



## Evaluation of a flipped classroom freshman engineering mechatronics design project

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## Abstract

Here we present an account of the development and evaluation of a mechatronics design project, the Supercapacitor Car Challenge, intended for freshman engineering students. The project consists of four weeks of structured lab activities, two weeks of unstructured free design work, and a final week devoted to the design challenge, the Distance Trial.

At the onset of this seven-week project, students are given a kit with parts to build a standard car design, and some additional materials they need for lab activities throughout the design project. The standard car is powered by supercapacitors and is designed to run for a short time until the charge in the supercapacitors is depleted. Students are to modify the design of the standard car to meet the objectives of the end-of-term design challenge.

The first four weeks of the project cover relevant electronics concepts and skills along with the fundamental physics underlying the performance of a toy car's electromechanical system. During this project, students learn the basic underlying electromechanical theory while using various laboratory equipment and developing skills in conceptual design, electrical and mechanical prototyping, and system performance under engineering constraints.

This report provides an account of the course, design project, and results of a study of direct and indirect assessment. Students were provided entrance and exit surveys, and results of direct assessment assignments are presented to complement the survey data.

## Introduction

This lab module is an Arduino-based supercapacitor-powered car design challenge. The objective is to introduce students to the fundamental concepts of engineering design that will be applied throughout their undergraduate engineering education and in preparation for the engineering profession. Students will learn to integrate digital and physical design, to use electronics prototyping tools, to use modern fabrication tools, and to make design choices based on fundamental physics.

The motivation for the supercapacitor car module stemmed from the need for more Arduino-based design projects in the freshman curriculum, a project with energy as an engineering design constraint, and a need for a fun engineering project that engaged freshman students. This project is design-centric, and so all laboratory activities are intended to support the design challenge at the end of the project – while also containing many learning objectives throughout which address general engineering concepts and competencies.

To develop this lab module, four design aspects (programming, physics, electronics, and mechanics) were considered. All aspects were presented at a freshman level and implemented in four two-hour labs. Students learn the concepts as relevant to their design project in each two-hour lab. These four aspects were chosen because they provide an opportunity for each student with different backgrounds to contribute his/her knowledge to the team.

This report details a design project from one of three quarter-long first-year Engineering Design Laboratory courses required of all incoming freshmen in the College of Engineering at Drexel University. Specifics of the lab module will be discussed in this report, including relevant aspects of both in-person and online learning components of this hybrid course. Student learning outcomes are assessed, and results are presented from indirect and direct assessment instruments implemented in this lab module. Indirect assessments include an entrance survey, mid-term survey, and exit survey from students participating in the project; direct assessment evidence of student learning includes lab reports and performance grades in the final challenge.

### Course overview

This is the first course in a series designed to introduce all freshman engineering students to the fundamental concepts of engineering design that will be applied throughout their undergraduate engineering education. Blended online and physical laboratory activities are used to achieve both overall and specific learning objectives.

The changing learning styles and expectations of today's first-year students were considered, and a flipped classroom model was chosen to complement new problem-based-learning, design-focused, seven-week design projects in the freshman curriculum created as part of a curriculum development effort. [1] Therefore, based on the ABET criteria student outcomes a-k (as currently defined [2]), the following course learning objectives (CLOs) were developed:

Students will be able to:

1. describe the engineering design process (e).
2. use the engineering design process to work through an engineering problem (a, b, c, e, k).
3. describe and use techniques for successful team management (d).
4. use analytical and computational modeling and/or visualization tools to describe the activities, tools, and products of working engineers (k).
5. describe distinguishing characteristics among College of Engineering majors (h).
6. make measurements and analyze engineering data taking into consideration limits of measurement, uncertainty, and errors (b).
7. demonstrate effective technical communication in oral, visual and written forms (g).

Students are able to access instructional materials and pre-recorded project-specific lectures any time throughout the term. Prior to the face-to-face laboratory session each week, students are required to watch online lecture videos, take quizzes, and read lab manuals, which are all developed by faculty representatives from the college. During the laboratory session, instructors summarize the learning materials and discuss course logistics in a lecturette before students move on to the lab activities.

Incoming freshmen cannot be assumed to have prior programming knowledge so for this particular design-focused project, students are introduced to a more intuitive visual programming language in place of the traditional Arduino language. It has shown that graphical programming is more inviting and also enables learners to learn text-based programming [3]. The visual programming language Snap4Arduino was used in the sections whose data is presented in this paper. Since then we have adopted the visual programming software Ardublock, which has proved to both work more seamlessly with the Arduino integrated development environment as well as being overall less buggy and simpler to install and use with the Arduino microcontroller than Snap4Arduino.

The design project weekly schedule is outlined in Table 1. The first four weeks of the project cover relevant electronics concepts and skills along with the fundamental physics underlying the performance of a toy car's electromechanical system. During this project, students learn the basic underlying electromechanical theory while using various laboratory equipment and developing skills in conceptual design, electronic and mechanical prototyping, and system performance under engineering constraints.

*Table 1: supercapacitor car design project weekly schedule*

	Online Lectures	In-Lab Activities	Deliverables
Week 1	<ul style="list-style-type: none"> <li>• Project overview</li> <li>• Arduino basics</li> </ul>	<ul style="list-style-type: none"> <li>• Circuit Basics</li> <li>• Introduction to Arduino</li> </ul>	<ul style="list-style-type: none"> <li>• Solve Arduino challenges and explain critical thinking questions</li> </ul>
Week 2	<ul style="list-style-type: none"> <li>• DC motor</li> <li>• H-bridges</li> </ul>	<ul style="list-style-type: none"> <li>• DC motor characterization</li> <li>• Differential motor control</li> </ul>	<ul style="list-style-type: none"> <li>• Demonstrate the use of the H-bridge</li> <li>• Produce an experimental torque/speed graph</li> </ul>
Week 3	<ul style="list-style-type: none"> <li>• Capacitor basics</li> <li>• Soldering</li> </ul>	<ul style="list-style-type: none"> <li>• Capacitor characterization</li> <li>• Circuit soldering</li> </ul>	<ul style="list-style-type: none"> <li>• Demonstrate basic soldering</li> <li>• Produce experimental charge/discharge graph of a capacitor</li> <li>• Submit lab 2 report</li> </ul>
Week 4	<ul style="list-style-type: none"> <li>• System integration and testing</li> </ul>	<ul style="list-style-type: none"> <li>• System performance assessment (straight line test)</li> </ul>	<ul style="list-style-type: none"> <li>• Sketch a conceptual design for performance enhancement</li> <li>• Demonstrate assembled car</li> </ul>
Week 5	<ul style="list-style-type: none"> <li>• Hacking a toy car</li> </ul>	<ul style="list-style-type: none"> <li>• Making a turn</li> </ul>	<ul style="list-style-type: none"> <li>• Demonstrate performance enhancement based on design changes</li> <li>• Submit lab 4 report</li> </ul>
Week 6	<ul style="list-style-type: none"> <li>• Measurement and uncertainty</li> </ul>	<ul style="list-style-type: none"> <li>• Preliminary distance trial</li> <li>• Free design</li> </ul>	<ul style="list-style-type: none"> <li>• Demonstrate performance improvement in distance trial</li> </ul>
Week 7	<ul style="list-style-type: none"> <li>• Topic of choice</li> </ul>	<ul style="list-style-type: none"> <li>• Final Distance trial</li> </ul>	<ul style="list-style-type: none"> <li>• Design brief</li> <li>• Presentation</li> </ul>

Pre-recorded lecture videos and materials are made available on the course learning management system, Blackboard Learn. To ensure that students watch the pre-lab lectures, and to re-enforce concepts from lecture, students were asked to complete weekly quizzes associated with the online lecture material.

After a few weeks of learning relevant equipment and techniques, students are tasked with creating a modified version of a standardized supercapacitor-powered toy car “Super-cap Car”, pictured in Figure 1A, which is given to each team of 3 to 4 students at the start of the module. The engineering design process emphasized in this module was the design-build-test cycle, with emphasis on iterative design and exhaustive testing of their design to enhance the performance of the car for the distance trial. During the structured lab activities at the start of the project, students are given relevant information and resources to aid in the information gathering phase of the design process. In addition to the engineering and science concepts relevant to the project, the online lectures provided information regarding project management techniques such as work breakdown structure, network diagram, Gantt chart, and bill of materials. To close the design cycle, students are asked to make brief presentations on their designs to the class before they complete the distance trial. This metacognitive exercise enables the teams to reflect on what they did during the term and provides an opportunity to share their experience with others in the section. They are asked to address the following questions:

1. Who are your group members and what is your car's name?
2. What design changes to your car or your code did you make, and how were these changes intended to improve the performance?
3. Were there any special considerations during testing you would like to share with the class? (e.g. special test procedures, certain areas which needed additional testing, types of coding approaches tested, etc.)
4. What would you have changed about your group's approach if you could do it again?

Their redesigned car is then entered into a performance challenge at the end of the module. The schematic of the final challenge “the distance trial” layout is shown in Figure 1B highlighting the path the car should take in the challenge. During the final challenge, the distance X is announced (students are previously unaware of this specific distance and must complete sufficient testing of their car’s performance prior to the distance trial), and students are then given ten minutes to update their code, but cannot do any more practice runs after this point. A detailed scoring breakdown for the challenge is provided to the students in a module overview document. Due to the variability in individual car design, constraints of the project, and the non-linear system dynamics due to the capacitor voltage and current output over time, in order to achieve the best outcome, several tests and measurements are required to fully characterize and ensure the performance of their cars using engineering techniques learned throughout the term.

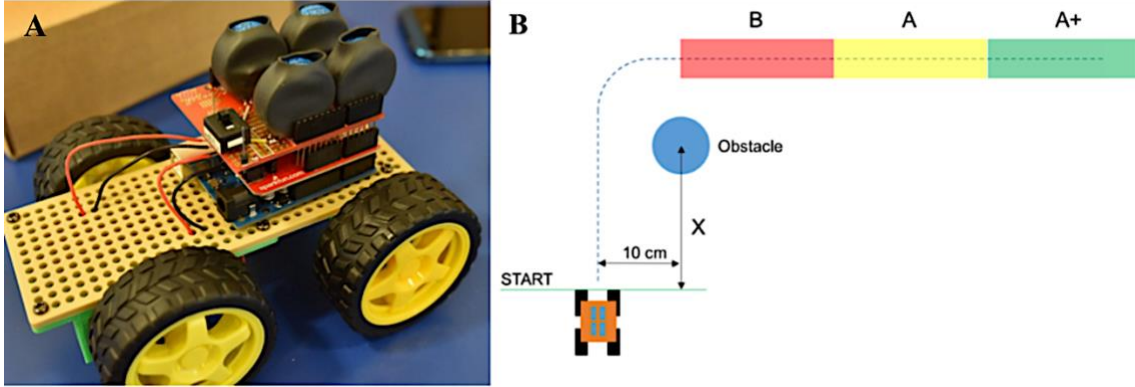


Figure 1: (A) standard Super-Cap Car; (B) Schematic of distance trial layout

In addition to the aforementioned course learning objectives, upon completion of this module, students will also be able to demonstrate the following learning outcomes for this particular design project:

1. successfully integrate digital and physical design.
2. use electronics prototyping tools in the design of a mechatronic system.
3. use modern fabrication tools in the design process.
4. make design choices based on fundamental physics and equipment characterization considerations.

Students will be graded using rubrics when possible. The final grades are calculated based upon the following components provided in Table 2. In the next section, the results of self-efficacy surveys, writing assignments, and the final distance trial performances will be presented and discussed.

Table 2: assessment tools and methods

Component	Weight	Description
Lab Attendance	10 %	Attendance will be taken in labs and is required.
Pre-Lab Assignments	15 %	These include quizzes, oral presentations and written assignments completed through Blackboard Learn prior to lab sessions.
In-Lab Assignments	15 %	These include weekly sign-off sheets as well as short oral presentations and written assignments completed during labs.
Writing Assignments	20 %	These are group written reports based on the lab activities.
Design Performance	10 %	This grade is determined based on your design performance relative to design specifications at the end of the design process.
Final Presentation	15 %	Oral presentation on design project.
Self-Efficacy Surveys	5 %	Online surveys which will compare knowledge and abilities before and after the course. Students receive emails prompting to complete these surveys on the designated weeks.
Teamwork Assessment	10 %	These will be two teamwork survey assignments throughout the quarter, each is available on Blackboard Learn

## Results

Indirect and direct assessments were employed to capture student perceptions of their proficiencies before and after the project and to evaluate the effectiveness of the project to meet the learning objectives. For the indirect assessment, surveys were sent to students who enrolled in the course with unique emails during the first week, the fourth week, and the end of the term. Direct assessment evidence in the supercapacitor car module was obtained from quizzes, lab reports and distance trial performance grades. All results were obtained during the winter 2016-2017 term.

### Indirect assessments

A Likert-type survey (Excellent = 4...Poor = 1) was administered during week one, week four, and week ten (the final week of the program) to assess how student's perceived efficacies in the CLOs progressed through the term. The survey completion data is presented in Table 3 and lists the percentage of surveys completion rate. Note that this course consisted of only one pilot section, so the sample size is rather small with a total of 22 students. The survey completion rate dropped throughout the term as anticipated; however, the typical percentage of the post-course survey for the college is around 33%, so the survey is still considered representative.

*Table 3: self-efficacy survey completion data (total respondents: 22)*

Survey	Survey completed	Completion percentage
Pre-course survey	22	100%
Mid-course survey	18	81.8%
Post-course survey	12	54.5%

The data presented in Figure 2 represents the sample mean values of the survey results. Since the size of the data set is relatively small, the included error bars represent the average standard error of the mean value of the responses for each CLO. The standard error of the mean is computed as the standard deviation divided by the square root of the number of respondents for each question. Results showed that students believed that the module increased their abilities in engineering as defined by the CLOs, and results also indicate that the level of confidence in engineering increased through the term.

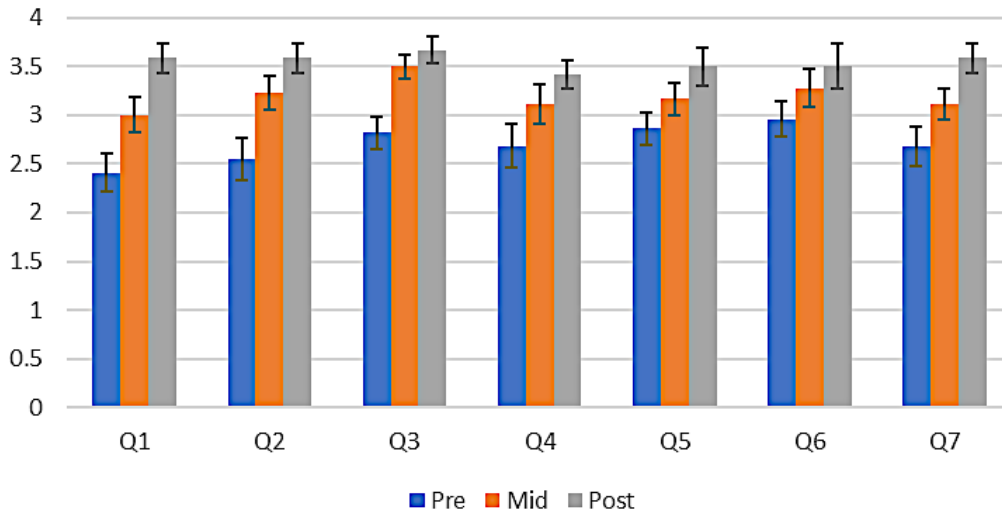


Figure 2: Perceived efficacy in achieving the CLOs. Q1-Q7 refer to CLO 1-7.

## Direct assessments

### *Laboratory Reports*

Two laboratory reports are required from each group to report laboratory activities and critical thinking on the challenge problems. The nine different grade components are listed in Figure 3, and grading rubrics utilizing these components were provided to all students on Blackboard Learn. Since the maximum possible points in each component are weighed differently, the comparisons are calculated as a normalized grade (actual points divided by possible points). The data presented in Figure 3 are the sample mean values of the normalized grade in percentage and error bars are included which represent the average standard error of the mean for each category presented in Figure 3. The orange bars indicate results from the week 2 lab reports, and the blue bars indicate the results from the week 4 reports. Overall, results indicated a noticeable improvement in writing technical reports, especially in preparing graphics/charts and in the discussion.



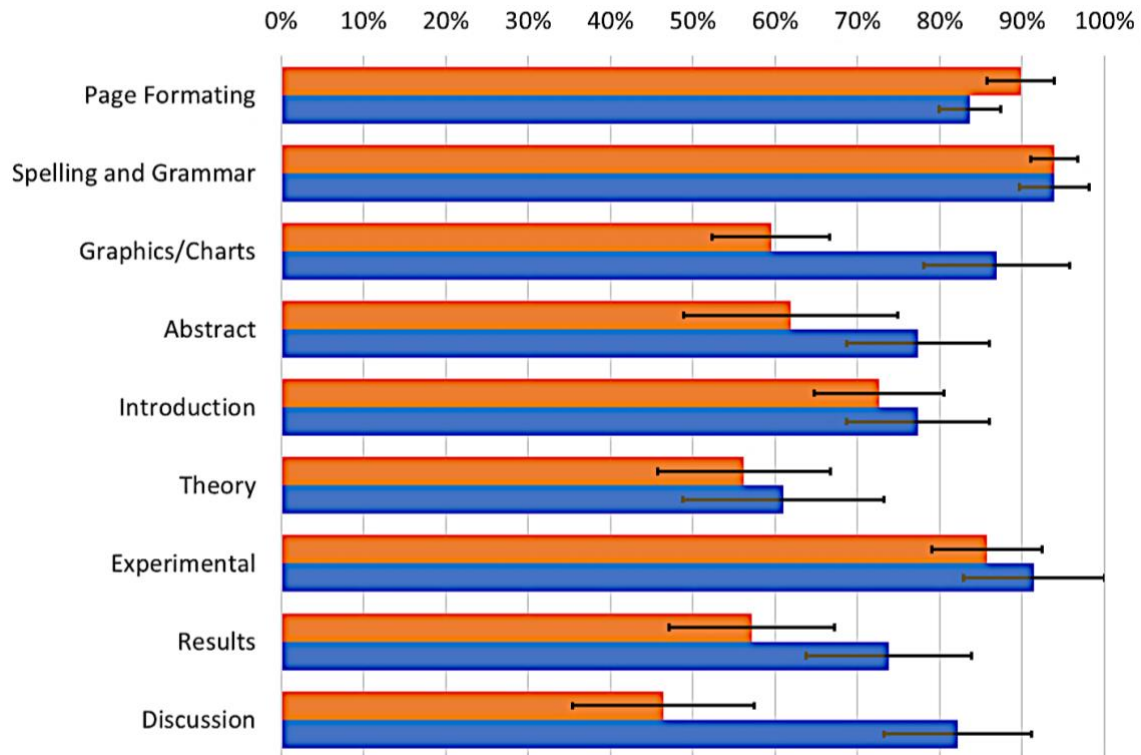
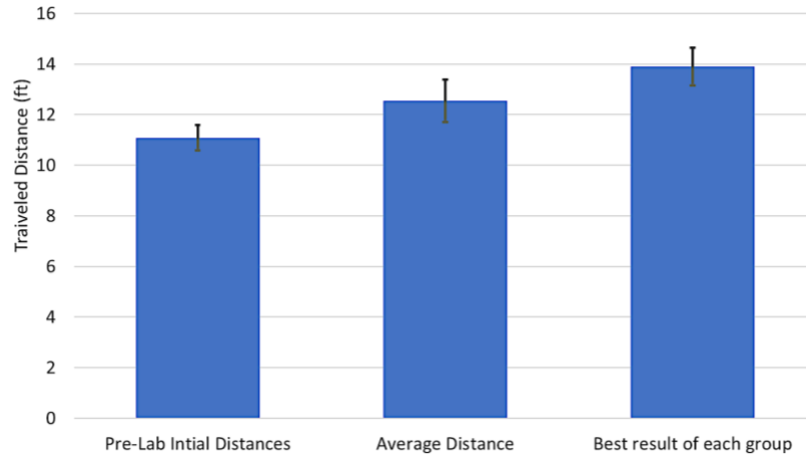


Figure 3: Normalized grades for lab reports (orange = lab two; blue = lab four)

### *Performance Challenge*

Before the course started, all standard car kits were maintained and tested by faculty members or teaching assistants to ensure consistency in the initial performances. Test data were recorded and compared with the average distance of all groups and the best result of each group in the final challenge, Figure 4. The pre-lab initial distance indicates the mean distance a standardized car kit can travel with one full recharge of the capacitors. Both average distance and the best result were recorded during the final challenge. Students may modify code programed in Arduino and re-design the mechanical structures with custom-made components. During the final challenge, each group may have three attempts to change and upload Arduino codes to the car. All distance results were recorded, and the mean distance is designated average distance in Figure 4. Even in the average distance, improvement of the car performances is noticeable by 13%. After maximum three trials, the mean distance of the best performance in each group improved 25% compared with the standardized car. All cars redesigned by students are shown in Figure 5.



*Figure 4: comparisons of distance trial performances*



*Figure 5: Cars redesigned by students*

## Summary

This report highlights efforts and outcomes of developing the supercapacitor powered car lab module. In this case study, both indirect and direct assessments have indicated that the project improves the student learning outcomes. The module has since been run in multiple terms and has shown its sustainability and has provided opportunity to assess the success of the three-term pilot program and appropriately plan the incorporation of the pilot modules into the general population of the first-year engineering design laboratory courses.

## References

- [1] B. Terranova, et. al, *Work in Progress: Curriculum Revision to Support Blended Project-Based Learning in the First-Year General Engineering Laboratory Courses*, ASEE proceedings, 2017.
- [2] <http://www.abet.org>, 'criteria for accrediting engineering programs', 2018. [online]. Available: <http://www.abet.org/wp-content/uploads/2018/02/E001-18-19-EAC-Criteria-11-29-17.pdf> [Accessed: 30- April- 2018].
- [3] A. Repenning, "Moving beyond syntax: lessons from 20 years of blocks programing in AgentSheets.," *Journal of Visual Languages and Sentient Systems*, 2017.