Berkeley Engineers and Mentors

Watt's Up?

Target Grade: Elementary/Middle
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Brief Overview

Circuits are a huge part of our everyday lives, and we encounter them more often than we would think. To learn what circuits are, the students will be introduced to electron flow by creating a human circuit. Applying this knowledge, they will be able to create graphite circuits that explore the applications of conductivity in a simple circuit that can light up a LED light. Graphite is special in that it is able to conduct electricity from the battery to the light. Finally, the students will be able to delve into robotics by making vibrobots, using their previous knowledge about circuits. Therefore, the students will be able to see several applications of circuits and understand their importance.

Main Teaching Goals

- A **circuit** is a closed loop through which charges can continuously move
  - *Open* vs. *closed* circuits
  - A simple circuit has 3 main parts: power source, conducting path, and load
- **Conductivity** is the degree to which a material can carry charge. Different substances have varying conductivities. Charges move freely in **conductors**.
- Circuits are the basis for **robots**

Careers and Applications

Although most types of engineers use electrical energy in the things they do, it is electrical and computer engineers who design the systems that produce electrical energy current and transport it to your home. Electrical engineers work with electrical energy in all its forms, from tiny charges to large-scale magnetic fields to the appliances that you use every day. Mechanical and robotic engineers work with electrical and computer engineers to create devices such as lasers used in medical treatments and robots that perform operations in space.
Robots, with their precision and and accuracy, continue to assist in jobs that include repetitive actions or are dangerous for humans. In everything from car production to space exploration, as well as medicine and the investigation of hazardous environments, robots help make our lives a bit easier.

Agenda

- Module 0: Human Circuit (10-15 min)
- Module 1: Graphite Circuit (10-15 min)
- Module 2: Vibrobots! (15-20 min)
- Conclusion (5 min)

Module 0: Human Circuits

Introduction

The students will model a giant circuit and mentors will help in visualizing the flow of electrons in a circuit. It might be helpful to think of a circuit as a river bed, with the electrons flowing through it. The demo will also focus on closed vs open circuits, and the understanding that circuits must be closed in order for there to be current flow.

Teaching Goals

1. Electricity is the flow of *electrons*
    a. Electrons flow from negative to positive
2. Closed vs. Open Circuits

Background for Mentors

Everything around you is made up of tiny particles called atoms. Atoms have even smaller particles inside them called ***electrons***. Electrons always have a negative charge. When electrons move, they produce electricity! Electricity is the movement or flow of electrons from one atom to another.
How do electrons move from one atom to another? They float around their atoms until they receive enough electrical energy to be pushed. *The energy that makes them move comes from a power source*, like a battery or electrical outlet. This works sort of the same way as water flows through a hose when you turn on the faucet. When you turn on a switch or plug in an appliance, electrons flow through wires and come out as electricity, which we sometimes call "power."

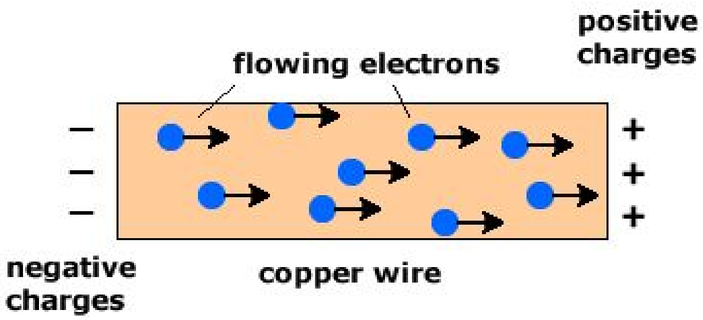


Figure 1: circuits are analogous to river beds through which electrons flow

A **circuit** is a path that electricity flows along. If the path is broken, it is called an *open circuit* and the electrons can't flow all the way around. If the circuit is complete, it is a *closed circuit* and electrons can flow all the way around from one end of a power source (like a battery), through a wire, to the other end of the power source. Along its way, it will carry electrons to electrical objects that are connected to it – like the light bulb – and make them work!

Therefore, electricity is the flow of electrons, and the rate at which electrons flow is the current.

Now what makes current flow in a circuit? When a wire is connected to battery ends or terminals, electrons flow from negative to positive. Remember that opposite charges attract and like charges repel. Electrons, having a negative charge, are repelled from the negative and attracted to the positive. Batteries provide a form of electricity called direct current (DC), in which electrons only travel in one direction - from the negative terminal, to the positive terminal and back out through the negative terminal. The current flowing through wires connected to batteries is much safer than AC or alternating current. It is also very useful for powering small things, like cell phones, radios, clocks, toys, and more. In alternating current, electrons change or alternate their direction regularly many times each second. Homes and businesses are powered through alternating current.

Materials

- 8-10 plastic balls aka “electrons” per site

Procedure

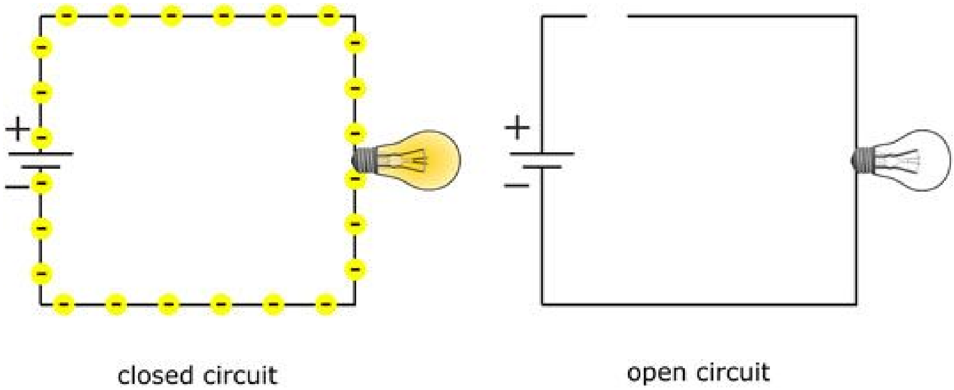


Figure 2: Circuits must be closed in order for the electrons to flow from - end to + end

1. **Open linear circuit**. Tell the students that we will be making a human circuit model. Have students stand in a line and have them link arms (or stand shoulder-to-should at the very least). Have a mentor at one end start passing plastic balls down the line. Emphasize that students can only hold one plastic ball at a time and that they can’t drop them! Also emphasize that the plastic balls can only flow in one direction! Soon, the plastic balls will start to build up at the end of the line and the student at the end should be confused about what to do with them all. Point out that this is clearly a problem and ask if there are any solutions to resolve this open circuit.
2. **Closed circuit**. Now have the first and last people of the linear chain to link arms to close the circuit into a circle or closed loop. Now have the mentor pass a few plastic balls down the line and see that the electrons continue to circulate without problem. Again, emphasize that the plastic balls can only flow in one direction around the circuit. This observation is important in the next module since students will see that the LED’s we are using will only work when it is connected in the proper direction.
    a. Start off by passing the plastic balls slowly and later increase the speed. (which illustrates that the electricity is flowing faster).

Additional Notes for Mentors
The students may have difficulty understanding what electrons are, but the main point is that they understand that these electrons flow to create electricity in a circuit.

Module 1: Graphite Circuits

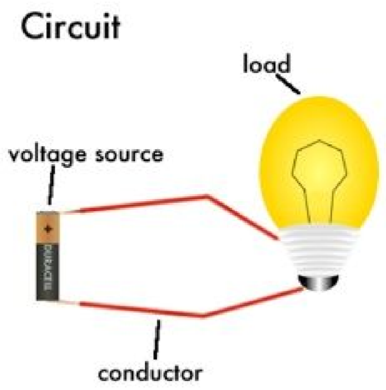
Introduction

In this module, the students will be making their own simple circuits. They can start by making traditional circuits with alligator clips, a battery, and a LED light. Then they can make new circuits with graphite as a replacement for the wires. By drawing graphite "wires" between the battery and the LED light, the students will learn about the movement of current and the conductivity of graphite.

Teaching Goals

1. 3 components of a circuit: power source, load, connecting wires
2. Graphite *conducts* electricity
    a. Conductivity is the degree to which a material allows electric current to flow
3. For middle school/advanced sites:
    a. Parallel vs. series circuits

Background for Mentors
An electric current is a flow of electric charge which is carried by moving electrons in a wire in electric circuits. In this case, the "wires" are the graphite lines and the battery produces the energy for the LED to light up. If the lines are drawn thicker, darker, or shorter, the LED should be brighter.



The **power source** in this case is the battery, which is a compact, easily transportable source of energy. It provides the energy that drives the electrons along in a current. Batteries contain chemical substances that react together to separate positive and negative charges.

An electrical **load** is simply any component of a circuit that consumes power or energy. As we will be learning today, loads are usually resistors.
A **resistor** obstructs the flow of energy in the circuit and converts it into thermal energy. The reason a light bulb glows is that electricity is forced through tungsten, which is a resistor. The energy is released as **light** and heat. More specifically, resistors control the flow of current to the other components in a circuit, thus limiting the current.

The various components are linked together by **wires**. Wires that can conduct electricity are usually made of metal, though current can also flow through some gases, liquids and other materials.

Conductivity is the measure of a material's ability to conduct an electric current. Different substances have varying conductivities. Graphite can conduct electricity because of the electron delocalization within the carbon layers. These valence electrons are free to move, so are able to conduct electricity. Though it is not by any means the best conductor, it works well enough for a simple circuit in the following experiment. Metals are good conductors because metal atoms readily release electrons to carry the current. Silver and copper are the best conductors, and most electric wires are made from copper.

For Advanced Sites:
A **series** circuit is a circuit in which resistors are arranged in a chain, so the current has only one path to take. The current is the same through each resistor. On the other hand, a **parallel** circuit is a circuit that has two or more paths for the electricity to flow. It's like a river that has been divided up into smaller streams, however, all the streams come back to the same point to form the river once again. If one of the parallel paths is broken, current will continue to flow in all the other paths.

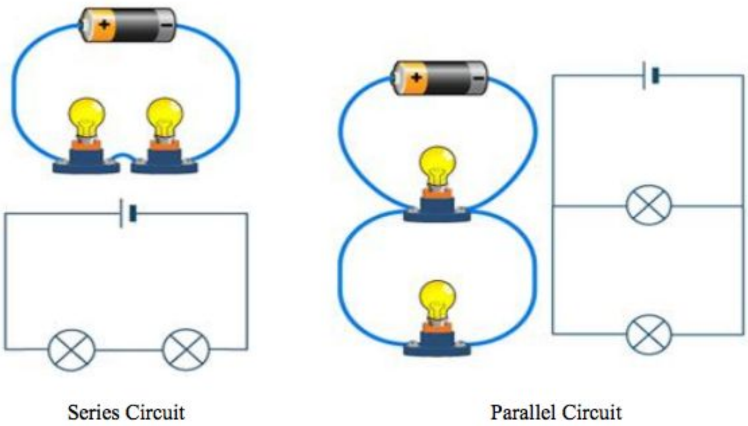
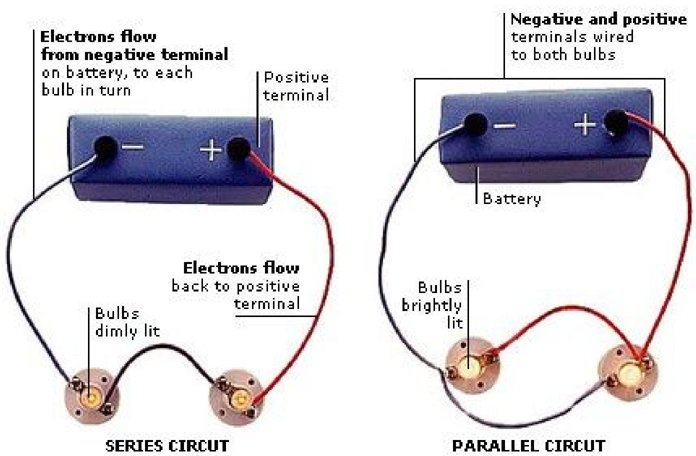


Figure 4: Simple illustration of series and parallel circuits

Ohm's Law states that the current through a conductor between two points is directly proportional to the voltage across the two points. The formula is V = I R,
where V is voltage, I is current, and R is resistance.
Voltage is the amount of energy produced.
Current is the rate of flow of electrons.
Resistance is the measure of opposition to electric current.

The more work (resistance) that a series circuit does, the more its current will decrease. Therefore, if you add a second bulb to this circuit, both will get equally dim, because you have added more resistance to your circuit, which decreases the flow of current.



In a parallel circuit, imagine your strand of lights all connected together. But instead of each bulb being connected one after the other, they are all connected separately. As you can see, each bulb has its own mini circuit that is separate from the other, but they all work together as part of a larger circuit. The more lights that you add, the higher your current climbs, but that increased current has an opposite effect on your resistance. Therefore, the bulbs in a parallel circuit each enjoy the full voltage of the battery and would be brighter than those in a series circuit.

For series circuits, the total resistance of the circuit is equal to the sum of the resistors. The voltage across the circuit is the sum of the voltages across each component.
Looking at parallel circuits, as you add more and more branches to the circuit the total current will increase because Ohm's Law states that the lower the resistance, the higher the current.

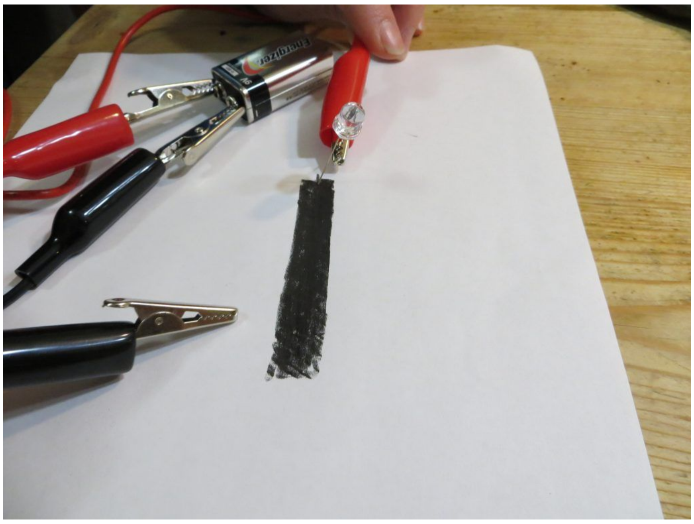


Figure 6: The setup for a graphite circuit!

Materials

- 1 graphite pencil per pair of students
- 1 sheet of white paper per student
    - Can be half-sheets to save paper
- 2 alligator clips per pair of students
- 1 individual LED light per pair of students
- 1 large battery per pair of students

Procedure

1. For the first circuit, connect two alligator clips to the two terminal ends of the battery and the two prongs of the LED.
    a. If the LED doesn’t light up, try switching the wires on the battery ends.
    b. The LED should be bright.
2. For the graphite circuit, use a pencil to draw a **dark**, **bold** shape on the piece of paper. **Make sure there are no gaps of white space and the shape is completely filled in.** The shape should be approximately 1-2 inches in diameter (and can be any regular shape).
3. Take one of the alligator clips from the original circuit and the free prong from the LED and touch them to the sides of the graphite shape.

4. The LED should light up! However, it should be much dimmer than before.
    a. Ask: Why isn’t it as bright?
        i. Graphite is a much poorer conductor than the wire in the alligator clips.
5. If the students try moving the alligator clip and the LED prong closer to each other, the LED should be brighter.
    b. Ask: Why does this happen?
        i. Decreased distance leads to less resistance in the circuit, which allows the current to flow more effectively.

For middle school sites:
If time allows, encourage the students to make series and parallel circuits!
Here are examples of more complicated circuits, but there is also a picture earlier in the lesson that illustrates simple series and parallel circuits.

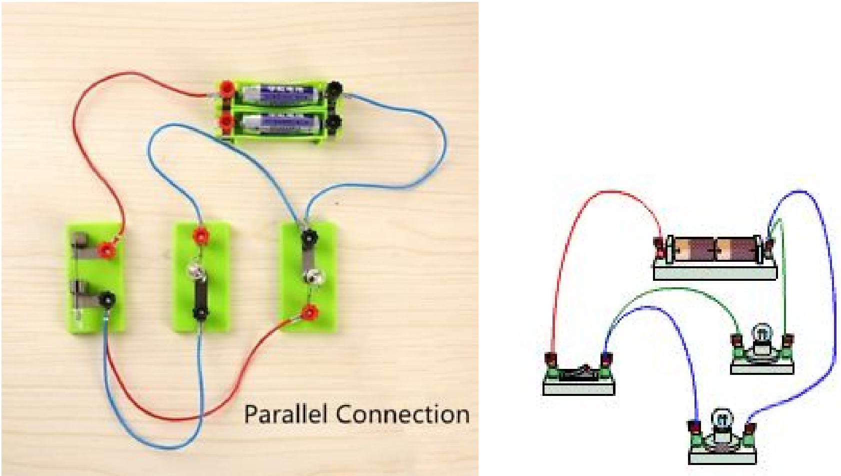
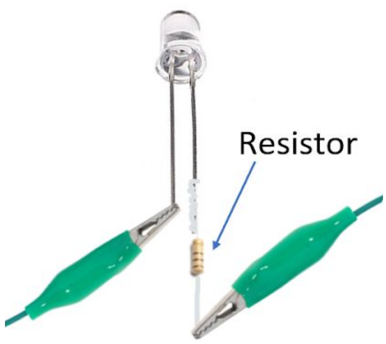


Fig. 7: On the left is a parallel circuit, and on the right, a series-parallel combination circuit (which the kids could attempt if they would like to)!

Additional Notes for Mentors
The LEDs have a tendency to short-circuit if used improperly. To prevent this:

- Each of the LEDs will come with a resistor wound around one of the prongs. **DO NOT let the students unwind the resistor**, since it prevents the current in the circuit from being too high (you will know if an LED is burnt out if there is a brief bright flash of light immediately after you close the circuit and it doesn’t stay lighted).
- When connecting the LED to the circuit, make sure that the students put one alligator clip on one LED prong and the other alligator clip on the resistor wire (**NOT on the other LED prong**).
- If the LED doesn’t work, switch the direction of current flow by **switching the alligator clips**, i.e. move the one on the resistor wire to the LED prong and the one on the LED prong to the resistor wire. If it still doesn’t work, get a new LED.
- Make sure the students don’t run the circuits for too long.
- Be careful of the wires of the LEDs--they are very sharp!



Module 2: Vibrobots

Introduction

The basis of a robot is none other than circuits! These circuits, driven by electricity, allow the robot to carry out certain actions, such as zooming across the room through motor activity. In connecting robotics to circuits, point out the battery, wires, and motor of the vibrobot.

Teaching Goals

1. *Circuits* are the basis of robotics
2. Engineering design process

Background for Mentors

The word “robot” can mean many things in today’s society, and with so many different kinds of robots, how do we define what one is? The most common definition of a robot would be a physical machine that is usually programmable by a computer and can execute tasks either autonomously or automatically by itself.

Robots are powerful machines that, with their precision and intelligence, prove useful in a variety of jobs. They give us access to places that are otherwise inaccessible to the human population, protect us from danger by performing tasks that are harmful to our health, and enhance the quality of our lives by performing tedious jobs and providing assistance to people with disabilities. Many tech and robotic companies produce innovative robots, with technicians, operators, software developers, and of course, robotic engineers working together.

Figure 8: A combat military robot

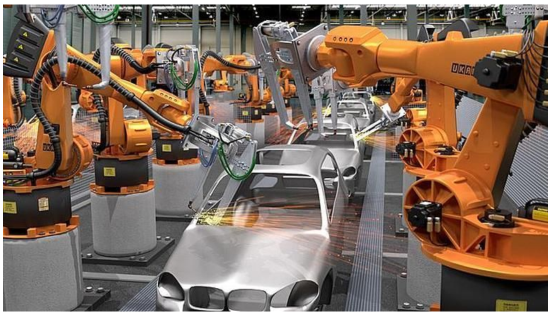


Figure 9: Industrial robots at work in a car factory

Figure 10: Telemanipulators being used in surgery

As for our simpler robots or vibrobots, what makes them move? We are using pager motors which have an added weight that unbalance the core rotating part of the motor. Therefore, the motor vibrates. In creating the vibrobots, we must include the *battery* and the *pager motor* with the attached *wires*. The functionality of robots would be lost without circuits. The circuit enables the motor to convert electrical energy to mechanical energy. Therefore, we can see how engineers use electricity to power devices such as robots.

In regards to the structure or build of the vibrobot, there is no “right way” to create it. However, there are questions that can be asked to guide the students. For example, what do you think would spin faster, a bot with its body tightly bundled up or one with long legs sticking out in all directions? What would move faster, a bot made of stiff paper clips or a soft bot made of cotton balls?

Materials

As robotics goes hand in hand with engineering, the students would perhaps like to experiment with different materials in creating their vibrobot. Encourage them to think about the type of robot they want to build based on what they want it to do. As vibrobots are not easy to steer, the design of the robot’s body can have a great impact on how it moves. They can build fast robots for racing or heavier, slower ones that go in circles for wrestling competitions. No matter what the design, encourage students to experiment and improve upon the desired behavior.

As this is an engineering design project, there is not a specific list of materials, but here are some suggestions:

- Cardboard
- Construction paper
- Straws
- Styrofoam
- Toothpicks
- Pipe cleaners
- Plastic bottle caps
- Paper clips
- Cotton balls
- Cutting tools
- Tape or glue

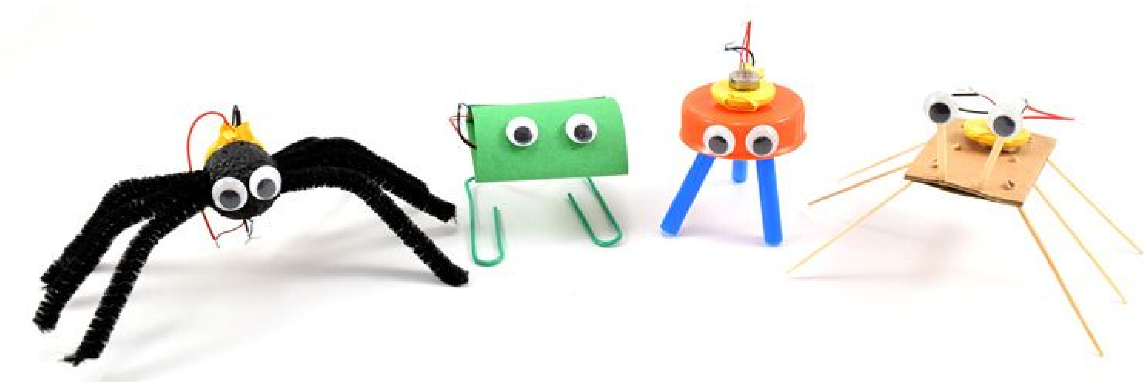


Figure 11: Examples of vibrobot designs

The bristlebot is an example of one of the most common vibrobots, and one that is simple in construction with a great outcome. The steps listed below can be applied to other vibrobot *designs as well.*

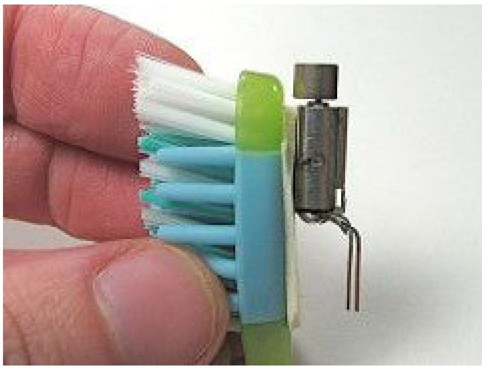
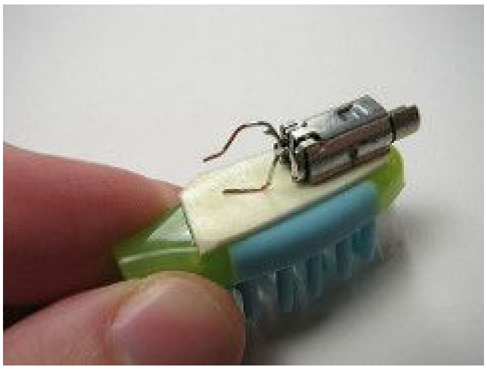
The bristlebots require one of each of these materials:

- Toothbrush head (should be detached)
    - Preferably angled bristles, as straight bristled brushes will make the bot go in circles
- 3V watch battery
- Vibrating pager motor
- Double sided foam tape

For younger students, this may be more of a guided build, while the older students will incorporate more of the engineering design process in creating the robots.

Procedure

1. Each group of students should have a piece of foam tape, about **1 inch** long
2. Attach strip of tape to the back of the toothbrush
    a. The tape provides a secure connection to the base that is able to handle the vibration of the motor
3. Stick vibrating pager motor on the tape, making sure the motor hangs over the *head* of the toothbrush

4. Bend one of the wire leads and stick onto the tape
5. Now stick the 3V battery onto the tape towards the other end of the toothbrush, making sure it is on top of the wire we bent in step 4
    a. It should not matter which side of the battery is up.

6. Finally, place the other copper lead on top of the battery, and the motor should run
7. Your bristlebot is complete! Encourage students to race their bots or just watch them go! It may be easier to keep track of all the bots if there is a certain designated/ blocked off area
8. If necessary, adjust the placement of the motor or battery to achieve the desired motion

Optional: Last but certainly not least, hold a vibrobot competition or race the bristlebots! Nothing like a little competition, am I right?

Additional Notes for Mentors

Both terminal ends of the motor and the battery must maintain contact for the bot to run. **Have tape on hand** if the wire that is on top of the battery won't stay in contact with the battery.

If the bot is going in circles or tends to steer left or right, check:

- Battery and motor placement
- Bristle shape (even a stray bristle can cause a difference in motion)
- Motor rotation direction (try flipping the battery)

Conclusion

Though robots are being made with greater capabilities to "learn" and process information, they are programmed to move or act in certain ways. Therefore, we can think of them as tools to help us get things done. However, creating robots would not be possible without electric circuits driving various electrical devices, as electrical energy in a battery can be converted to light, sound, and mechanical energy for example. With circuits and engineering design, the possibilities for robot making are endless.

References

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Summary Materials Table

Material	**Amount per Group**	**Expected $$**	**Vendor (or online link)**
3V watch/ coin cell battery	1 per pair/group of students	$8.19 for 20 $5.60 for 6	Amazon

Vibrating pager motor	1 per pair/group of students	$16.99 for 15 $11.99 for 15 $8.89 for 10	Amazon Amazon Amazon
Angled Brush head	1 per pair/group of students	If pricey could use flat tooth brushes (place under textbook)	Amazon
Double-sided foam tape	1 per pair/group of students	$5.78 for 150" roll	Amazon Any double sided foam tape could work as long as width is 0.5 inch
Cardboard, toothpicks, styrofoam, plastic bottle caps, straws, pipe cleaners, aka whatever is available	1 per pair/group of students		Inventory
Scissors, glue/ tape	As needed		Inventory
Tennis balls?	1 per student		Inventory
White paper, pencils, alligator clips, LED light, battery	1 per pair/group of students		Inventory