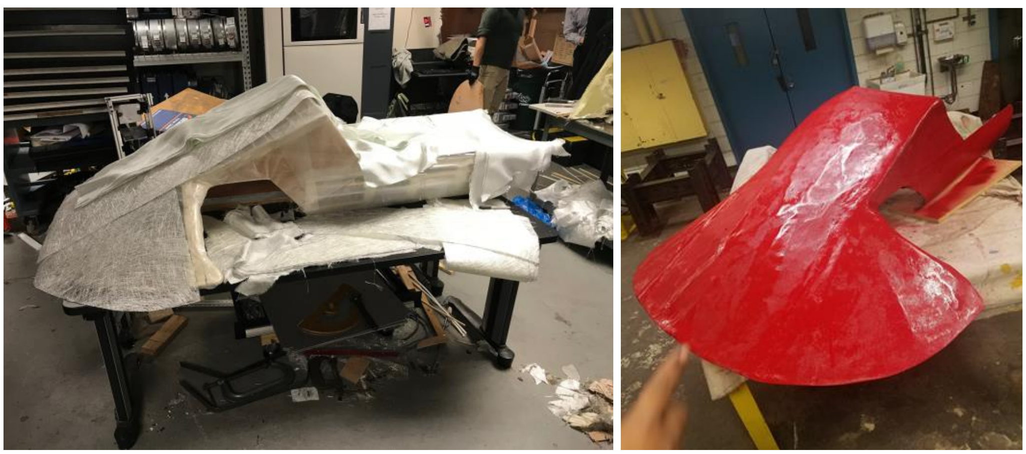


Figure 7. Fiber Glass Shell of the Go Kart

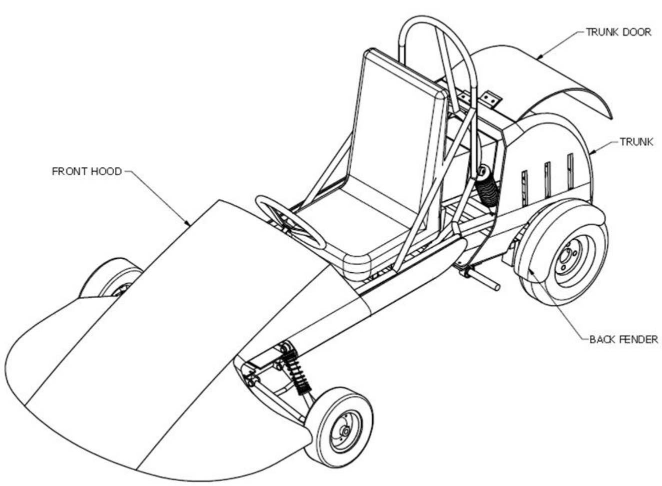


Figure 8. Final Go-Kart Design with Body Shell

The last step is conducting failure mode and effect analysis (FMEA) to identify unknown design hazards. FMEA allows students to determine all possible failures of every part in the kart, analyze its characteristics including how severe it will be, how frequent will it happen, and how easy to identify the failure. Each of the characteristics is rated from 1 to 10, with 10 representing the most dangerous situation. The risk priority number (RPN) is calculated by multiplying these three rates. The failures having high RPN will be treated. Designers can propose design changes to reduce the RPN, such as adding a shield or interlock system, increasing safety factor, developing quality assurance program to reduce defective parts. Details about FMEA can be found in [8].

Table 2. FMEA of Go-Kart

Failure Mode	Severity	Occurrence	Detection	Actions of Prevention
Frame: Low Impact Resistance	Accident Related Injuries	Low Chance	The outer shell will absorb majority of the impact	RPN = 36 No action taken
	R = 6	R = 3	R = 2	
Frame: Cracks in Welds	Frame falls apart	Moderate Chance	Hidden	RPN = 336 Increase weld strength through higher quality welds and add cross beams for support
	R = 8	R = 6	R = 7	
Battery Acid leakage	Acid burns	Failure of battery case	Batteries are inspected for damage	RPN=144 Batteries are placed behind the driver on a shelf to prevent any damage
	R = 8	R = 2	R = 9	
Impact causes Battery spill	Acid burns	Impact higher than strength of battery case	Batteries are placed in shelf for safety	RPN=80 No Action Taken
	R = 8	R = 2	R = 5	
Brake: Improper tensioning	Brakes fail to activate causing accident	Poor wiring skills	Hard to detect	RPN=378 Brakes are checked by multiple technicians for safety.
	R = 7	R = 6	R = 9	
Brake cables snapping	Brakes fail to activate causing accident	Improper maintenance	Brake lines are checked before operation	RPN = 105 No Action Taking
	R = 7	R = 3	R = 5	

5. STUDENT LEARNING ASSESSMENT

This project was accomplished at Fall, 2017. Due to its complexity, students ran into a lot of difficulties at the beginning. The most significant difficulty is researching the solutions of the sub-functions as shown at Figure 3, which requires students to research data sheets and product manuals written with unfamiliar terminologies. On the other hand, the challenges forced students out of their comfort zone, hence made this project interesting and rewarding.

Student learning outcomes are assessed in two ways, a student survey as an indirect method, and student grades in the final project as direct method. The survey contains a lot of questions designed to evaluate students learning and teaching effectiveness, in which 5 questions, as shown in Table 3, are directly related to the capstone project. The last survey was conducted in Spring, 2014, in which a relatively simple project was assigned in the senior design class. The comparison between Spring 2014 and Fall 2017 in which this project was accomplished shows overall increase in all aspects.

Table 3. Sample Survey Questions and Results

Related Survey Questions	% of Students agree or strongly agree	
	S, 2014	F, 2017
My research has made me more confident in my ability to conduct research	75%	90%
During my research experiences, professor became more confident in my ability to conduct research	70%	75%
My research has made me more confident in my ability to succeed in future coursework/career.	70%	83%
Doing research increased my motivation to reach my school and career goals.	75%	82%
My research experience has made me more knowledgeable about product design and multidisciplinary problem solving	80%	95%

We also collected the grade of students' final project at each semester since Fall, 2014, as listed in

Table 5. The concept of PBL was adopted at Fall 2016 as a strategy for curriculum improvement. Real world, multidisciplinary projects were assigned in the senior design class since then. Each semester students are separated into 4 teams, and all students in the same team have the same grades. The final project was grades at the end of the semester, by a group of faculties based on the quality of the final project report, and the final presentation. The grading rubric of the project report is shown in Table 4. The final project grades are depicted using box

plots, Figure 9. The box plot shows the distribution of the data. The top and bottom lines shows the min/max value of the category; the box represents data between first and third quartiles; the line inside the box is the median value. It can be seen from the figure that the overall distribution of final project grades are improved in the last 3 semester, ever since PBL strategy was adopted and multidisciplinary projects are assigned. It can be seen that the average grades are improved in the last 3 semesters. Whether or not this difference is statistically significant, we need to run an independent samples t-test to compare student performance in two categories, before and after the adoption of PBL. Detailed explanation of the statistical test can be found in [10] [11].

Table 4. Grading Rubric of the Final Project Report

Criteria	Grade	Notes
Technical Merit (60%)	0-10	
Chapter 1. Design Problem: All the key information including problem statement, bench marking, customer requirements and needs.		
Chapter 2. Product Development Proposal: Concept generation and evaluation, sketches of all ideas, QFD, specifications, material list, project time line, and team structure		
Chapter 3. Detailed Product Design: Preliminary sketch, kinematic analysis, FEA analysis, Product CAD and professional engineering drawing of every customized part		
Chapter 4. Manufacturing and Prototyping: Manufacturing process of every customized part		
Chapter 5. FMEA: frequency of occurrence, severity of consequences, types of hazard, and consideration of correct actions.		
Chapter 6. Product Redesign: Identified design issues, redesign activities, and suggestions to future engineers.		
Report Completeness (20%)	0-4	
Abstract		
Table of contents with page numbers and has all sections		
Lists of figures, List of tables exist with accurate page numbers.		
Summary of what the group has learned		
References and citation		
Writing Quality (20%)	0-4	
Formatting of the document is professional and consistent, including heading styles, fonts, margins, etc.		
Professional looking page design and layout.		
Sentences are well-written with no incorrect word choices, grammar, punctuation and spelling		
All figures, tables and equations are correctly numbered, have captions, and are correctly referred		
Overall, the information is presented in a logical way that is easy to follow. Readers can replicate the project based on reading the report		

Table 5. Final Project Scores

Group #	Before PBL				After PBL		
	F 14	S 15	F 15	S 16	F 16	S 17	F 17
1	70	60	66	75	90	93	100
2	87	80	72	84	100	78	96
3	87	84	81	93	84	87	80
4	96	93	72	66	87	98	90

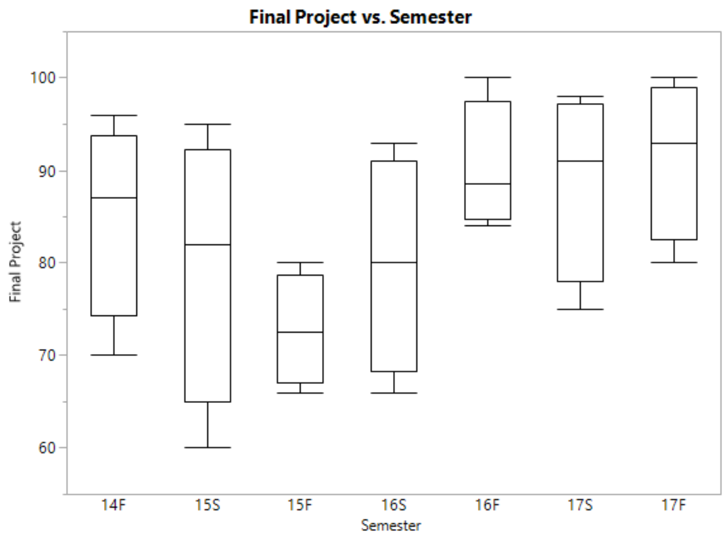


Figure 9. Box Plots of Student Performances at Each Semester

Difference	10.8542	t Ratio	3.018721
Std Err Dif	3.5956	DF	25.98771
Upper CL Dif	18.2452	Prob > |t|	0.0056*
Lower CL Dif	3.4631	Prob > t	0.0028*
Confidence	0.95	Prob < t	0.9972

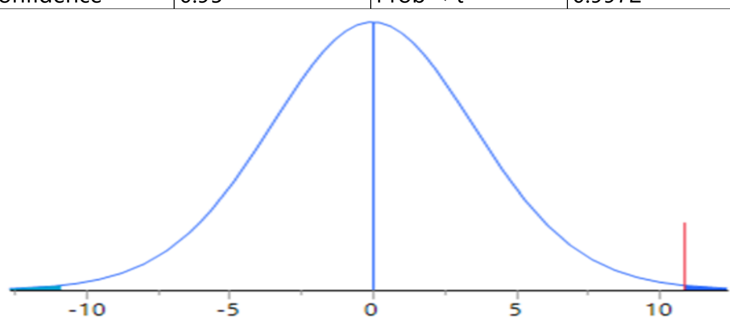


Figure 10. Independent Samples t-Test of Final Project

The statistics of the final project are analyzed using independent samples t test as shown in Figure 10. It can be seen that the final grade is 10 points higher after PBL. The t-Ratio is beyond 3, p value is 0.56% for a two tailed distribution, shown as the two shaded areas on the bell shaped curve in the figure. Since the confidence level is 95%, the p value is significantly smaller than 5%. It is safe to state that the before and after groups are significantly different. Since the test statistic $t = 3.02$ is greater than the critical t value, we can state that the introduction of PBL and multidisciplinary project improved the student learning in the final project.

6. CLOSURE

In this paper, we documented the product development process in a senior design project. Student learning are evaluated using both student survey and the score of final project. Independent samples t-test was used to analyze and compare student learning before and after the adoption of PBL. The result has shown that PBL and multidisciplinary projects help improve student learning in all aspects. We are planning to further improve this project in the coming semesters, including re-design a body shell considering the aerodynamic performance of the go-kart, upgrade the suspension system. Moreover, we will initiate new curriculum changes to other classes using the concept of PBL.

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REFERENCE

[1] W. Sumarni, "The Strengths and Weaknesses of the Implementation of Project Based Learning: A Review," *International Journal of Science and Research, Vol 4, 3,* pp. 478-484, 2015.

[2] K. Chua, W. M. Yang and H. L. Leo, "Enhanced and conventional project-based learning in an engineering design module," *International Journal of Technology and Design Education, Vol. 24, 4,* pp. 437-458, 2014.

[3] S. Analytis, J. A. Sadler and M. R. Cutkosky, "Creating Paper Robots increases designers' confidence to prototype with microcontrollers and electronics," *International Journal of*

Design Creativity and Innovation, Vol. 5, 1-2, pp. 48-59, 2017.

[4] M. G. Mauk, R. Y. Chiou, C. Ruiz, D. Varapula, C. Liu and J. Song, "Project-Based Learning: Microfluidic Lab-on-a-Chip Point-of-Care Medical Tests for Engineering Undergraduates," in *2017 ASME International Mechanical Engineering Congress and Exposition*, Tampa, Florida, 2017.

[5] J. A. N. Cocota, T. D'Angelo and P. M. de Barros Monteiro, "A Project-Based Learning Experience in the Teaching of Robotics," *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, Vol. 10, 4,* 2015.

[6] E. J. COYLE, L. H. Jamieson and W. C. Oakes, "EPICS: Engineering Projects in Community Service," *International Journal of Engineering Education, Vol. 21, 1,* pp. 139-150, 2005.

[7] G. Pahl, W. Beitz, J. Feldhusen and K. H. Grote, Engineering Design: A Systematic Approach, 3rd Ed, Springer, 2007.

[8] K. Ulrich and S. Eppinger, Product Design and Development, 6th Edition,, McGraw Hill, 2016.

[9] "Pre Set Epoxies for Laminating, Infusion, Tooling and Assembly," Pro-Set, 2018. [Online]. Available: www.prosetepoxy.com.

[10] D. C. Montgomery, Design and Analysis of Experiments, 8th Edition, Wiley, 2012.

[11] "SPSS Tutorials," Kent State University, 2018. [Online]. Available: https://libguides.library.kent.edu/SPSS.

[12] A. Xiao and A. Zhang, "Development of a Speech Controlled Robot in an Engineering Design Class," in *2015 ASME International Mechanical Engineering Congress*, Houston, Texas, 2015.