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A Hands-on Outreach Activity to Promote Electrical Engineering to Underrepresented Groups in Local Middle and High Schools

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Abstract

This study reports the design, development, and execution of a 45-minute electronics workshop for underrepresented middle and high school students to make them interested in pursuing higher education in electrical engineering. The 45-minute workshop included a hands-on activity consisting of four experiments, with incremental complexity, to introduce the students to basic concepts in electronics, such as resistance, capacitance, Ohm's law, and frequency. Students were put in groups of 2 or 3, and each group was given a breadboard with four simple electronic circuits already built for them. In all four circuits, light and/or sound were used to make the experiments more engaging to the students. The hands-on activity started with a straightforward circuit consisting of a resistor and an LED, and then it was progressively made more extensive and more complex by introducing one or two new components in each step. For each section, after presenting some basic theory, students received instructions on how to power the circuit, apply small changes, make observations, and interpret them. A post-survey was conducted to assess students' engagement and interest in the workshop and electrical engineering as a career. Most of the participants declared the workshop was extremely interesting, or interesting. Most of them definitely agreed or agreed that the workshop improved their understanding of electrical components through the hands-on activities. More than half of the students indicated that they are interested in pursuing a career in electrical engineering. This collaborative work with MESA shows that short and highly engaging hands-on activities using inexpensive electronic components can effectively improve underrepresented students' engagement and attention to the electrical engineering discipline.

1. Introduction

In today's rapidly evolving technological landscape, STEM education is the foundation for future advancements, economic growth, and societal progress. It prepares students for careers in fields like engineering and computer science. It equips them with the skills necessary to thrive in a technology-driven world. It also fosters innovation and problem-solving abilities to address global challenges like the energy crisis, climate change, and healthcare. According to the Bureau of Labor Statistics, employment in STEM areas in the United States is projected to grow by 9.5% from 2019 to 2029, which is a much faster growth compared to the expected overall employment growth (3.7%) [1]. However, research shows that many high school students do not choose STEM fields because they do not have enough knowledge about those areas or do not think they have the required skills to pursue STEM education and careers [2], [3].

Indeed, the STEM workforce in the US has been getting more diverse; however, women and ethnic minorities are still significantly underrepresented in STEM fields [4], [5]. According to the American Society for Engineering Education (ASEE), only 24.1% of all engineering bachelor's degrees in the US are awarded to women [6]. For underrepresented minorities, the percentage is only 16.8%. Therefore, promoting STEM fields to women and underrepresented groups is crucial for fostering diversity and ensuring equal opportunities in the STEM workforce to improve the intellectual capacity of the United States and its global competitiveness [7]. Middle school and high school are found to be crucial times for these promoting efforts [8]. A recent study [9] has shown that women are more inclined than men to contemplate pursuing engineering during high school, before college admission, rather than considering it earlier in their education. Advocating for an earlier exploration of engineering majors, potentially during middle school, could provide women and underrepresented minority students with the time needed to engage in requisite courses and facilitate a smoother transition into STEM fields for these groups. Field trips, summer camps, virtual reality experiences, and hands-on activities have been shown to be effective ways of fostering interest in STEM fields in girls and underrepresented groups [2], [3], [10]-[18].

Washington State University has recognized the significance of this matter and has responded by designing and implementing several programs, such as Northwest Louis Stokes Alliance for Minority Participation (LSAMP) and Team Mentoring Program (TMP), which aim to recruit and retain more underrepresented students in STEM programs and help them in their path to successful graduation [19]. With the same goal in mind, at Washington State University Vancouver (WSU Vancouver), we have collaborated with Southwest Washington MESA (Math Engineering Science Achievement) to host a field trip to the WSU Vancouver campus for a group of underrepresented students from local middle schools and high schools. The National Association of Mathematics, Engineering, and Science Achievement (MESA) has a mission to create opportunities for traditionally underrepresented students to pursue higher education and careers in STEM fields. Washington MESA, established in 1982, is serving over 3,500 students through six centers across Washington State [20]. The field trip was designed to provide MESA students with an opportunity to have a first-hand experience with different areas of engineering, through lab tours, competitions, and hands-on activities.

This paper presents details and experiences involved in organizing and managing a workshop focusing on electronics to attract underrepresented students to the electrical engineering discipline. The workshop content, the overall student experience, and lessons learned will be discussed.

2. MESA students' one-day field trip

Southwest Washington MESA planned and organized the event as part of the annual Washington MESA Day event. The field trip to WSU Vancouver took place on Saturday, April 22nd, 2023. The event started at 9:00 AM, with participants checking in. After completing the check-in process and the general instructions, students were put in groups of 6 to 12 to participate in the different STEM-related activities designed for them:

- "Fun with Electronics"
- "Epic Projects Led by College Students"
- "Smart Flowerpots = IoT"
- "Hand on Brains"
- "STEM Nerd Girls & Engineering Station"
- "Clark Aerospace Station"

- “Powerful Tour: Engineering and Computer Science Lab Tour”

The event was scheduled as five 45-minute rotations to allow the students to choose to participate in the activities they were most interested in. A total of 131 students, including 110 middle school students and 21 high school students, from multiple middle and high schools attended the event, and 45 volunteers assisted. The volunteers include MESA coaches, MESA student parents, college students, staff, and faculty.

Among the seven workshops, this paper focuses on the “Fun with Electronics” workshop designed and instructed by a WSU Vancouver electrical engineering professor.

3. “Fun with Electronics” workshop on electronics

The “Fun with Electronics” workshop was designed to introduce the students to basic theory and applications of electronics and allow them to conduct some simple but engaging hands-on experiments. This activity occurred in one teaching lab at WSU Vancouver’s Engineering and Computer Science (ENCS) building. This workshop was given four times or sessions to a total of four groups. As a result, 23 middle school students and six high school students participated in this activity. In each 45-minute session, the number of students was limited to 12, and they were asked to form small teams of 2 or 3. This made it possible for the workshop instructor to interact closely with all students throughout the session.

Each session started with introductions and some safety instructions. All students were asked to wear safety goggles per the lab requirements. The students received step-by-step instructions to go through some hands-on activities. At the end of each session, the students were asked to fill out an evaluation survey.

3.1. Description of the hands-on activities

The hands-on activity was designed in four parts, each consisting of a simple electronic circuit, a short presentation to introduce the circuit, and a simplified version of the underlying theory. Each small group of 2 or 3 was given a breadboard, with the four circuits already mostly built for them and ready to use, as shown in Figure 1. In some parts of the experiment, students were instructed to make minor changes to the circuits and observe the change in results. In each part, the instructor asked simple questions to encourage students’ engagement.

The experiments start with an elementary circuit consisting of a resistor in series with an LED, and they get progressively larger by adding more components while introducing new concepts in electronics. The following describes the details of each of the four experiments.

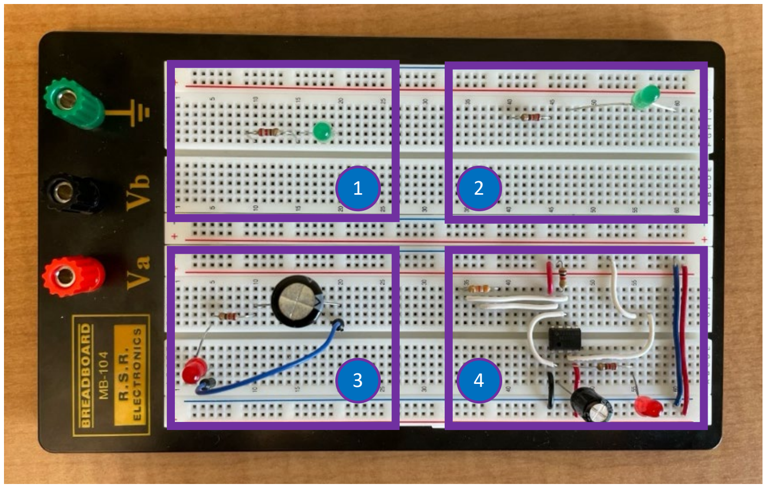

Figure 1. The circuits used for the hands-on activity.

- **Experiment 1: Introducing Ohm's Law**
  - *Short lecture:* Students were given a short lecture on the definition of voltage, current, and resistance, and some simple graphics were used to show them how voltage, current, and resistance are related via Ohm's law. Also, resistors and LEDs were introduced to them as two basic electronic components.
  - *Parts used:* Resistor, LED, and Battery pack.
  - *Learning Objectives:* Students will understand the concept of Ohm's law by observing how a resistor controls the amount of current going through the LED, hence adjusting its brightness.

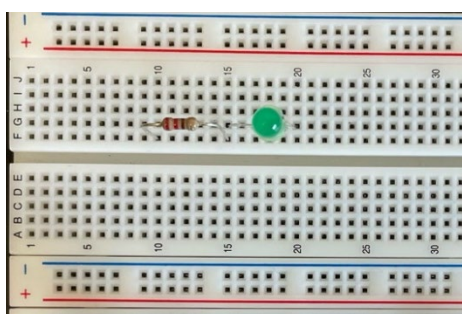

Figure 2. Circuit for Experiment 1.

  - *Instructions:*
    - ➢ Students received instructions on how to properly power up the circuit using the battery pack to light up the LED. The column numbers on the breadboard were used to instruct them on the exact places to connect the power.
    - ➢ Then, they learned a little bit about the resistor color code. Without expecting them to know how to read the color code, the point was just to show them that those colors actually mean something and that they represent the amount of resistance.

- Students were asked to replace the resistor with a larger resistance provided to them, observe the impact on the brightness of the LED, and explain it using Ohm's law.
- Then, they were asked to flip the resistor and observe that the circuit still works. Meaning that resistors are not polarized elements, i.e., there is no positive or negative end.
- After that, the students were asked to flip the LED and observe that this time the LED would not light up, which is because LEDs are polarized components.

- *Outcomes:*
  - Most groups were able to complete this simple experiment very quickly. Some groups had some difficulty understanding how breadboards work and where exactly they were supposed to make the battery connections. All groups were able to observe the impact of the resistance on the brightness of the LED.

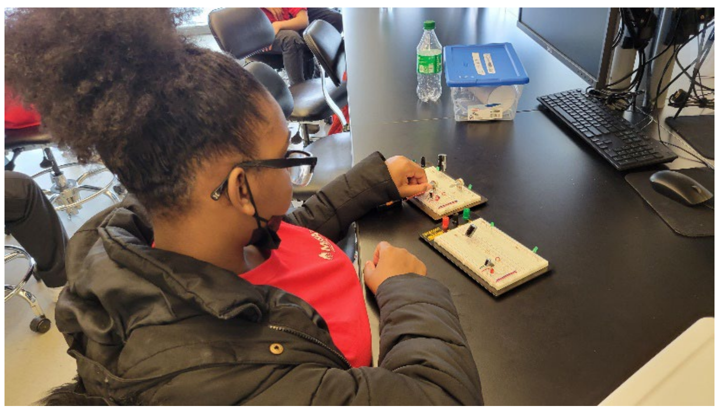

Figure 3. A MESA student adds new components to a circuit.

- **Experiment 2: Introducing Potentiometers**
  - *Short lecture:* Experiment 1 observations were used to raise the question of what if we did not want to replace the resistor every time we wanted to change the brightness of the LED. Potentiometers were introduced as the solution.
  - *Parts used:* Resistor, Potentiometer, LED, and Battery pack.
  - *Learning Objectives:* Students learn how a potentiometer, which is basically a variable resistor, can be used to conveniently adjust the brightness of the LED by controlling the amount of current without having to replace the resistor with a different one.

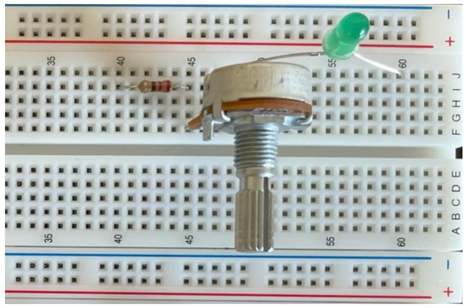

Figure 4.Circuit for Experiment 2.

- *Instructions:*
  - Using the column numbers on the breadboard, students were instructed to place the potentiometer in the right location to complete the circuit and power it up similar to experiment one.
  - Students were asked to turn the knob and report what they observed.
  - Students were asked to disconnect the power and observe that the LED would turn off immediately. This sets up the stage for the next experiment.
  - *Question:* In real life, where do you see potentiometers?
- *Outcomes:*
  - Most students had become more confident in working with the breadboard. This experiment seemed to be more exciting to them than the first experiment. Some groups were able to think of good examples of where in real life they see potentiometers.

- **Experiment 3: Introducing Capacitors**
  - *Short lecture:* Capacitors were introduced as energy-storing components. It was emphasized that, unlike resistors, some capacitors are polarized and it is important to be able to identify the positive and negative leads and correctly place the capacitor in the circuit. Without going into any details, the concepts of capacitor charge and discharge were explained to them.
  - *Parts used:* Resistor, Capacitor, LED, and Battery pack.
  - *Learning Objectives:* Students learn how a capacitor can be used to temporarily store electrical energy and use it later.

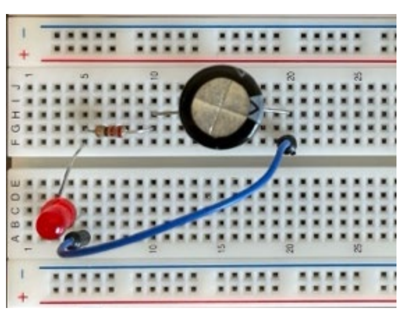

Figure 5. Circuit for Experiment 3.

- *Instructions:*
  - Students received instruction to power up the circuit and light up the LED.
  - *Question:* Does this look any different from how the circuit in Experiment 1 worked?
  - Students were asked to disconnect the power and observe that, unlike the previous experiments, the LED does not turn off immediately. It gradually gets dimmer until it turns off.
  - *Question:* What element is causing this different behavior and why?
  - Students were asked to repeat the same experiment with another capacitor of a much larger capacitance. They were directed to the check numbers printed on the capacitors to verify the capacitances.
  - *Question:* What is the impact of replacing the capacitor with a larger one?
  - *Question:* If capacitors store energy, how are they different from batteries?
- *Outcomes:*
  - Students were able to observe that unlike a resistor or an LED, which consume electrical energy, a capacitor can store the energy (charge) and deliver it (discharge) later. They observed that when the capacitor was replaced by a larger one, after cutting the power, the LED stayed on a little bit longer because the larger capacitor was able to store more energy.

- **Experiment 4: Introducing Integrated Circuits**
  - *Short lecture:* What if we wanted to make the LED blink? One obvious way would be to repeatedly connect and disconnect the power. But is there a smarter way to do this? Yes, Integrated Circuits (ICs). There are many different types of ICs, each designed to do a certain task. The IC used in this experiment is called a "timer" IC, which can implement the ON-OFF cycles that we are looking for to make the LED blink. The resistors and capacitors that you see in the circuit are needed to make the IC work. Furthermore, the size of those resistors and capacitors determines how fast the LED will blink.
  - *Parts used:* Resistor, Capacitor, LED, Potentiometer, IC, Speaker, and Battery pack.
  - *Learning Objectives:* Students learn how integrated circuits can be used to implement more complex tasks.

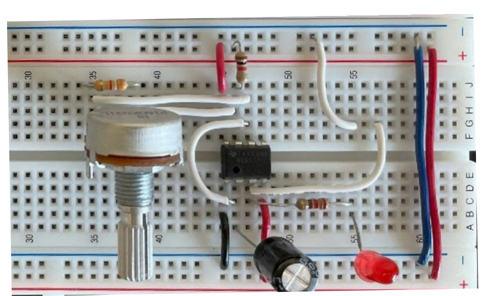

Figure 6. Circuit for Experiment 4.

- *Instructions:*
  - Students received instructions to power up the circuit to make the LED blink at a constant rate.
  - *Question:* Do you think we can make the blinking faster or slower?
  - Students were instructed to add a potentiometer to the circuit and turn the knob to see how the blinking rate changes.
  - *Question:* How is sound generated?
  - Students received instruction on how to add a speaker to the circuit, power up the circuit, turn the potentiometer, and observe how that changed the LED blinking rate and the sound generated by the speaker.
- *Outcomes:*
  - This experiment seemed to be the most interesting part of the activity for most students. They were excited to see how turning the potentiometer controlled the LED blinking rate and the frequency of the sound generated by the speaker. A lot of them started taking videos of the operating circuit, probably to show it to their parents or friends later.

Figure 7. The workshop instructor interacts with MESA students.

4. Program assessment

After completing the workshop, students were asked to complete a short survey with the following questions:

Q1. How interesting did you find the session?

Q2. Did this session improve your understanding of electrical components such as LEDs, resistors, ICs, and speakers?

Q3. What was the most fun activity from the session?

Q4. Would you be interested in pursuing a career in electrical engineering in the future?

Table 1 shows the survey results from the middle school participants and the high school participants. The survey results show that the hands-on activity was overall a success. 95% of students found the experiments interesting or extremely interesting. 78% stated that this hands-on activity improved their understanding of electronic components. Most students (78%) chose Experiment 4, the blinking LED and the speaker, as the most fun activity. When asked if they would be interested in pursuing a career in electrical engineering, 59% of the students responded either yes or definitely yes, which shows that this hands-on activity was able to make underrepresented middle school and high school students interested in electrical engineering.

Table 1: Survey data

Middle School Students (N = 23)					
Q1	How interesting did you find the session?				
	Extremely interesting	Interesting	Neither interesting nor uninteresting	Uninteresting	Extremely uninteresting
	10	12	1	0	0
	43%	52%	4%	0%	0%
Q2	Did this session improve your understanding of electronic components such as LED, resistors, IC, and speakers?				
	Definitely yes	Yes	Neither yes nor no	No	Definitely no
	9	9	4	1	0
	39%	39%	17%	4%	0%
Q3	Pick the most fun activity from the session.				
	LED lights	Capacitors	Potentiometer	Blinking LED	Speaker
	3	0	2	4	14
	13%	0%	9%	17%	61%
Q4	Would you be interested in pursuing a career in electrical engineering in the future?				
	Definitely yes	Yes	Neither yes nor no	No	Definitely no
	2	11	5	4	1
	9%	48%	22%	17%	4%
High School Students (N= 6)					
Q1	3	3	0	0	0
	50%	50%	0%	0%	0%
Q2	5	1			
	83%	17%	0%	0%	0%
Q3	0	0	2	2	2
	0%	0%	33%	33%	33%
Q4	1	3	1	1	0
	17%	50%	17%	17%	0%

5. Conclusions

This paper presented a hands-on outreach workshop held at WSU Vancouver, in collaboration with Southwest Washington MESA, intending to promote electrical engineering to underrepresented groups in local middle and high schools. The workshop, named “Fun with Electronics,” consisted of four experiments, beginning with a simple circuit with one resistor and one LED in Experiment 1 and adding a potentiometer and capacitor in Experiments 2 and 3, respectively. In the last Experiment, students used some resistors, a capacitor, an LED, a potentiometer, an IC, and a speaker to conduct complex tasks, including blinking the LED and making noise in the speaker. The post-survey results indicated that most students found this hands-on activity interesting and stated that the experiments improved their understanding of the basic electronic components. Furthermore, more than half of the participating students stated that they would be interested in pursuing a career in electrical engineering. Therefore, it can be concluded that short but highly engaging hands-on activities allowing students to play with the circuit boards can attract underrepresented middle and high school students to electrical engineering.

6. Acknowledgment

The authors greatly appreciate the support of the National Science Foundation under DUE # 1915644.

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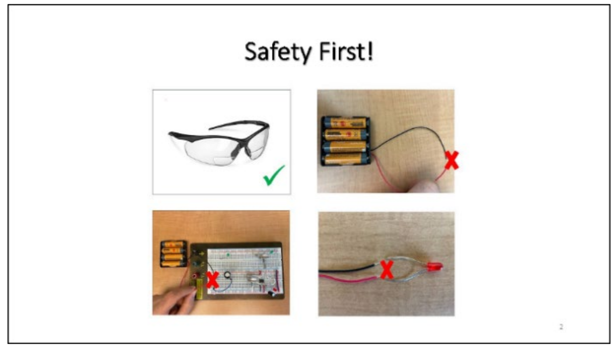
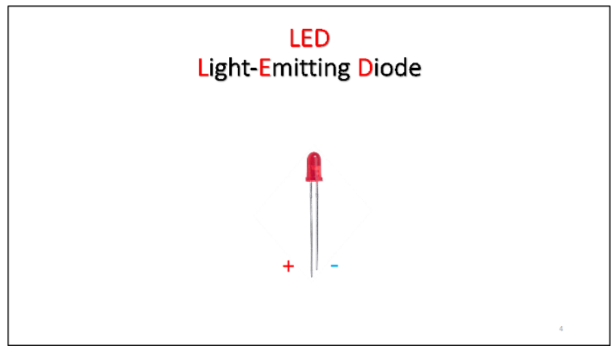
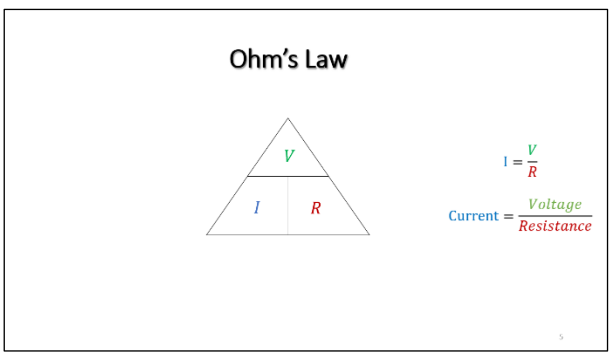
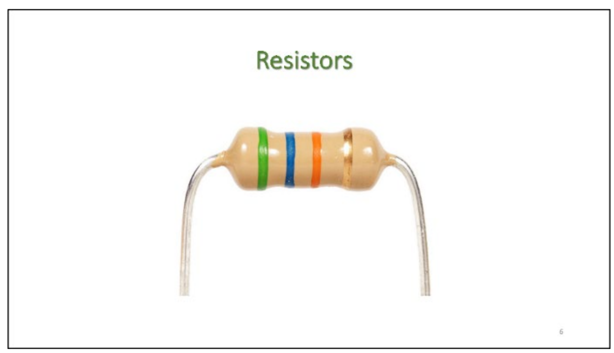
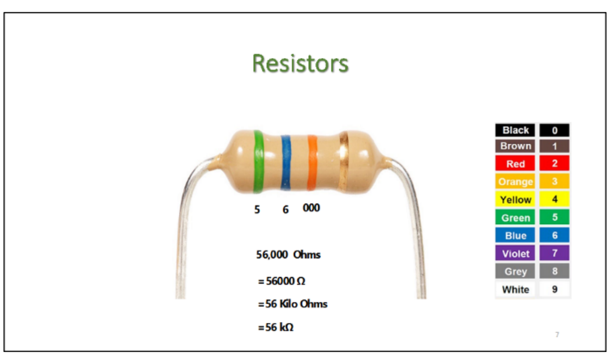
Appendix - The PowerPoint slides used in the "Fun with Electronics" workshop.

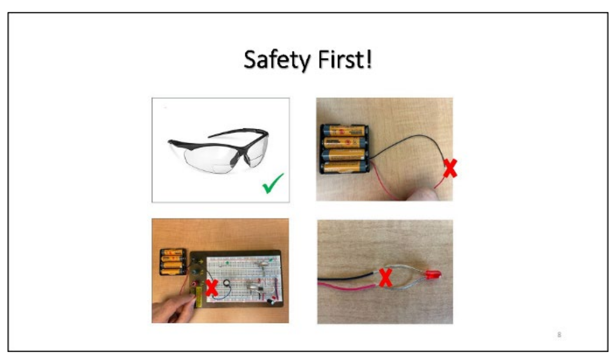




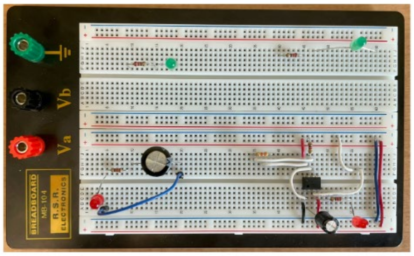


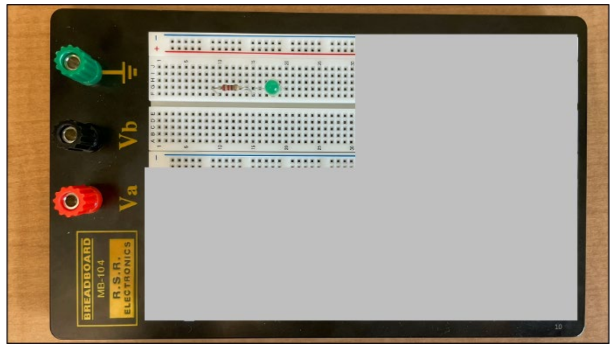




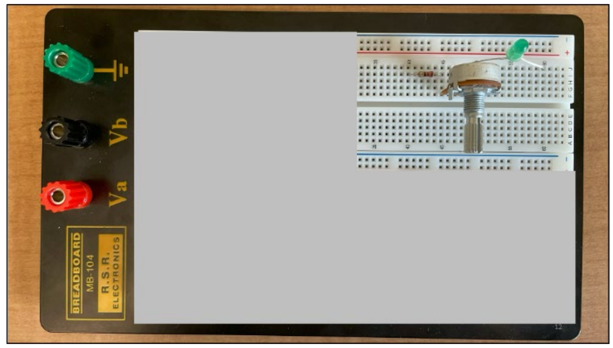


Circuit on a Breadboard

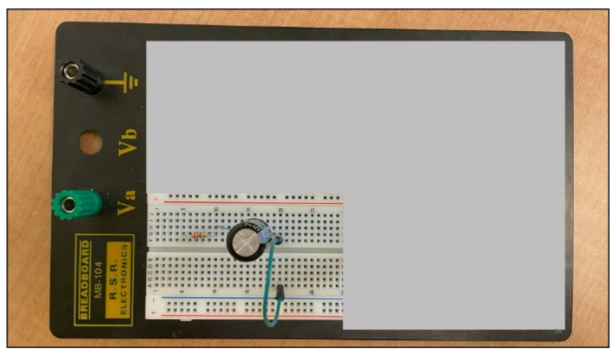


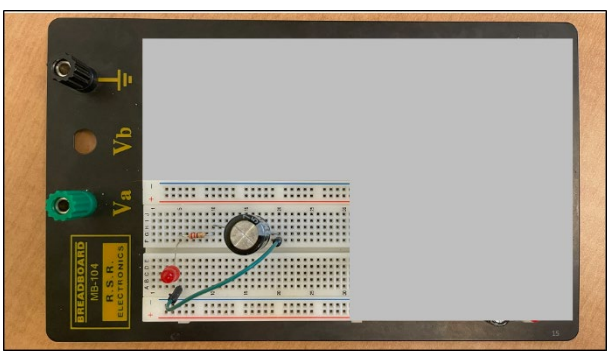


Potentiometers

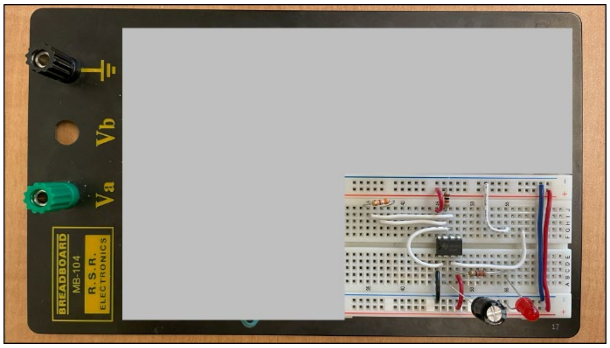


Capacitors





IC
Integrated Circuit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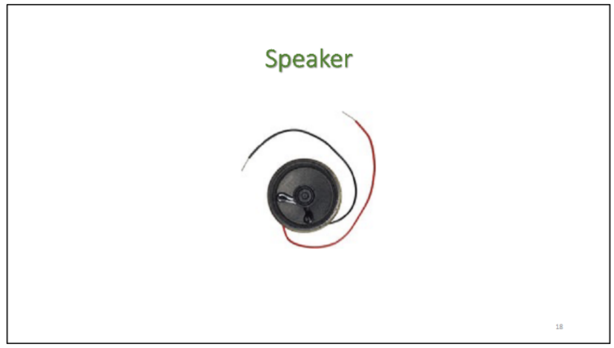
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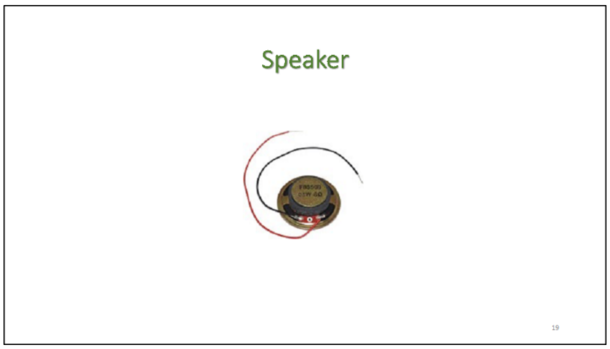
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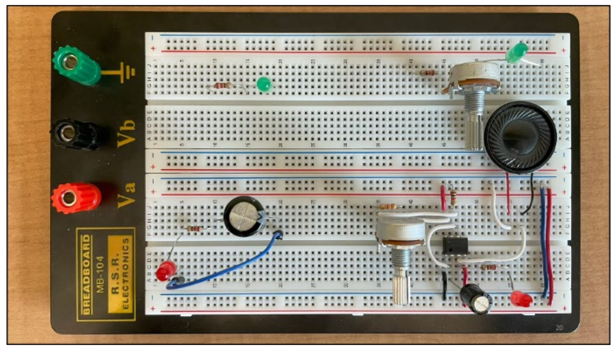
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