AC 2007-661: FRESHMAN LAB EXPERIMENT: CITRUS POWERED CAR

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Freshman Lab Experiment: Citrus Powered Car

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Abstract

Recently, a number of institutions have taught the fundamentals of electro-chemical cells using lemons and citrus juice as the electrolyte in the cells. Experiments were developed involving oxidation reduction reactions which allowed students to also learn about electric current and voltage. The experiments typically concluded by using the cells to power small lights or a small digital clock. Our idea was that these activities could be made more engaging for engineering students if the experiment was adapted to a competition format and the electrochemical aspects were enhanced by providing a variety of electrode materials for the students to investigate.

The basic experiment was redesigned so that student teams would design a citrus powered car and compete against other student teams' designs for extra credit. The experiment was broken down into three main parts, each as an incremental step towards designing the citrus powered car. First, the students were given an introduction to electro-chemistry by performing oxidation reduction reactions with two different metals and making electrode potential difference measurements with a digital multimeter (DMM). Second, the students then used this data to determine how many citrus cells would be needed to power a light emitting diode. From these first two parts the students would compare what they learned with results from other groups using different metal pairs. After tabulating the data from all teams, each team would then design a citrus powered car.

The citrus cell car could be powered by three different methods: directly from the citrus cell, indirectly using a capacitor charged from the cell or a hybrid involving both the cell and a capacitor. The design specifications listed the competition ratio, the price list for chemicals/metals/capacitors, and the competition rules. The students had to design the car with the highest competition ratio by maximizing speed and distance as well as minimizing cost by using mechanical, electrical and chemical knowledge. This experiment was well received by students and was a big success in the course.

1 Introduction

Polytechnic University's Introduction to Engineering course was created with the mandate to motivate students and promote engineering as a profession by offering students a view into different engineering disciplines through experimentation and projects. It was developed to allow students to survey the various engineering disciplines without great depth in any specific discipline. Goals of the course included learning design strategies and concepts while encouraging teamwork. The course consists of lectures (1hr/wk), laboratory work (3hrs/wk) and recitations (2hrs/wk) for an academic semester.

Course evaluation survey results clearly indicate that students prefer a competition lab over a conventional lab. We believe the spirit of competition and the extra credit incentives provided a reward for the student teams' efforts and encouraged learning.

After the conclusion of the competition, students presented their results in the form of a PowerPoint presentation to the rest of the class during their weekly recitations. This enhanced their public speaking, improved their ability to explain the benefits of their design, and allowed them to identify several areas for improvement.

A citrus powered car was chosen for this experiment because it allowed some real chemistry to be done without the overhead of full plumbing and ventilation that most chemistry experiments require. It also allowed students to build something functional and mobile. Introductory freshman courses experiments which involved motion are often well received and thought of as fun and exciting.

2 Materials

For ease of assembly, Lego® components were chosen for the car chassis and they proved to be very versatile. The Technic Lego system was affordable, easy to clean, reusable, lightweight and the familiarity of the system allowed designs to be constructed in a short amount of time. The special Technic elements allowed the use of gear trains and various wheel sizes.

A single citrus cell was able to provide only a moderate power. In order to increase the electrical power output, multiple cells needed to be connected together, in series or parallel as the student teams decided. This added to the weight of the overall design and so the designs required a gear train. Overall, the motor had to be lightweight, needed an internal gear train, had to consume very little power and had to be able to move the weight of its citrus cells and car chassis. Originally, small cell phone motors as well as regular robotics motors were considered. Most of these common motors draw too high a current (typically one ampere or more). A workable solution came in the form of the Lego Technic 9V Motor (versions 71427 and 43362).

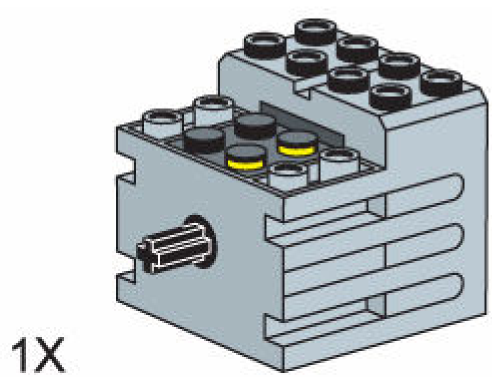

Fig. 1 Lego Technic 9V Motor

(Source: www.legoeducation.com)

These motors can function with as little as 6mA at 1.5V, and contains an internal gear train. The use of Technic elements allows easy attachment to the chassis. The Lego kit also includes special gears.

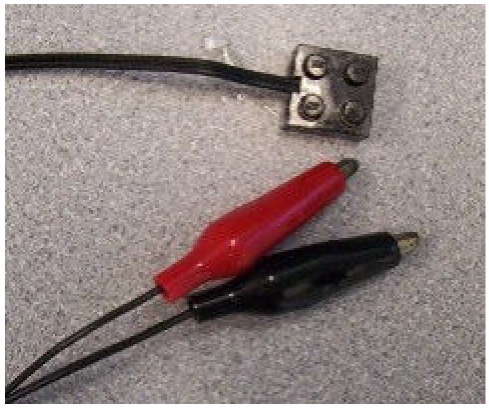

Fig. 2 Lego Alligator Cables

To more easily connect the motor to the chemical cells, Lego alligator cables were made by cutting the Lego connectors in half and splicing the ends with alligator connecting clips. This allowed easy connections from the Lego motor to the citrus cell and the DMM for measurements.

The final cost for parts was $40 per student group: $17 for the motor, $10 for construction parts, $4 for electrodes, and $9 for remaining miscellaneous supplies. Most of these parts are common and can be reused. The only consumables are lemons, citrus juice and magnesium strips which are completely consumed during the experiment.

3 Concept behind the electrochemical reactions

An oxidation reduction reaction was used to generate electrical power for this lab. Two metal electrodes were submerged into an electrolytic solution of citrus juice and a potential difference was produced between the two electrodes. When connected to a load, a current would flow from one electrode to the other. Choosing the correct pairs of metals for use as electrodes with the citrus electrolyte is important to reach sufficient voltage and current levels to run a model car.

3.2 Development of the citrus batteries

During the alpha test phase a simple citrus cell was made using lemon juice as the electrolytic solution with a penny and a dime as the electrodes. To begin with the lemons were kneaded and rolled to break the juices from the pulp. By plunging the two coins side by side into the lemon an electro-chemical cell was formed and the resulting voltage difference was measured with a DMM. The voltage measured was typically about 0.8V. The reaction actually caused the dime to dissolve. It was observed that closer electrode spacing resulted in higher voltages, with one centimeter being optimal and exposing more metal surface area to the electrolytic solution also improved results.

3.3 Why a chemical car?

We chose to base the activity on a competition, and a citrus cell powered car provided a suitable vehicle. High school experiments exist using citrus cells to power a LED, calculator or buzzer; however powering a small car was perceived as a greater challenge. Freshman level engineering students tend to be interested in mechanical devices and collecting data for an experiment with motion was considered novel. The citrus cells are able to provide fairly consistent voltage but the overall electrical power is limited by the amount of current the citrus cell could provide. The current was small, far less than the usual 1A most DC hobby motors require. So a light weight vehicle design was required.

3.4 Improvements using Large Capacitors

A citrus cell is a somewhat unreliable power source. Due to the limitations of the cell, the current drawn depends on the how well the citrus cell was designed and constructed. By using a capacitor, energy can be stored and released in a more uniform manner, so even a poorly designed cell would be able to provide a higher current. It was decided to incorporate capacitors in the design options. Super capacitors have an extremely high energy density and have the capability to store energy on hybrid vehicles as well as provide supplementary energy storage. This technology made the citrus car a good model of the modern hybrid car.

Lego sells a capacitor module in their robotics kits that contained a 1 Farad 2.5V super capacitor for roughly $17. One Farad is a large capacitance; normally they are only found in the form of cylinders as large as a tuna fish or even a soda can. However, with the enhancement of capacitor technology, these 1 farad capacitors can be as small as a coin, priced at typically $5 each. The latest packages can reach incredible capacitance at amazing package sizes.

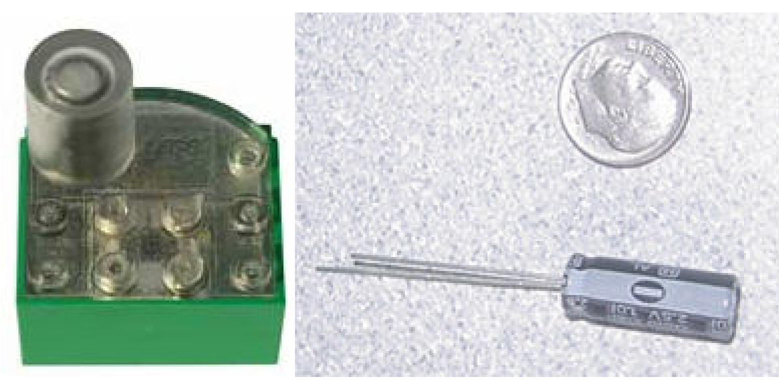

Fig. 3 “Super” Capacitors

Left: Lego 1 Farad 2.5 v Lego capacitor module, Right: similar capacitor from electronics vendor

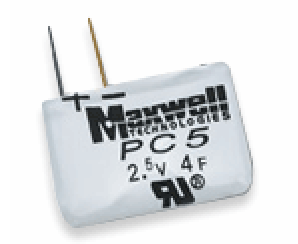

Fig. 4 "Super" Capacitor by Maxwell

Maxwell 2.5V 4 Farad Ultra Capacitor size: 5 x 14 x 24 mm

Since the cells do not provide a very consistent source of power, the charge on the capacitor was monitored directly using a DMM. When the terminal voltage of the capacitor reached the terminal voltage of the citrus cell, the capacitor was fully charged.

4 Actual development model

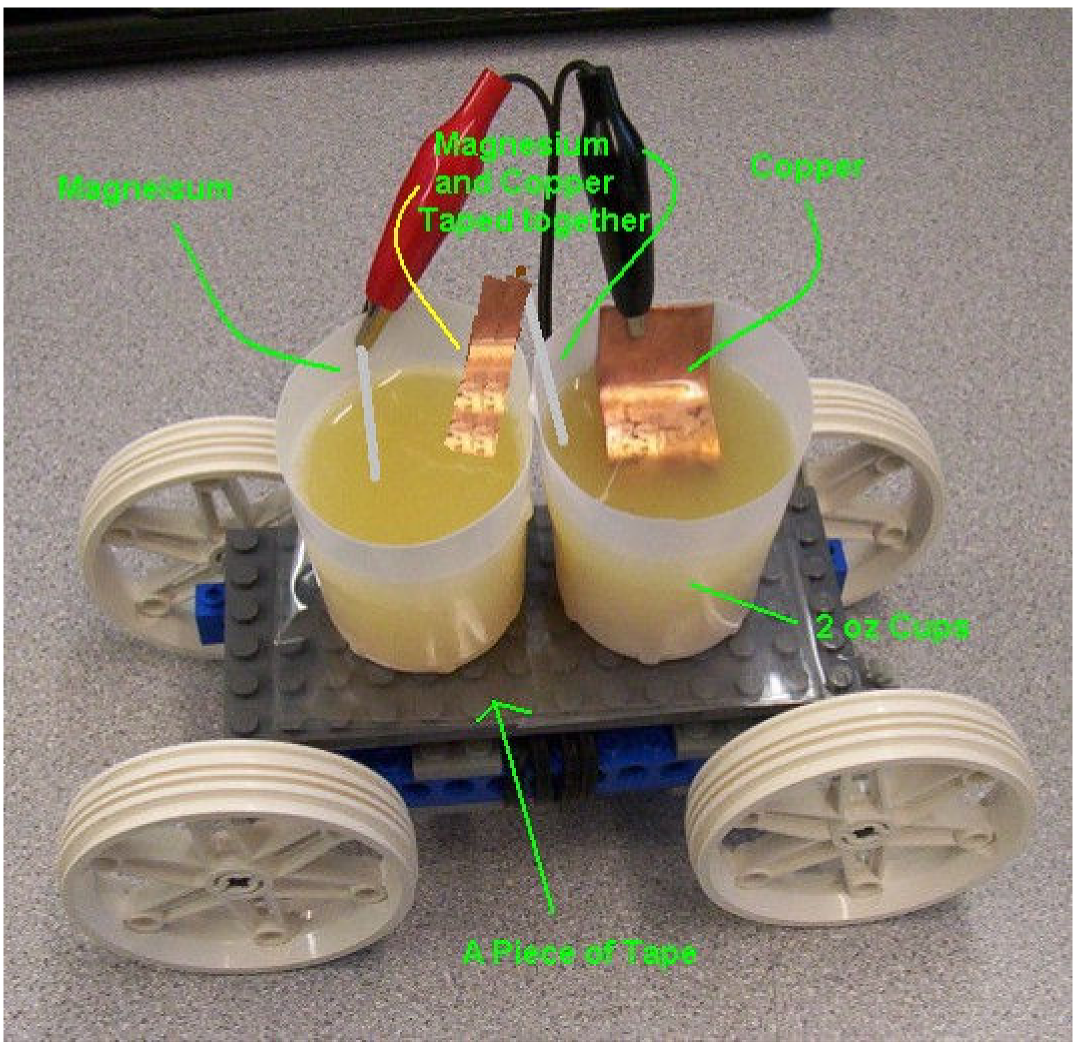

Fig. 5 Actual Lemon Car

In the model shown in Fig.5 two cups of citrus juice were used rather than lemons because they were easier to mount and saved the excess weight of the pulp and skin. The two cups generated approximately the equivalent voltage of two AA batteries.

Fig. 6 Sample Electrodes

Samples of electrodes: left: magnesium, right: copper with magnesium taped together

5. Implementation

During the first beta test of this experiment four teaching assistants with no connection to the development of this lab experiment were used as sample students. They managed to successfully complete the lab in less than two hours.

For the first student beta testing of this lab, the summer section of the course consisting of 20 students participated. They were broken down into groups of two and all of them managed to complete the lab in the recommended three hours. 30 minutes were given for instruction, one hour for initial electrochemical experimentation and 1.5 hours for the cart competition portion.

5.2 Lab Procedure

First the students were given a 30 minute presentation on the background information of the experiment as well as the lab procedure, competition rules and report assignment. They were then broken down into groups of two. The groups were offered different combinations of metals to create a citrus cell from a single lemon and those two metals. They constructed the cells and measured the voltage and polarity using a digital multimeter (DMM). The purpose of this first part was to familiarize the students with citrus cells and how to use a DMM. The results from each trial were recorded on an Excel sheet and were later displayed for the class.

Next the student teams calculated how many cells it would take to light up a LED using the same metal combination they used in the first part of the experiment. If the LED lighted up they would record this as well as the measured voltage and current. All this data was then displayed to the class, so the students could compare the different metal combinations. With larger classes multiple trials can be obtained for each metal combination.

Group	Group Members	Part 1				Part 2		
		Electrode 1	Electrode 2	Voltage (V)		LED Lit?	# of lemons used	Voltage used
A	Anonymous Anonymous	Magnesium	Copper	1.75		Yes	2	3.41
B	Anonymous Anonymous	Nickel	Copper	0.0516		No	3	0.045
C	Anonymous Anonymous	Zinc	Copper	0.92		Yes	3	2.788
D	Anonymous Anonymous	Aluminum	Copper	0.591		No	3	1.3
E	Anonymous Anonymous	Magnesium	Copper	1.3		Yes	1	1.633
F	Anonymous Anonymous	Nickel	Copper	0.015		No	2	0.03
G	Anonymous Anonymous	Zinc	Copper	0.94		Yes	2	1.812
H	Anonymous Anonymous	Aluminum	Copper	0.592		No	2	1.137
I								
	Part 1 and 2 Sheet		Section:	Anonymous		Date of Experiment:		11/3/2006

Table 1 Voltages from different metal pairs

Sample Data from a class

In part 3 of the experiment, the student teams were required to design a chemical cell to be used to power a small toy car, using the tabulated results from the first two parts of the experiment. First they would sketch and design a citrus battery comprised of multiple cells. After it was verified to work by the TA the materials were provided and the students could build the actual battery cells. The cells were then placed on the car or used to charge a capacitor.

5.3 The competition

For the competition, each car was judged based on a competition ratio. The ratio included a comparison of time, distance and cost of components. This allowed students to learn about the kinds of trade-offs engineers have to make when designing products. Cost was an important factor in most designs, more reactive components were more reliable but at a cost of diminishing the ratio.

Time was recorded in seconds until the car stopped moving or when the timer reached 60 seconds. 60 seconds was chosen due to limited space and testing time. Distance was measured in feet. Some of the original test designs would run for over 30 minutes and could travel more than 150 feet. Cost was used in dollars ($).

The Competition Ratio is defined as

$$CR = \frac{\text{distance}}{(1+\text{time})} * \frac{100}{\text{Cost}} + \text{distance}$$

Item	Cost
Capacitor	$1.00
2oz Lemon Juice (with cup)	$0.25
1.5" Mg Strips	$1.00
Cu Strip	$0.25
Zn Strip	$0.50
Al Strip	$0.25
Ni Strip	$0.25
Lemon Car Components	$0.00

Table 2 Competition Price List

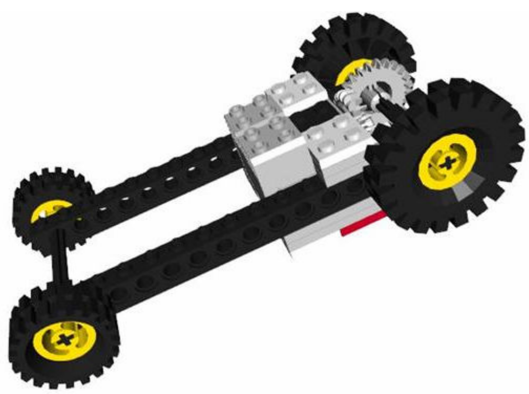

Fig. 7 Sample Chassis

Non-optimized sample chassis provided for students

The results and photos of the competition were recorded and provided to the students. The students then analyzed their designs and determined why their design did or did not succeed in the competition. The results and analysis were then presented to the class in a PowerPoint presentation and to the staff in a written lab report.

Team	Team Members	Price ($)	Distance (ft)	Time (s)	Competition Ratio	Place	Average Velocity
A	student student	4.50	0.00	1.00	0.00	6	0.00
B	student student	4.00	47.00	60.00	66.26	2	0.78
C	student student	8.50	31.00	36.00	40.86	3	0.86
D	student student	4.00	1.00	2.00	9.33	4	0.50
E	student student	5.25	57.00	60.00	74.80	1	0.95
F	student student	4.00	1.00	4.00	6.00	5	0.25
G		1.00	0.00	1.00	0.00	6	0.00
H		1.00	0.00	1.00	0.00	6	0.00
I		1.00	0.00	1.00	0.00	6	0.00

Competition Sheet Section: D3 Date of Experiment: 11/3/2006

Table 3 Citrus-Powered Car Competition Results

Actual Competition results

5.4 Completed Student Citrus Cars

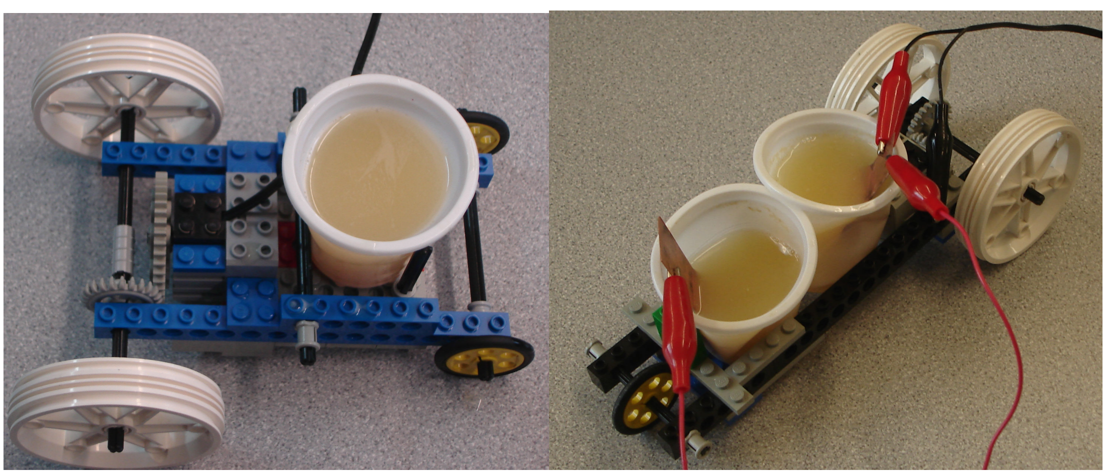

Fig. 8 Citrus cell on car designs

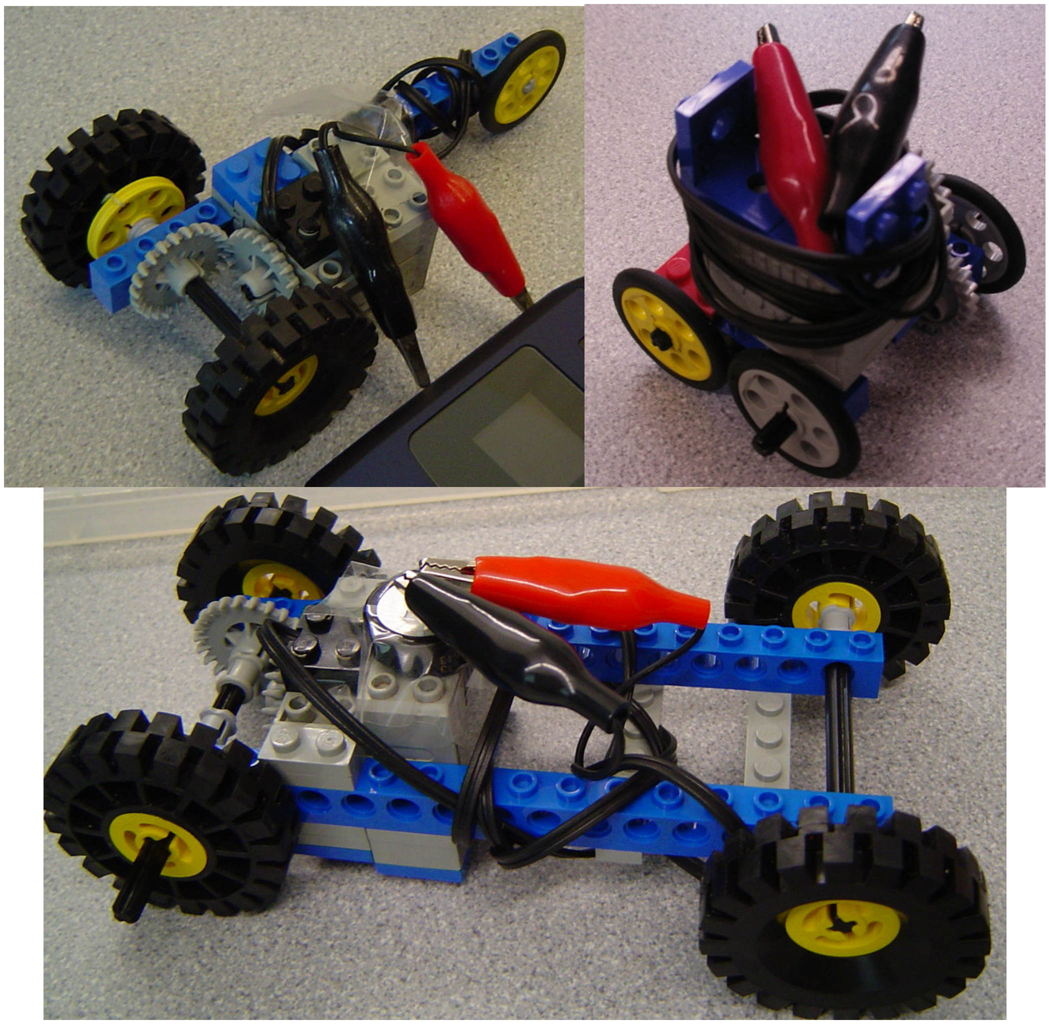

Fig. 9 Capacitor style designs

5.5 Student Assessment

At the conclusion of the lab, the teams were assigned a lab report and a presentation to explain what they learned. The reports and presentations were used to assess how well the students understood their design choices and what they learned from their experiences. Some teams concentrated on the importance of the chassis design; others focused on the importance of creating a cell that could provide enough current or voltage to move their model. Most of the students, in one way or another, described their learning experience as hands on; they required significant design revisions that they understood in order to successfully complete the experiment.

During initial full tests of this experiment, one section of 18 students was chosen to conduct the experiment and their feedback was used to refine the lab. The experiment has run successfully since then and students have reported in course evaluations that they enjoyed the experience and were amazed they built an actual moving vehicle from a few electrodes and citrus juice. One student wrote "It allowed for a hands-on interaction with principles that were previously intangible..."

The groups that were most successful used the suggested basic chassis design and concentrated their efforts on the cells. One common pitfall was to add too many cells to a single car or over-complicating the design. Some student expressed their opinions that there was no real use in creating a citrus powered car and that they were turned off by using Lego components in the experiment. This is an intrinsic issue with using Lego components but it is felt that the flexibility and convenience of using Lego components outweighs any such concerns.

6. Future Plans

Some student teams created hybrid cars running from both citrus cells and a pre-charged capacitor in series. This boosts the initial power delivered and creates a much faster car. In the future there are some plans to investigate other methods of energy conversion to allow the students to design using multiple energy sources. These could include solar power and hydrogen fuel cells.

Summary

The citrus car experiment has been successful integrated into our freshman engineering course. By providing a variety of electrode metals, making capacitors available and allowing for varied car designs, a useful design experience was provided to our students. Students benefited from exposure to design trade offs and to cost considerations of their designs.

The support of Dr. Janice Aber in the development of this lab experiment is gratefully acknowledged.

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