Making it for real: Redesign of a First-Year Engineering Project

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***Abstract*—This Research to Practice work-in-progress paper presents the development and initial implementation of a project assigned to first-year students in an Introduction to Engineering Design course at Penn State Erie, the Behrend College. Traditionally, students learn about the engineering design process through design-only projects such as redesigning an electric toothbrush or selecting components for a renewable-energy powered water well. Although these projects were hands-on, they did not include students converting the design concept to a tangible product. In fall 2017, a new project using Arduino kits was introduced to the course. Students were asked to build a line-following robot car with a chassis of their own design as long as it kept the wires and circuit board inside. In designing the robot car, students sketched design concepts, selected the best one, and used low-fidelity materials to create beta prototypes. Once they had a working chassis, students created it in Autodesk Inventor and realized the final design of the chassis through 3D printing and laser cutting.**

To measure if the new hands-on project has an impact on student learning, students were asked to report which instructional activity they learn best from and how they relate engineering design to real life before and after the project. We found that at the completion of the robot car project, students became less in favor of lecture-based instructions. Rather, they have developed a preference in figuring out the solutions on their own. Students highly appreciated the open-ended design project and the hands-on experience of building a prototype.

As with any project carried out for the first time, the robot car design project ran into some technical difficulties. Nonetheless, students reported that this hands-on project is fun and rewarding, and they now have a much deeper understanding of the engineering design process behind every product in the market. This paper discusses the student design project in detail, including the results of the project based off of student surveys and faculty observations, and suggestions for improvement and implementation at other schools.

Keywords— hands-on, project-based learning, Arduino, first year experience, engineering design.

I. Introduction

For many students at Penn State Erie, Introduction to Engineering Design (EDSGN 100) serves three purposes: introducing students to engineering, to the engineering design process, and to the campus and life in college. It is the hope that while learning about the design process students find the excitement of becoming an engineer that will push them through the hard work for the next few years at Penn State.

Students in EDSGN 100 are typical first year engineering students, with most of them also starting their first year in college. EDSGN 100 is offered to a maximum of 425 students per year with 250 students in the fall and 175 in the spring. Each week, all students participate in a common lecture accompanied by a computer lab session where students learn how to use programs including Microsoft Excel, Psplice, and Autodesk Inventor. The third component of the course is the weekly recitation where students can apply theories from the lecture to a design project. A detailed overview of the previous week to week schedule can be found in Lynch et al, 2017 [1].

In order to learn about engineering design, students participate in two separate team-based projects aimed at taking students through the design without demanding advanced physics, electronics, or coding they have yet to learn in the next few years. As a result, those projects have focused on the conceptual design phase of the product, lacking the prototyping aspect that gives students a sense of ownership. The toothbrush redesign project asked students to dissect an electronic toothbrush and come up with new theoretical designs based on customer needs. The water well design project is a system-based design project where students design a renewable-energy powered well for a community in a developing country. Although both projects have hands-on activities, students are not asked to create a tangible prototype.

This paper discusses the pilot of a new hands-on project introduced to the honors sections of EDSGN 100 in fall 2017. This project consisted of design, assembly, and testing of a line-following robot car. Students were asked to use low fidelity materials for the first prototype, update and develop a final design using CAD software, and create a final prototype of their design using the rapid prototyping techniques of laser cutting and 3D printing.

The authors had two research questions: 1. Which approach helps engineering students learn the best? 2. How does a prototype-based project affect student learning? This paper discusses some of the preliminary answers to these questions, and presents future steps to expand on the difference between prototype-based projects compared with other hands-on activities.

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II. BACKGROUND

A. Project-Based Learning and Benefits

Project-based learning has proved to be an effective instructional method especially in the STEM field [2, 3]. It allows students to apply theoretical understanding to solving problems hands-on, simulating what scientists and engineers encounter in the real world. In so doing, students achieve conceptual understanding by integrating previously discrete knowledge, challenging assumptions, creating new construct, testing new ideas, and build new learning at the completion of the project [2]. Students in project-based courses and curricula have demonstrated higher level of self-directed learning [2, 3, 4] with the material.

Project-based learning environment has six important features: 1. Students are challenged with a driving question; 2. Students demonstrate their mastery of the learning goal; 3. Students explore the driving question by participating in scientific practices; 4. Students engage in collaborative activities in order to find the solution to the driving question; 5. Students use technology tools to assist with problem-solving; and 6. Students create artifacts to externalize their internal understanding [2].

When hands-on project-based learning is incorporated at the beginning of the engineering program, early career students are introduced to the excitement of engineering. Being able to design and then build a prototype helps students make connections between theoretical understanding and the practical side of prototyping, testing, analysis, and problem solving [5, 6]. In addition to learning about engineering, students improve in creativity, metacognitive learning, project management and team communication skills [3, 6-13]. Project-based learning has been found to greatly improve retention rate among engineering students [6, 10, 14].

Many studies on project-based learning echo these benefits. As explained by Lemons et al [7], hands-on building of a physical model enables students to verify if their conceptual understanding is consistent with the behaviors in engineering reality. Not only can students visualize their model, the flaws in preliminary idea generation are easily exposed, which necessitates re-examination of concepts followed by a redesign of the model. The often open-ended nature of the project encourages inductive learning [15] and creativity, hence enhancing learning motivation and engagement.

B. Characterics of Successful First-Year Design Projects

Drawing on the literature in project-based learning, the ideal hands-on design project for EDSGN 100 should have the following traits: a. the artifact students build should be challenging but achievable for first-year students; b. the design of the artifact should allow students the freedom to be creative; c. the design process must require interactive group collaboration; d. the design process must be structured, guided, to ensure collaboration is beneficial to learning; and e. students should be given enough time to revisit conceptual designs and correct misconceptions.

III. LINE-FOLLOWING ROBOT PROJECT

In fall 2017, a new student group project was piloted in the three honors sections of EDSGN 100. The objective of the new project is to complete the design-build-test cycle by giving students a hands-on opportunity to build a functional prototype. The end goal for students is to build a line-following robot car whose sensors track a black line and direct its direction and speed. In order to build the robot, students must assemble the electronics in a chassis of their own design, update and upload the provided code, create a low fidelity prototype, or a *beta prototype,* in order to calibrate the line sensors and run the code. In parallel students are required to develop specifications for their design and create a 3D CAD model of a chassis which would serve as their *final design*. Students are provided the opportunity to create a *final prototype* of their design through 3D printing and laser cutting.

To help students develop an ownership of the project, we intentionally left the chassis design to students. They were encouraged to be creative as long as the following requirements are met: 1) the chassis must contain all the robotic components during operation; 2) the chassis must be able to be disassembled; and 3) the sensors must be protected from hitting obstacles such as the walls. The major components of the project are described below.

A. Electronics and Coding

The circuitry and coding for this project were intended to be accessible for beginner students. Students were provided with a pictorial guide to help them connect the appropriate wiring and a short tutorial on coding and commenting to assist students in reading and updating the provided code. Students were able to update the code to change the speed at which the robot moved forward, turned, and the sensitivity of the sensors to changes in light.

B. Beta Prototyping

Students were required to sketch up a list of design concepts to help visualize their chassis, compare and analyze the strengths and weaknesses. As a group, they then selected the best concept for constructing a beta prototype out of materials including cardboard, tape, and pipe cleaners. Once they had a working chassis, they could identify further improvements needed prior to creating the final design.

C. Final Design and Rapid Prototyping

Using the results of the beta prototyping, students were required to create a CAD model of their final design in Autodesk Inventor, and show that it matched all the design requirements provided in the design prompt. Students would receive extra credit if they chose to create their final prototype by using the rapid prototyping facilities at the school. An example final design and prototype is displayed in Fig. 1. At the project's end, students were required to present on their robot, the design process they went through, as well as a reflection of the entire design process, including what the team might do differently if asked to go through the project again. Following the presentations, students were given the opportunity to validate their design and receive extra credit by running their robot on a provided race circuit.

D. *Characteristics of the Line-Following Robot Project*

The project was created to meet the characteristics of a successful first-year design project: a. the electronics and coding, along with the CAD provided challenging yet achievable tasks for the students, b. the open-ended nature of the chassis design provided the freedom for student creativity, c. the tasks were complex enough to require participation of all the students in each team, d. the project management aspect of the course allowed students to work together as a team, and e. through beta prototyping students could test out their ideas before creating the final design.

IV. Initial Response from Students and Faculty

In the pilot of fall 2017, each of the three honors sections had a maximum of 20 students. Three experienced faculty members taught the recitation sections of the courses. Students were introduced to the line-following robot project in lieu of the water well project after completing the toothbrush redesign during week 8 of a 15-week semester. To examine how the new project may affect student learning, students were surveyed before and after the project. After sorting out consenting participants and completed surveys, a final 51 sets of complete responses were used for data analysis.

A. *Student Survey*

Prior to the start of the line-following robot project, students were asked to rank two groups of statements to collect information on how they learned best and their initial interpretation of engineering design. Students were asked to rank these statements again at the completion of the project in order to see if their responses would change. The results are listed in Table I.

Of the statements provided, three proved to be statistically different ($p<0.05$) in the paired-sample t-tests between the pre- and post-project surveys. These statements are bolded in the tables. Prior to the project, students ranked the statement Q1a higher than they did after the project, meanwhile the reverse effect was seen for the statement Q1d. The shift in preference is consistent with the research that shows project-based courses can result in higher level of self-directed learning [10].

Surprisingly, student ranking on the statement Q7 dropped after the line-following robot car project. However, despite the puzzling decrease, several students provided car-focused examples to illustrate how they relate the project experience to the real world in technical and nontechnical aspects. We suspect that the wording of the question may have limited how students relate engineering design to real life in general. The statement could have been reworded to encourage students to view engineering design in a much broader sense.

B. *Open-Ended Responses*

In the post-project survey students were given the opportunity to provide open-ended responses to several questions. Students could provide examples for Q5 and Q7

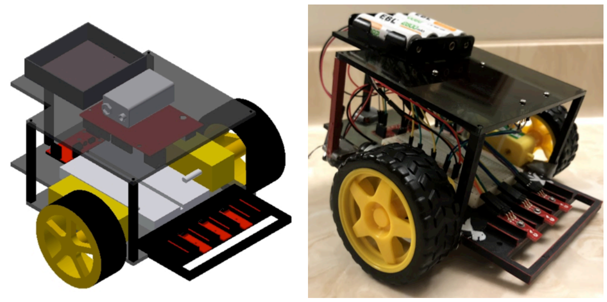

Figure 1: Example of a Final Design modeled in CAD (left) and a Final Prototype created using rapid prototyping (right)

and were also asked: Q8-"What did you enjoy most about the project?" Q9-" What could be improved?" and Q10 provided the opportunity for additional comments. The most frequent topics (mentioned 5 or more times) in response to Q8-Q10 and are displayed in Table II. For Q8 all of the students provided positive feedback. All but one student provided feedback for Q9 and nearly half the students provided feedback for Q10.

Although the robot car project did not change student understanding of engineering design (Q5), many students did comment on what they have learned. For example, one student wrote "I now have a better understanding of how to properly back up ideas and concepts with numerical proof."

This and many other comments along the same line indicate students had a valuable experience working on the tangible, goal-oriented collaborative project. Several responses from students touched on multiple themes. The following example would be counted for both creative process and teamwork: "I enjoyed working with a new group of people and coming up with creative designs and connecting it back to the process we used before."

TABLE I. AVERAGE STUDENT RESPONSES TO THE PROVIDED STATEMENTS PRE- AND POST- PROJECT. STUDENTS RATED EACH STATEMENT ON A SCALE FROM 1 (STRONGLY DISAGREE) TO 5 (STRONGLY AGREE).

Statement		***Pre-***	***Post-***
Q1. As a student, I learn best by…	**a. listening to my professor's presentations**	**3.55**	**3.24**
	b. following examples provided by my professors	4.24	4.10
	c. using my hands to build things	4.45	4.55
	d. figuring out the solution to a problem on my own	**4.02**	**4.27**
	e. remembering how it was done before	3.76	3.63
	f. discussing how to solve a problem with others	3.96	4.12
	g. practicing problem solving again and again	3.84	3.78
Q2. I get the most satisfaction when I made something and it worked.		4.67	4.63
Q3. I study engineering to learn knowledge that will be useful in my life outside of school.		4.53	4.51
Q4. I enjoy solving engineering problems.		4.35	4.22
Q5. EDSGN 100 changes my ideas about how engineering design works.		3.76	3.71
Q6. The subject of engineering design has little relation to what I experience in the real world.		2.39	2.22
Q7. To understand engineering design, I sometimes think about what I saw in real life and relate them to the topic being taught.		**3.94**	**3.49**

C. Faculty Observations

Compared with previous semesters, the students appeared to be much more engaged with the line-following robot project. The faculty noted that students appeared to have a lot more fun and were more creative in their designs. They were more motivated as they have put in more hours in the robot car project. Students seemed determined to make their prototype functional and wanted to tackle any obstacle in their path. On the other hand, students also expressed more frustration when technical difficulties arose that were outside of their control, such as those related to 3D printing or operation of the microcontroller. Overall, all faculty agreed that the net result of implementing the project is highly beneficial to students.

V. Discussion

The project given to students follows the guidelines set by the literature. The pilot of the line-following robot revealed promising benefits of adding the build-test portion to the originally hands-on but design-only course. Students received the project very well and at the end of the project switched from "listening to presentations" to "finding solutions on my own" as the preferred learning approach (Q1d).

The pilot study does have a few limitations. Including data from a control group would have allowed us to compare a design-only project with the prototype-based project. Faculty observations – although consistent across three instructors – would have been more robust if measured quantitatively. In future iterations of the project students will be surveyed prior and after both types of projects to find if there is a difference. Questions will be added to the survey to address student motivation level as well as to identify the most helpful learning approach.

The open-ended responses indicated that the project had a positive effect on creativity and teamwork. To follow up on the long-term impact of this project, the retention rates of these students will be tracked through their career at Penn State.

TABLE II. Most Frequent Open Repsonses for Each Comment

Survey Question	Comment themes listed with counts of each mention	
	Comment theme	***Freq.***
Q8. What did you enjoy most about the project?	Creative process	18
	Prototyping and building/hands on	13
	Teamwork	12
	Freedom of design	9
	Rewarding to see final results	8
Q9. What could be improved?	More time to work on the project	17
	The rapid prototyping process	16
	Instructions could be clearer for coding and rapid prototyping	10
	Additional help with coding	7
Q10. Do you have any other comments?	Project was fun	12
	Project was better than alternative projects (toothbrush and water well).	5

Given students' positive feedback to the hands-on project, we plan to continue it for the honors sections of fall 2018 and extend the project to all other sections once we have obtained enough 3D printers to support all the students taking the course. For future classes the course will be structured to bring back the water well project in order to expose students to a system-based design project.

Implementing the new project presented challenges to the faculty as well. For example, it was hard to predict and mitigate common technical errors that could be made by the students. The instructions for the activities will need to be updated in order to target common errors observed in the pilot semester and provide future students with the tools needed to troubleshoot when things go wrong. The instructions for the project are being revised for fall 2018. The process of submitting rapid prototyping instructions can be improved upon in order to help facilitate successful communication between students and the staff running the 3D printer and laser cutter. Students will also be provided an optional in-depth learning module on how to code.

In the long-term future, this project may be expanded to allow for more open-ended design outside of the chassis. Currently, the required design is limited to the mechanical components of the robot. For students planning to go into electrical engineering, or who start the course with higher proficiency of coding, students should have the choice of adding elements such as light up turn signals, or improve the code to allow for better performance.

In conclusion, the line-following robot car project meets the needs for a successful design-build-test project for a first-year engineering course. This project is ideal for smaller schools that may have less accessibility to machine space compared with larger universities. This project will still be beneficial as a design-build-test experience even if students are offered only the low fidelity beta-prototyping process. That said, the rapid prototyping does have added value as it allows students to connect their CAD knowledge learned in the class to their design. As this course evolves and changes with time, it is important to continue to implement achievable design-build-test projects to allow students the full benefits of hands-on experiences.

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