Charge Up! Wireless Power Transfer Activity for High School Students

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Charge Up! A Wireless Power Transfer Activity for High School Students

Akshay Sarin†, Sung Yul Chu†, Heath Hofmann, Al-Thaddeus Avestruz

Abstract

Charge Up! is an engaging activity for inspiring young high school students to pursue careers in electrical engineering. The activity is designed to teach fundamental principles of wireless power transfer (WPT) to high school students. The students get exposed to the iterative engineering design process by building an important component for the given WPT system, the receiver coil. Using these receiver coils mounted on top of remote-controlled (RC) cars the students perform WPT to charge the car battery from a given transmitter system. The students thus learn about WPT through a hands-on activity. The WPT system was designed using pervasive techniques in the field and care was taken to ensure successful operation across a range of student designs. The activity was made fun and enjoyable by including RC car race competition to measure the performance of the student made coils. The activity was tried on a small group of 24 high school students as a part of a summer camp activity. An initial poll and post quiz were carried out to gauge and analyze the effectiveness of the activity. This evaluation showed that 96% of the students had developed an intuition for inductor design, and 62.5% of the students were able to correctly identify the concept for magnetic coupling including proper alignment, the distance between two coils and the relative size of the receiver coil with respect to the transmitter coil. The students gave an average rating of 8.2/10 for how much they liked the competition, further indicating their engagement in the activity.

Introduction

The transportation sector accounts for 28% of global energy consumption and 23% of total CO_2 emissions [1]. The Intergovernmental Panel on Climate Change (IPCC) recommends up to 60% reduction of the CO_2 emissions from the transportation sector by 2050 to meet the target of 1.5° temperature rise every year. This radical transformation requires rapid electrification of the transportation sector. Estimates suggest that there will be over 250 million electric vehicles (EVs) by 2030 [2]. The growth of EVs has led to the rapid rise of Wireless Power Transfer (WPT) for the charging of these vehicles [3]. WPT is an emerging field and promises to become a necessity in the future with the emergence of electric vehicles and increasing renewable energy generation.

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Thus, to combat the energy challenges for tomorrow we need to inspire and prepare young students to become expert engineers. In this paper, we present an interactive activity for teaching engineering design and electrical engineering concepts to high school students. The activity is designed to educate the high school students with fundamental principles of WPT: inductor design and magnetic coupling, and to provide them hands-on experience with wireless charging.

Teaching WPT using magnetic induction requires advanced concepts of Faraday's law and Maxwell's equations, which are challenging concepts to teach to high school students [4]. We designed the WPT activity to teach these concepts to high school students using live demonstrations and hands-on experiences. It is a fun and enjoyable activity that also teaches the iterative engineering design process. In the initial trial, the activity was performed with 24 high school students participating in a summer camp at the University of Michigan. We hope to continue offering the activity as an outreach activity as well as in the summer camps. We also encourage other universities to try the activity and are happy to provide assistance needed with adapting the activity to other settings.

Power Up Summer Camp Overview

Power Up is one of the four Electrify Tech Camps sponsored and run by the Department of Electrical and Computer Engineering of the University of Michigan. Camp participants are introduced to the concepts of Electrical Power and Energy at an introductory level suitable for high school students. The camp runs for a week during summer and students get hands-on experience with basic electrical circuits, harnessing power from various energy sources like the solar cells, and basic power electronic circuits. A typical day in the camp starts with an hour-long lecture by a faculty member, followed by hands-on learning in the lab under the supervision of graduate student instructors. The laboratory activities are designed to demonstrate the practical aspects of the concepts learned in the lecture as well as exposing students to the complexity of electrical engineering problems. Some of the lab-activities are tracking the maximum power point for a solar cell using a resistor kit, manipulating electrical switches to control light bulbs, energy storage design with ultra-capacitors. This year as part of one of the design activities of the camp, the students were familiarized with the concepts of Wireless Power Transfer (WPT). The 2019 summer camp had 24 students, who were divided into groups of 3 for all the hands-on activities.

Wireless Power Transfer Activity

The main goal of the Wireless Power Transfer (WPT) activity is to educate the high school students with fundamental principles of WPT: designing and fabricating inductors, the concept of magnetic coupling and to provide them hands-on experience with wireless charging. Before the actual activity, the students were given an overview of inductors as magnetic energy storage elements, transformers, and ac power-flow in the morning lecture. However, the lectures merely gave an introduction to these complex engineering topics. Hence, in the lab before the activity, the students were introduced to the idea of WPT using magnetic induction by a simple demonstration of the activity. WPT using magnetic induction requires two coupled inductor coils, the transmitter (Tx) and receiver (Rx) coil, see Fig. 1. The WPT activity was designed around having students

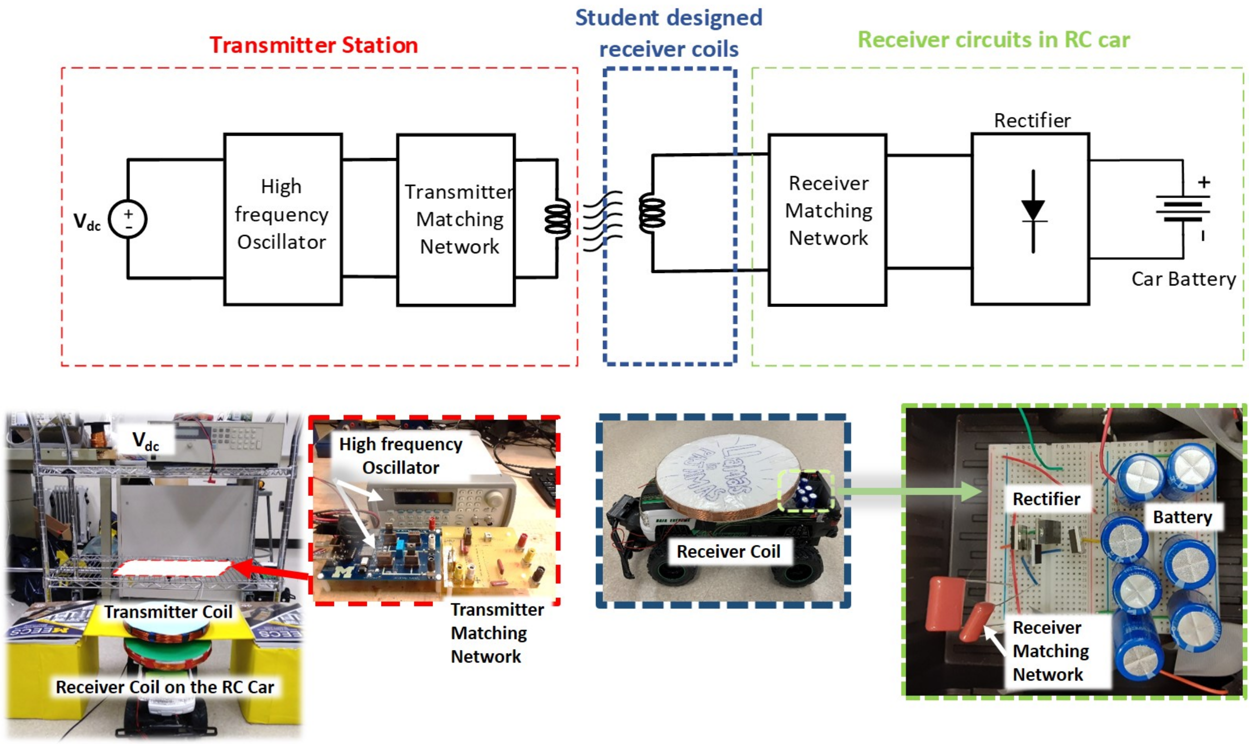

Fig. 1. WPT system configuration and their associated actual counterparts used in the activity. The students were provided with the transmitter station and the circuits in the RC for enhancing the performance of WPT. The receiver coils on top of the RC car were made by the students.

build their Rx coil given the other system parameters. To ensure successful power transfer across a variety of student-designed receiver coils, the activity uses carefully designed resonant circuits at both transmitter and receiver end; the WPT coils and the corresponding resonating capacitors significantly improve the performance over the non-resonant inductive WPT [5].

The activity is divided into three parts :

1. Inductor Design: In the first part of the activity the students were tasked to design the appropriate Rx coil for the WPT system. Students were given the design constraint of having inductance (L) of the Rx coil within a certain desired range as a dictated WPT system. The inductance of a particular kind of Rx coil is given as

$$L = \frac{\mu_0 N^2 \pi r^2}{l},$$

where r (radius of the coil), N (number of turns) and l (height of the coil) are the design parameters for achieving the desired inductance and μ_0 is a magnetic constant. This formula assumes certain approximations. The students were given the formula; however, they were made aware of the fact that the formula is only valid under certain conditions. Thus, the students had to go through an iterative engineering design process of approximating certain parameters and then tweaking the designs to reach the desired design goals. Students were allowed to measure the inductance of their coil at any time so that they were able to adjust the design parameters.

For the design the students were given a styro-foam circular discs of different sizes, wires of different kinds to make their Rx coil. Fig. 2 shows the different coils made by the student groups.

Fig. 2. Receiver coils made by different student groups. Some student groups selected different radii and also had different number of turns.

2. Wireless Charging: In the next step the student coils were mounted on an RC car and students were asked to park the car underneath the transmitter station in a specific amount of time. The aspect of parking is important because for an efficient WPT the Tx and Rx coil must be aligned properly. This is needed to ensure that the Tx and Rx coil share magnetic flux maximally. Once this car was parked under the transmitter station, Tx coils were powered. The electrical energy received is stored in the storage, which was made using ultra-capacitors so as to charge the car to full capacity quickly.

3. Race: The students then raced the charged cars till exhaustion to compare the energies received. This part of the activity was a fun way to enable the performance comparison between the different groups.

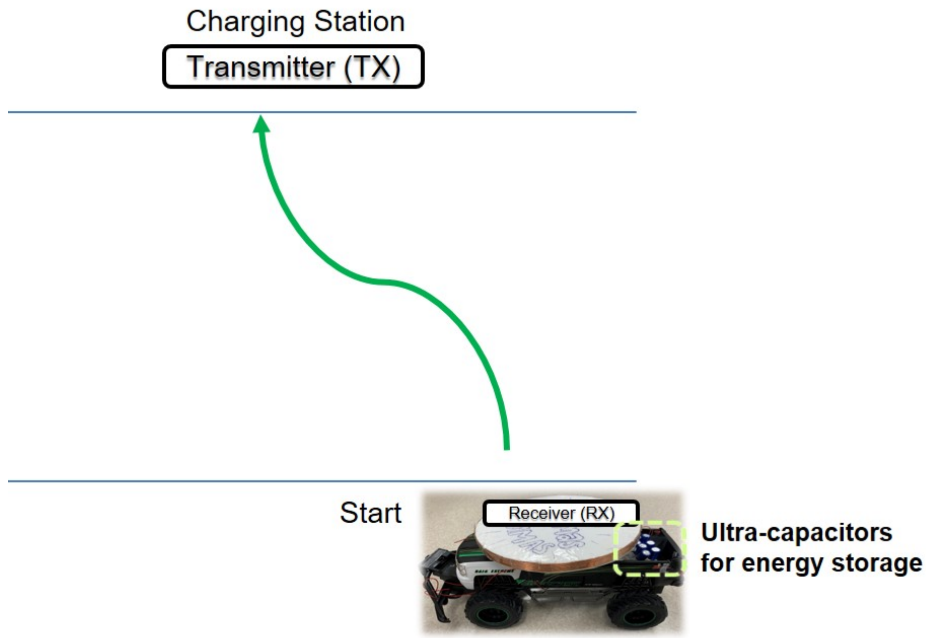

Fig. 3. Parking activity summary. The students drive the car with Rx coil to the charging station to charge the car battery.

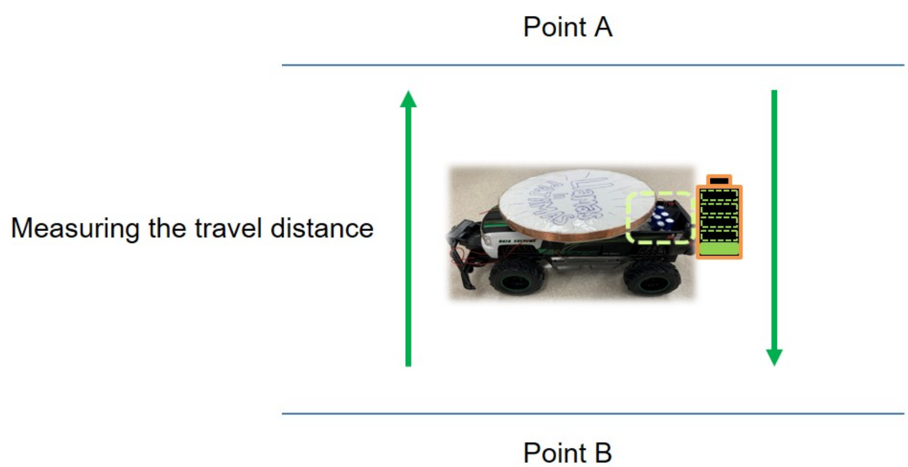

Fig. 4. Race activity summary: The students drive the car between the two indicated lines. The distance traveled by the cars depends on the energy received during charging. A better Rx coil design lead to more distance travelled. The total distance covered by each car was measured to determine the winner of the competition.

Results

The WPT activity was designed for a summer camp with high school students to develop curiosity in the STEM fields, particularly electrical engineering by leveraging the promise of emerging technologies like Wireless Power Transfer. The initial background of students was understood on the first day of the camp through an informal poll on their familiarity with fundamental electrical engineering concepts. Table-1 shows the questions asked as well as the response rate. It can be seen that the students had an idea of general electrical concepts like wireless power transfer and electric cars, but only a few students knew the components used in common electrical circuits like inductors, capacitors, and resistors.

On the last day of the camp we tested the knowledge of the students using a small quiz with 5 questions which have been categorized into 5 different categories based on the types of questions. The questions and the student responses are summarized in Table - 2. The results clearly indicate that the students improved their intuition and understanding for the questions related to hands-on components of the activity.

Table 1: Initial poll results on the first day of the camp

	Who has heard about these topics?	**Response Percentage**
1	Electrical Circuit	50.0
2	Resistor	54.2
3	Inductor	12.5
4	Capacitor	33.3
5	Wireless Charging	70.8
6	Electric Motor	83.3
7	Electric Car	79.2
8	AC/DC	58.3
9	Electric grid	20.8
10	Solar Power	87.5

Table 2: Post Camp quiz results

	Category	**Question**	**Correct Response (%)**
1	Fundamentals of Inductors	How to increase the inductance of the solenoid (what you made)?	95.83
2	Advanced Concept/ Doing Math	If your coil (whose number of turns is 10) inductance is 50 μH, then how many turns do you need more to make inductance 200 μH?	29.17
3	Wireless Power Transfer	What are the important parameters for effective magenetic (inductive) WPT? A1. Misalignment A2. Distance between Tx and Rx A3. Similar inductance of Tx and Rx coils	 62.5 58.33 25
4	Resistor Combination	Write the equivalent resistance of the combination shown.	54.17
5	AC/DC Conversion	Can you draw the output voltage waveform of a rectifier circuit without the capacitor that we used?	37.50

Discussion

From the post-lab questions, it can be seen that the students gained good intuition about the concepts related to WPT even though they had little knowledge at the beginning of the camp. Only 13% of the students had heard about inductors before the camp whereas 96% of students were able to correctly identify how to increase the inductance of a solenoid in the post-quiz.

The students also filled out surveys to rate the various activities of the camp. Fig. 5 shows the survey results. Students enjoyed 'Labs' which included all the activities and with wireless power transfer being the most favorite activity. The "Wireless Power Transfer" and "Inductive Coils" were also among the most popular student choices as newly learned concepts during the summer camp. It can be inferred from these results that the Wireless Power Transfer activity was the most engaging yet the most instructive activity of the Power Up Summer Camp. Also, 74% of students responded that they were encouraged to pursue EE (Electrical Engineering) or CE (Computer Engineering) after the camp, which is one of the ultimate goals of the summer camp for high school students, as shown in Fig. 6. The rating percentage was the top among four different Electrify Tech Camps[1].

[1]The percentage ratings from different camps were: 50% (Sense It Detroit), 65.2% (Nano Size It), 65.2% (Sense it Ann Arbor).

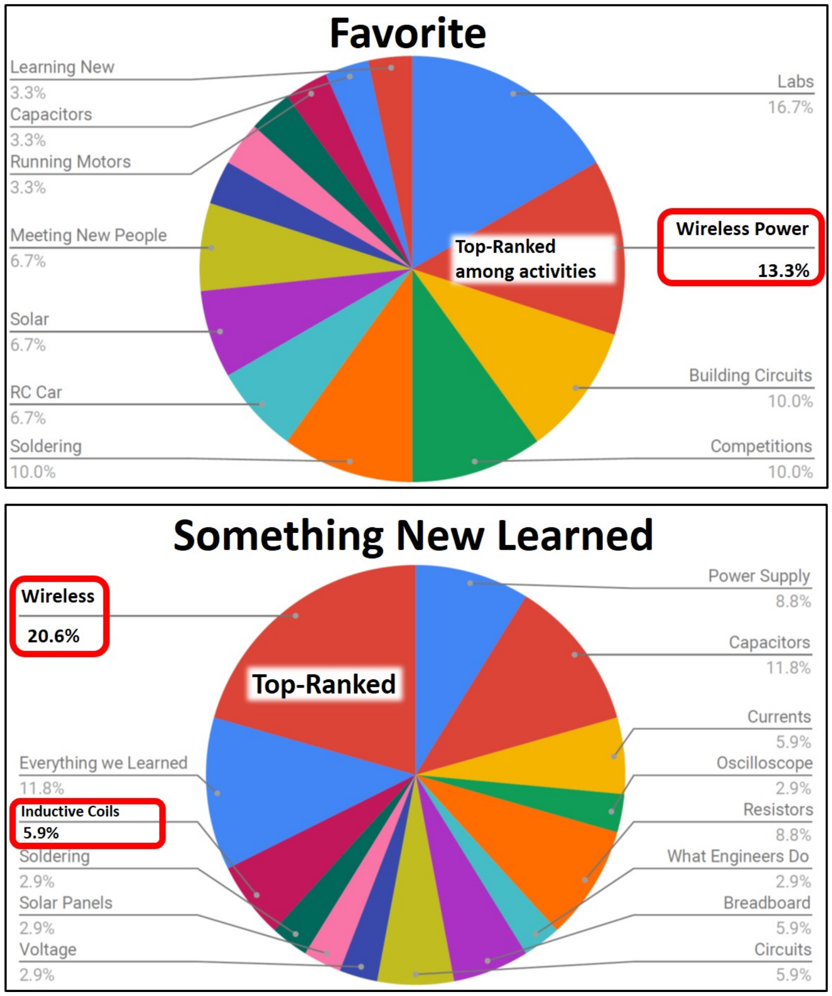

Fig. 5. Post survey results for Power Up Electrify Tech Camps. Top: What was your favorite part of camp? Bottom: What was something new you learned this week?

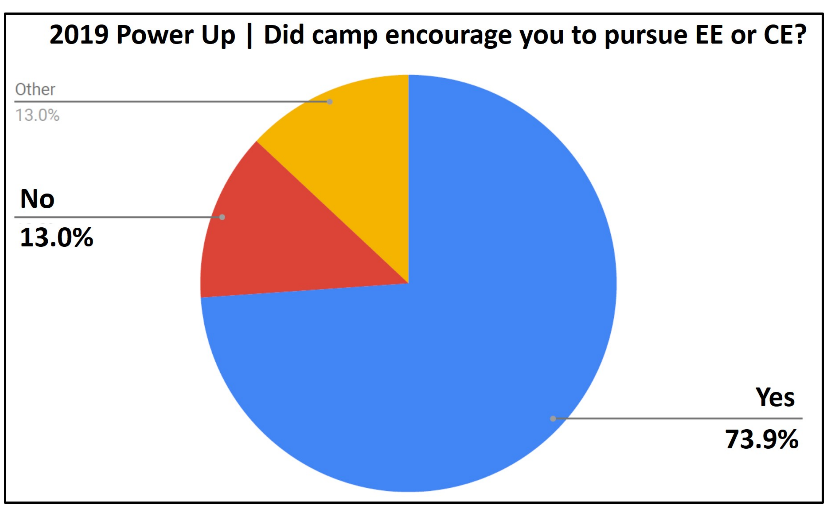

Fig. 6. Post survey results for Power Up Electrify Tech Camps: Has this camp encouraged you to pursue a major/career in electrical or computer engineering?

Future Work and Guidelines for Performing the Activity

We hope to continue having the WPT activity in the future summer camps as well for the other outreach activities around the campus. We also encourage other universities to contact us if they are willing to conduct the activity at their campuses. Here are some technical guidelines for performing the activity effectively with high-school/middle school students:

- Design a resonant WPT transmitter that works safely from no-load to full-load. This is necessary to ensure that under no-circumstance the transmitter side becomes unsafe for operation. The Tx coil should, in general, be large in size to allow variation of size at the receiver side.
- Design the receiver side resonant circuit and rectifier circuit with resonant frequency tuned to the transmitter frequency. The receiver side should also be resonant to allow effective power transfer for a range of student designs as well as for a range of parking skills.
- Design ultra-capacitor storage to charge quickly from the WPT system.
- Modify the RC car power supply to work with the fast-charging ultra-capacitor storage.

The race-track and the other details can be chosen freely for the activity.

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