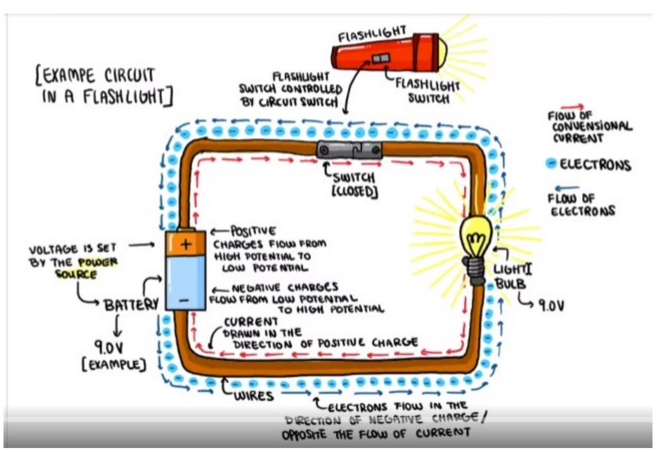
ELECTRICAL ENGINEERING

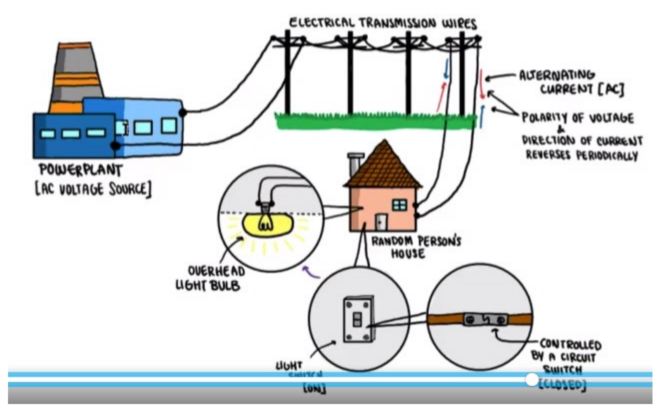
An Ambitious Science Teaching Unit

Why does the electrical system break down?

During power outages, why will some things, like a flashlight work and others, like the overhead lights, will not?

By Lauren Petersen





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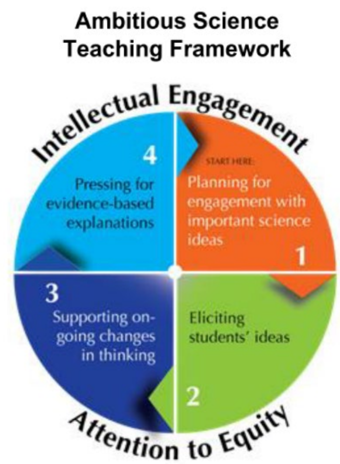
Curriculum Purpose



With the implementation of the Next Generation Science Standards, the physics curriculum has changed. One of the concepts that saw the most change was in how we teach electricity. Circuits and Ohm's law is not in the standards, but there is an emphasis on electromagnetism and electricity generation- specifically around renewable resources and human impact. This unit, developed through the Ambitious Science Teaching framework, attempts to create cohesive, model-based learning experience for high school level physics students to explore these concepts through the anchoring event of a power outages. They will explore our electrical system from simple circuits and the function of a switch, tracing the electrical energy back through the power grid, to how generators use electromagnetism to create this energy that powers our lives.

Learning Goals

(1) Students will be able explain how simple circuits work using concepts of potential difference/voltage, current, and resistance.
(2) Students will create a model of how electricity works within our power grid including power plants, power lines, transformers, and electrical outlets.
(3) Students will be able to demonstrate the concept of electromagnetism through an electromagnet, motor, and generator.

Prerequisite Topics

This unit is designed assuming students understand

- Gravitational Potential Energy
- Law of Conservation of Energy
- Basic Atomic Structure

Next Generation Science Standards: Performance Expectations

*All performance expectations are linked so you can view the Science and Engineering Practices, Disciplinary Core Ideas, and Cross Cutting concepts associated with them

- Energy and Electromagnetism Standards
  - HS-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
  - HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
  - HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
  - HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction

- Earth Science Standards
  - HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios
  - HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems
    - *While this standard is hit in the culminating project, it can be hit more directly by adding a class discussion/debate of the various types of power plants and their pros and cons.*

- Engineering Standards
  - HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
  - HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Anchoring Event: A Power Outage

Framing of the Anchoring Event

The anchoring event, a power outage, should be a relatively common experience among our students. It is important to start with their own experiences, asking them to share out about their experience with a power outage. You can ask them where they were, how long it lasted, if they know what caused it, what they did first, etc. Then, you can choose to focus on a particular outage- maybe there was one during a school day, or a long lasting one locally, or a power outage that got national attention. For example, in my linked slides below, I used the recent Texas power outage to provide some common observations. By showing students media- in the form of headlines, TikTik videos of personal experiences, or news clips, we give them a reference point outside their own experiences. After showing them the media, you can ask they what they observe, what they know about power outages and our electrical system, and what they wonder about/ want to know about. These conversations should be recorded and saved through some digital means, such as Padlet or similar technology, and referenced throughout the unit.

My Example Anchoring Event Presentation: The Texas Power Outage of 2021

Gapless Explanation

In this model, its all about the energy source. For the flashlight, it is a simple circuit consisting of a battery, switch, and light bulb. This works because the battery using a chemical reaction to create an electrical potential difference across its two terminals. The two ends of the battery are like the high point and low point on a mountain- when there is a path, things will fall down the mountain- just like when there is a path, electrons will flow from the negative terminal (low potential energy) to the positive terminal (high potential energy)- even though we draw current from high to low (fun fact- this is because early physicists got it wrong, but even when we figured out the actual mechanism of electricity- the current convention stuck) When you press the switch, it completes the circuit and causes the electrons to 'push' each other from the area of high potential to low potential, creating current through the light bulb- heating up the filament and causing it to glow. Or, in the case, of an LED bulb, it causes the electrons to flow through a junction and emit photons as they do so. However, the lights in our house are connected to a different power source. Our homes are connected to power plants through the electrical grid- a complex circuit consisting of high voltage power lines, transformers, and miles and miles of wires. Any break in this system- whether that's a down power line or a car that crashed into a transformer, can cause a power outage by disconnecting our home from the power plant. Which brings us to how a power plant works to generate electricity. For that, we need to understand electromagnetism. At the most basic, electromagnetism is the idea that current can create and magnetic field, and that moving magnetic fields can create a current. Most generators used in power plants consist of coils of wire on a turbine in a magnetic field created by either electromagnets or permanent magnets. By moving these coils using wind power, water, or steam, the motion induces a current in the wires, and thus creates electricity to power our cities.

Initial Model

To focus their initial power outage models, and make a comparison- we ask students to draw a model that answers the Big Question- “When there is power outage in the area, why/how can flash lights create light energy but your light switches won't?" In the graphic organizer for their models linked below, students are given columns for the flashlight and the overhead lights, as well as a column for their questions and wonders.

To scaffold their initial model, you may provide a list/picture of “example model elements” such as light bulbs, switches, powerlines, and more may be added. In addition, we put goals for their model- focusing on the energy transfers and transformations.

Initial Model: Power Outage

Unit Sequence with Lesson Summaries

Lesson & Timeline *if available, links are provided to student handouts and other instructional materials	**Activity Summary**	**Learning Objectives**	**Assessment**
Anchoring Event & Initial Models *1 hour*	Students will share their own experiences with power outages, be presented with media from a recent power outage (in 2021- Texas power outages). They will make observations, ask questions, and create initial models both individually and in groups.	Access prior knowledge	Formative • Model • Flipgrid Presentation of Model
Demonstration: Electrostatics *1 hour* Jump to lesson: pg 11	Students will watch the teacher (video or live) demonstrate the electrostatic force with sticky tape, a balloon, and a Van de Graaff machine.	I can qualitatively describe the electric field around a charged object. I can use the concept of electric potential to describe electric fields and circuits.	Formative • Whole class and turn and talk questioning throughout • Student Handout
Activity: Understanding Electric Potential *1 hour* Jump to lesson: pg 13	In this POGIL- style investigation, students will explore electric fields by playing an electric field hockey simulation, map electric potential using a pHet Charges and Fields simulation, and apply the concept of electric potential to a circuit.	I can qualitatively describe the electric field around a charged object. I can use the concept of electric potential to describe electric fields and circuits.	Formative • Handout with guided questions
Activity: MIT Circuit Challenge *30 min* Jump to lesson: pg 15	Students will be challenged to light the bulb using only a battery, bulb, and wire.	I can use the concept of electric potential to describe electric fields and circuits.	Formative • Completion of challenge, lighting their bulb • Group Criteria for Circuits
Simulation/Lab: Series and Parallel Circuits *2 hours* Jump to lesson: pg 17	Students will use a circuit builder simulation (due to remote) to discover the properties of a circuit that affect bulb brightness and explore the similarities and differences between series and parallel circuits.	I can compare and contrast the brightness of bulbs in series and parallel circuits I can analyze data to conclude the structure of a circuit based on the behavior of the circuit elements. I can relate the brightness of the bulb to the power by the current and voltage.	Formative Student guided lab report handout

Lesson & Timeline	Activity Summary	Learning Objectives	Assessment
Interactive Mini-Lecture: Electricity *20 minutes* Jump to lesson: pg 18	Students will watch an interactive lecture on electricity to solidify their definitions of voltage, current, and resistance in an electrical circuit.	I can define voltage, current, and resistance as it applies to a circuit.	Formative • Student answers to embedded questions and discussions in lecture
Mid-Model Manipulation *30 min*	Students will complete a summary table through whole class discussion and update their models	Applying all prior learning objectives	Formative: • Model • FlipGrid presentation of Model
Quiz: Electricity* *15 min* *Optional Assessment, can also use model manipulation as assessment if preferred	Short, approx. 15 min quiz to assess students on their definitions and concepts of electricity, voltage, and current.	I can use the concept of electric potential to describe electric fields and circuits. I can compare and contrast the brightness of bulbs in series and parallel circuits I can analyze data to conclude the structure of a circuit based on the behavior of the circuit elements. I can relate the brightness of the bulb to the power by the current and voltage.	Summative
Activity: Webquest The PowerGrid *1.5 hrs* Jump to lesson: pg 20	Students will explore various websites in a jugsaw to gain an understanding of how our power grid works- including learning the difference between AC and DC power.	I can model the power grid including how electricity travels from the power generation plant to my home.	Formative: • Student share-outs of their piece of the jigsaw • Student answers on SMART lesson
Activity: Cost of Electricity *45 min* Jump to lesson: pg 25	Students will analyze a statement from our local power company and use information from it to calculate the cost of electricity. If available, students will compare it to their own home's electrical use.	I can calculate the cost of electric power.	Formative • Student Handout • Discussion of own home's energy use

Lesson & Timeline	Activity Summary	Learning Objectives	Assessment
Mid-Model Manipulation *30 min*	Students will complete a summary table through whole class discussion and update their models	Applying all prior learning objectives	Formative: • Model • FlipGrid presentation of Model
Lab/Simulation: Motors and Generators *2 hours* Jump to lesson: pg 22	Students will create an electromagnet, explore a motor, and then use a motor as a generator in this hands on activity series.	I can use the concept of electromagnetism to explain how a motor works I can use the concept of electromagnetic induction to explain how electricity is generated	Formative • Creation of an electromagnet • Use of motor and generator • Student handout
Interactive Mini-Lecture: Electromagnetism *30 min* Jump to lesson: pg 24	Students will watch a lecture on electromagnetism, including demonstrations of electromagnetic induction.	I can use the concept of electromagnetism to explain how a motor works I can use the concept of electromagnetic induction to explain how electricity is generated	Formative • Student answers to questions embedded throughout
Cosmos Episode: The Electric Boy *50 min* **optional lesson for providing historical context*	Students will watch an episode of Cosmos about Faraday's discoveries and research around electromagnetism.	Student will explore the history of the development of our current understanding of electromagnetism.	Formative • Student reflection quickwrite
Quiz: Electromagnetism* *15 min* *Optional Assessment, can also use model manipulation as assessment if preferred	Short, approx. 15 min quiz to assess students on their definitions and concepts of electromagnetism, motors, and the powergrid	I can use the concept of electromagnetism to explain how a motor works I can use the concept of electromagnetic induction to explain how electricity is generated	Summative
Project: Power Plant Engineering Option Research Option *Varies based on student* *30 min to introduce* *1 hour for presentations*	Students will have two options- they can either research a local power plant that is part of our electrical grid- including its history, efficiency, and power output or build a model of a powerplant and explain how that energy source has been used throughout history.	Students will dive deep on either a type of energy generation, or a local power plant. Discovering how the engineering has changed and grown.	Summative- • Students will create presentations on their chosen topic, and present in a FlipGrid video presentation
Final Models *1 hour*	Students will complete a summary table through whole class discussion and update their models	Application of all learning objectives	Summative: • Final Model • Flipgrid Presentation of Model

Lesson & Timeline	Activity Summary	Learning Objectives	Assessment
Assessment: Colony on Mars Model	Students will be presented with a model for electricity generation on Mars. They will need to chose a type of power plant, and create a model showing how to get electricity to the places that need it- the living quarters, the science facility, air processing plant, and the grow house. As a part of their model, they will explain what materials would be needed.	Application of all learning objectives	Summative: • Model of Colony on Mars

Lesson Plans

Lesson: Electrostatic Demonstrations

<table>
<tr><td colspan="2">Lesson Title: Electrostatic Demonstrations</td><td>Duration: 60 minutes or 1 class period</td></tr>
<tr><td>Key Topics:
• Charge
• Static Electricity
• Electrostatic Force
• Electric Potential</td><td>NGSS Performance Expectations:
• HS-PS2-4 Energy Conservation
• HS-PS3-3 Electric Fields</td><td>Learning Goals:
• By the end of this lesson, students well be able to qualitatively describe the electrostatic force between two charged objects
• By the end of this lesson, students will be introduced to the concepts of electric potential and current.</td></tr>
<tr><td colspan="3">Lesson Summary:
In this lesson, students will go through a series of demonstrations to discover the electrostatic force and observe its interactions. First, they observe the electrostatic force between two charged pieces of sticky tape. Next, they charge a balloon and observe it interacting with neutral pieces of paper. Finally, they explore a Van de Graaf generator to learn how those forces can cause electricity.

Student Handout: Have them draw models of each demonstration & answer questions in notebook or on blank sheet of paper
Powerpoint Presentation: Demonstration: Electrostatics</td></tr>
<tr><td colspan="2">Opening Activity: Problem of the Day</td><td>10 min</td></tr>
<tr><td colspan="3">Teacher presents students with two questions:
1. Draw/find a model of the atom showing particles and charges. Circle the one most related to electricity.
2. How do masses move in Earth's gravitational field under the influence of the force of gravity?
   a. From high gravitational potential energy to low gravitational potential energy
   b. From low gravitational potential energy to high gravitational potential energy
   c. Depends on the mass
   d. They can move from high to low or low to high depending on what direction

Give students 5-8 min to answer independently. Then, direct students to check their answers with their group members. Call on students randomly to share their answers. When talking about how objects move in gravity fields, relate this to electric fields- expect that things with negative change go ‘uphill’ which make electrostatic force different from gravity.</td></tr>
<tr><td colspan="2">Demonstration 1: Sticky Tape</td><td>10 min</td></tr>
<tr><td colspan="3">With students following along, place two pieces of tape on top of each other down on the table (it is helpful to create tabs- see powerpoint). Then, working in pairs, have students..
1. Bring two ‘B’ or top pieces near each other, observe interactions
2. Bring a top and bottom piece near each other, observe interactions
3. In pairs, have students summarize their observations and propose reasons why.</td></tr>
</table>

4. Have each pair check their observations and possible reasons why with another set of partners.	
Demonstration 2: Balloon	5 min
With students following along, ask students to make observations of how the balloon interacts with small pieces of paper (hole punches work well). Then, charge the balloon by rubbing it on your head or clothes. Observe the interactions with the paper, they should be attracted. Ask the students the following and structure their discussion in a turn and talk. (may be helpful to provide sentence starters for when students agree or disagree) - Were the pieces of paper originally charged? - Can a charged object attract a neutral object? Share out with whole class, then use this simulation to and ask- does this model agree with our answers? https://phet.colorado.edu/en/simulation/balloons-and-static-electricity Discuss how charged objects can attract neutral objects through polarization.	
Demonstration 3: Van de Graff Generator	10 min
First, explain how the Van de Graaf generator works. Demonstrate the basic properties of the Van de Graaf generator using a piece of fur or hair stuck on top, creating lightning sparks between the charged sphere and grounding sphere, and such. Throughout the demonstration, explain what is happening and ask students to ask questions and make predictions. For example, you may ask "Why are the sparks occurring father apart when the spheres are father apart?" Have students turn and talk to a partner, or submit answers through a digital means such as Padlet. Next, use the concept of electric potential to explain what happens when we touch the Van de Graff. Follow this demonstration: https://www.youtube.com/watch?v=ubZuSZYVBng&t=2s to explain how potential and current can explain why you can safely touch the generator. Invite students to come up and touch! If they are brave enough, you can even create a chain of students- have the last student in the chain point at the grounding sphere, and let all students feel it!	
Closing Activity: Exit Ticket Questions	2 min
At the end of the lesson, as an exit ticket, have students use sticky notes or a digital means to answer the following: 1. Define the electrostatic force, electric potential/voltage, and a current as best as you can. 2. Write down at least two questions you have about these demonstrations and concepts. Collect these and use to guide reteaching/reexplaining of these concepts.	

Lesson: Understanding Electric Potential

Lesson Title: Understanding Electric Potential		Duration: 60 minutes or 1 class period
Key Topics: • Electrical Potential Energy • Voltage • Electric Fields	NGSS Performance Expectations: • HS-PS2-4 Coulomb's Law • HS-PS3-5 Electric Fields	Learning Goals: • I can qualitatively describe the electric field around a charged object. • I can use the concept of electric potential to describe electric fields and circuits.

Lesson Summary: In this lesson, students will explore three different simulations to build a conceptual understanding of electrical potential.

Student Handout: Activity Understanding Electric Potential

Opening Activity: Problem of the Day	10 min

Teacher presents students with questions to access their prior knowledge.

1. Go to google and search "model of atom." Choose a model that shows the charged subatomic particles in atoms. Circle which one has to do with electricity.	1. Which of the following statements describes how charged particles interact? 1. Oppositely charged particles attract 2. Similar charged particles attract 3. Positive charges attract 4. Negative charges attract	1. How do masses move in Earth's gravitational field under the influence of the force of gravity? a. From high gravitational potential energy to low gravitational potential energy b. From low gravitational potential energy to high gravitational potential energy c. Depends on the mass d. They can move from high to low or low to high depending on what direction

Part 1: Electric Field Hockey	10 min

Students explore an electric field hockey simulation to get a qualitative idea of how charged particles exert force on each other, and draw conclusions about the relative strength of the force with varying charges and distances.

Part 2: Charges and Fields	15 min

Student's explore pHet Charges and Fields simulation and use the embedded tools to map lines of equipotential around the charges. Teacher provides examples of topographical maps to compare to the lines of equipotential, relating the voltage shown to electrical potential energy-similar to lines of equal gravitational potential energy.

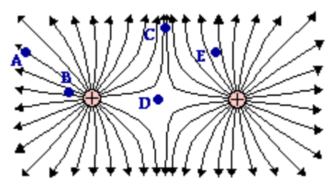
Part 3: Map that Circuit	15 min

Student's use physicsclassroom.com's electric potential concept builder to map the change in potential through a circuit.

Closing Activity: Connections	10 min
Collaboratively as a class, students will discuss and fill out a summary table (see on provided student handout) to summarize the key ideas from each simulation, and how the different simulations relate to one another.	

Lesson: MIT Circuit Challenge

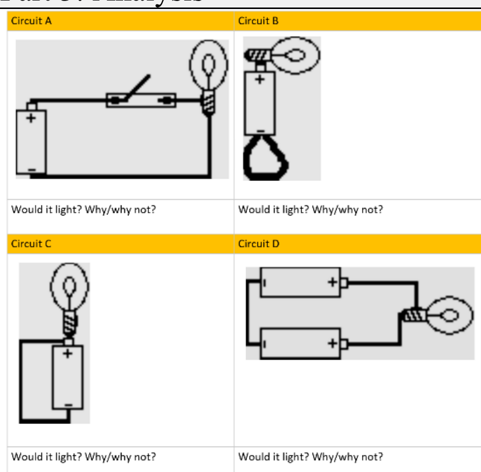
Lesson Title: MIT Circuit Challenge		Duration: 30 min
Key Topics: • Circuits • Switch • Voltage	NGSS Performance Expectations: • HS-PS3-5 Electric Fields	Learning Goals: • I can use the concept of electric potential to describe electric fields and circuits.
Lesson Summary: In this lesson, students will be challenged to light a bulb using only a battery and a wire. Through discussion, students will discover the basics of electric circuits- including closed vs. open circuits, switches, and current. Student Handout: [MIT Circuit Challenge]()		
Opening Activity: Problem of the Day		10 min

1. Which of the following correctly describes the electrostatic force on a positively charged particle approaching a negatively charged particle? 1. As the + particle gets closer, the force of attraction increases 2. As the + particle gets closer, the force of attraction decreases 3. As the + particle gets closer, the force of repulsion increases 4. As the + particle gets closer, the force of repulsion decreases	1. Which of the following is NOT true regarding electric potential? a. The space around negative charges has negative electrical potential b. The space around positive charges has positive electric potential c. As you travel farther from a charge, the magnitude of the electrical potential decreases d. All particles flow from high to low electric potential	1. Label the particle that is at the highest electrical potential and the one at the lowest electrical potential. 

Part 1: Video Primer	5 min
Teacher shows the first 2 min of the following video: https://www.youtube.com/watch?v=aIhk9eKOLzQ in which MIT graduates are presented with the challenge of lighting a bulb with a single battery and wire. Teacher then distributes materials.	

<table>
<tr><td>Part 2: Student Exploration</td><td>15 min</td></tr>
<tr><td colspan="2">Students are asked to light their bulb. Ideally working individually or in pairs, encourage students to try various set-ups. Often, one or two students will get it pretty quickly- while the majority take a while. Teacher needs to tell students not to show others once they get it to give all students an equal chance to process. For the students who accomplish quickly, tell them to find at least 2 other ways the bulb will light using different arrangements.

After about 5-10 min, teacher should provide a hint. A good one is "How can you force the electricity to travel through the bulb?" At this point, most students in the room can light their bulb- but it is important to wait until all students feel that success, so letting them peak at their peers is encouraged.

After most students have it, you can show the last minute to the video.</td></tr>
<tr><td>Part 3: Analysis</td><td>10 min</td></tr>
<tr><td>
</td><td>After all students have lit their bulb, they are presented with other possible arrangements such as those shown.
Students should predict and test whether each would light. After answering, challenge students to work in groups of 3-4 students to come up with a list of criteria that leads to a functioning circuit. Then, have each group share out. Ideally, they come up with a complete loop that goes from the positive to negative terminal, with the bulb a part of that loop- and this can be a part of the class discussion.</td></tr>
</table>

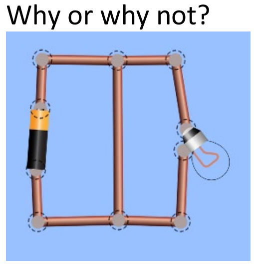
Lesson: Series and Parallel Circuits Lab

Lesson Title: Series and Parallel Circuits Lab		Duration: 60 minutes or 1 class period
Key Topics: • Series Circuits • Parallel Circuits	NGSS Performance Expectations: • HS-PS3-5 Electric Fields	Learning Goals: • I can compare and contrast the brightness of bulbs in series and parallel circuits • I can analyze data to conclude the structure of a circuit based on the behavior of the circuit elements. • I can relate the brightness of the bulb to the power by the current and voltage.

Lesson Summary: In this lab, which can be done using circuit kits or a circuit builder simulation, students will investigate how the number of bulbs/resistors, and type of connection (series or parallel) affect the power, or brightness, of the bulbs.

Student Handout: [Simulation Series and Parallel Circuits]

Opening Activity: Problem of the Day	10 min

1. Current will only flow in a ______ circuit. a. Open b. Closed	1. Will current flow through the light bulb in this circuit? Why or why not? 

Part 1: Ohm's Law	10 min

In this part, students use a simple circuit consisting of one battery, one bulb, and a switch to investigate the relationships between current, voltage, and resistance. If using a simulation, students can adjust this values. If using physical circuits, students can use different resistors or different batteries with a multimeter. Students collect data to graph voltage vs. current, determine that the slope is the resistance, thus deriving Ohm's law.

Part 2: Series Circuits	15 min

In this part of the lab, students create a series circuit with 1, 2, and 3 bulbs to see how adding bulbs affects the voltage across each bulb, current in the circuit, and brightness of the bulbs.

Part 3: Parallel Circuits	15 min

In this part of the lab, students create a parallel circuit with 1, 2, and 3 bulbs to see how adding bulbs affects the voltage across each bulb, current in the circuit, and brightness of the bulbs. They will also be comparing the parallel to the series circuit.

Closing Activity: Crack that Circuit Game	Will vary

As a challenge, students can explore combination circuits or apply their knowledge in the Crack that circuit game (https://universeandmore.com/crack-the-circuit/) where they use observations of bulbs and switches to infer the structure of the circuit hidden in fun game-like levels.

Lesson: Interactive Mini-Lecture Electricity

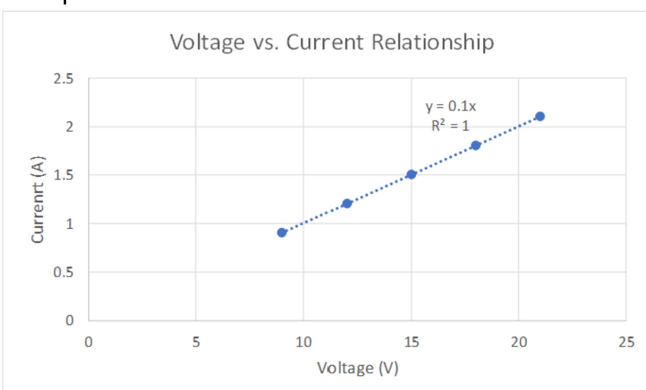
Lesson Title: Electricity Lecture		Duration: 60 minutes or 1 class period
Key Topics: • Current • Voltage • Resistance	NGSS Performance Expectations: • HS-PS3-5 Electric Fields	Learning Goals: • I can define voltage, current, and resistance as it applies to a circuit.

Lesson Summary: In this interactive lecture, students review the vocabulary of voltage, current, and resistance.

Teacher Slides: [Lecture Electricity]

Opening Activity: Problem of the Day

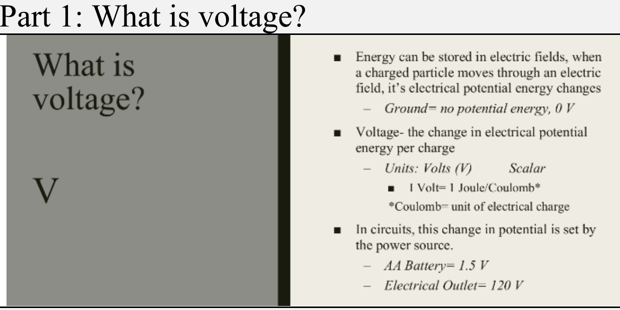
1. The graph below was collected from the simulation using a simple circuit with a 10-ohm bulb.



Use the graph to answer the following questions.

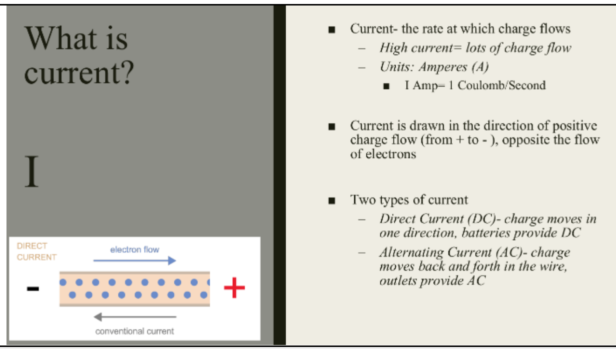
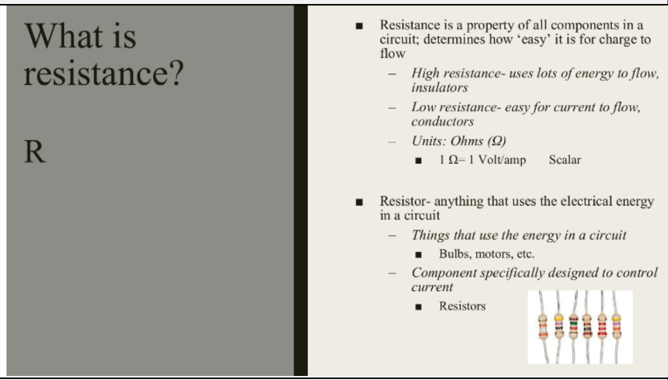
1. With constant resistance, as voltage increases, current….
2. Use unit analysis to see what the simplified units of the slope are.
   *You may need to check your electricity notes to see what the units are equal to
3. Based on your unit analysis, and looking at the numbers- what is the equation that relates voltage, current, and resistance?

Part 1: What is voltage?	7 min



When presenting this slide, remind students of the 'Understanding Electric Potential' activities- ask them how voltage was represented in those models. In addition, you can ask them to look on their own electronic devices to find voltage information.

Part 2: What is current?	7 min

	When presenting this information, it is helpful to explain to students why current and electron flow are not the same- demonstrating the history of science and how it evolves as our understanding grow. Also, this is a great time to preview the War of Currents, which they explore more in the PowerGrid activity.
Part 3: What is resistance?	5 min
	When sharing this slide, ask students to predict using thumbs up and thumbs down whether high resistance means higher current or lower current. You can also ask them why in parallel there is higher current in a turn and talk- then use the supermarket analogy (more lines open means faster flow) to explain.
Closing Activity: Exit Ticket	5 min
As the end of the lecture, have students define the three main terms in their own words as an exit ticket to summarize and help the definitions sink in.	

Lesson: PowerGrid WebQuest

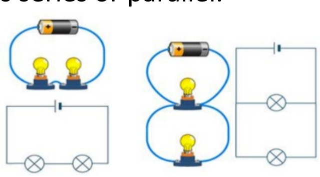
Lesson Title: PowerGrid WebQuest		Duration: 120 min or 1.5 class periods + homework
Key Topics: • The Power Grid • AC vs. DC Current	NGSS Performance Expectations: • HS-PS3-3 Energy Transformation • HS-ETS1-3 Engineering Problems	Learning Goals: • By the end of the lesson, students will be able to track our electricity from its generation, though distribution, transmission, and use.

Lesson Summary:
In this lesson, students will explore the various parts of the PowerGrid here in Northern America. They will start with an infographic introduction, followed by a research jigsaw where each student will dive deeper on a step in the grid. Then, they will read about the war of currents and the initial development of our power grid.

Student Handout: *Student Handout*
PowerPoint Presentation: Activity: Webquest The PowerGrid

Opening Activity: Problem of the Day	10 min

Assess students knowledge of circuits (the prior lesson).

1. Label the following circuits as series or parallel. 	1. In which circuit, series or parallel, will the lightbulbs be brightest? Why?	1. In which circuit, series or parallel, will the circuit 'break' if one bulb goes out? Why?

After going over the problem of the day, tell students we are going to look at the biggest circuit- the power grid.

Part 1: Introduction to the Grid	10 min

In part of this activity (see powerpoint presentation linked above) students will explore the following two links independently to gain an overview of the powergrid and fill out the top lines of their graphic organizer (see student handout linked above)

Part 2: Parts of Grid Research Jigsaw	30 min

Put your students in groups of 4. Assign each person in the group a particular part of the powergrid (generation, transmission, distribution, and end use). For their assigned part, there are two links each on the powerpoint presentation for students to read and explore.
5 min- introduce jigsaw
15 min- individual exploration
5 min- round robin share, having each student fill out the missing information from their group
5 min- whole class share out

Part 3: War of the Currents	20 min

For this last part, students will explore two websites to learn about how the powergrid was established. They will explore an infographic about Alternating current vs. Direct current, and compare the two.	
Closing Activity: Transformers in Your Home	5 min
As an extension, have students explore how energy is transformed on their own home level. Using an iphone ‘cube’ as an example, the input and output voltages are shown on the device. Have students try to find as many transformers in their home as they can!	

Lesson: Motors and Generators Lab

<table>
<tr><td colspan="2">Lesson Title: Motors and Generators Lab</td><td>Duration: 120 min, 2 class periods</td></tr>
<tr><td>Key Topics:
• Electromagnets
• Motors
• Generators
• Electromagnetism Induction</td><td>NGSS Performance Expectations:
• HS-PS2-5 Electromagnetic Induction</td><td>Learning Goals:
• By the end of the lab, students will be able to describe how both a motor and a generator rely on electromagnetism to work.</td></tr>
<tr><td colspan="3">Lesson Summary:
In this lesson, students will build an electromagnet and play with a motor and generator to discover how moving magnetic fields and create a current, and vice versa. The will start with a simple electromagnetic to see the connections between electricity and magnetism, then explore a simple motor and see how it uses electromagnetism to work, then see how a motor in reverse is a generator.

Student Guided Lab Handout: Lab/Simulation: Motors and Generators</td></tr>
<tr><td colspan="2">Opening Activity: Problem of the Day</td><td>10 min</td></tr>
<tr><td colspan="3">For their opening activity, ask students to list as many types of power plants as they can. (ie. Hydroelectric dams, windmills, etc.)
Explain that today, we are going to discover how the majority of these (all but Solar) actually create the electricity from the energy of the water, wind, etc.</td></tr>
<tr><td colspan="2">Part 1: Build an Electromagnet</td><td>20 min</td></tr>
<tr><td colspan="3">In this part, students will build an electromagnet from a nail and wire. Instructions and questions are provided above. Ideally, students are working individually but sitting in groups so they can discuss their observations.
As students are working through the handout, circulate. Ask students to explain “What, how, and why” What are they observing? How do they think that could be happening? Why is it working?
The key idea here is that students understand that electricity can create magnetism, starting to build that conceptual connection.</td></tr>
<tr><td colspan="2">Part 2: World’s Simplest Motor</td><td>20 min</td></tr>
<tr><td colspan="3">Using “World’s Simplest Motor” (Amazon Purchase Link) have students create a simple motor using a battery, holder, and wire coil.

At this point, students will need some brief direct instruction to figure out what is happening. Once all groups are exploring the motor, show this video to introduce how motors work. https://www.youtube.com/watch?v=CWulQ1ZSE3c At this point, you can also show them the inside of a hobby motor, where the coils and permanent magnets are clearly visible.</td></tr>
<tr><td colspan="2">Part 3: Generators</td><td>30 min</td></tr>
<tr><td colspan="3">Now students will use that same motor as a generator. By disconnecting the battery, and instead hooking up an ammeter, students can manually spin the coil and see current being</td></tr>
</table>

induced. At this point, the teacher can walk around with a stronger magnet to show how in a stronger magnetic field, more current is induced. After seeing that, students will explore a hand crank generator (Amazon Purchase Link). Direct students to look inside to see the coils, and give plenty of time to explore and answer the questions in the handout. During the exploration, teacher should be circulating the class- always asking for the what? How? And why?. In addition, if any student uses the generator in a creative way- for example, using one generator to power another, or to connect to a circuit/motor, ask students to hold that example.	
Closing Activity: Quickwrite	10 min
Bring students back together as a whole class. Have each group share out one thing they learned or observed. As a quickwrite, ask students “How is electricity generated?” to assess how much direct instruction they will need after this lesson.	

Lesson: Interactive Mini-Lecture Electromagnetism

Lesson Title: Electricity Lecture		Duration: 60 minutes or 1 class period
Key Topics: • Electromagnetic Induction • Motors • Generators	NGSS Performance Expectations: • HS-PS3-5 Electric Fields	Learning Goals: • I can define voltage, current, and resistance as it applies to a circuit.
Lesson Summary: In this interactive lecture, students review electromagnetic induction, motors, and generators Teacher Slides: [Lecture Electromagnetism]()		
Opening Activity: Problem of the Day		7 min
Access prior knowledge		

1. Which of the following describes an electromagnet? a. A magnetic field created by current b. An electric field created by magnets c. A magnetic field created by electrons d. An electric field created by current	1. Which of the following is NOT a part of a motor? a. Coils of wire b. Permanent magnets c. Axle d. A transformer	1. Alternating current… a. Consists of protons and electrons moving in wires b. Consists of electrons moving in one direction in a wire c. Consists of electrons moving back and forth in a wire d. Consists of protons moving in one direction in a wire.

Lecture	20 min
When going through the lecture, teacher presents demonstrations. These demonstrations can include electromagnetism demonstrations not used in the motors and generators activity- such as moving a magnet near a coil of wire to induce current; dropping a magnet down a copper pipe (Lenz's law), and a larger motor/generator. For each slide, before presenting the information- ask students what they remember from the lab in a timed pair-share. Use their responses to build the information on the slide.	
Closing Activity: Exit Ticket	5 min
As the end of the lecture, have students define the three main terms in their own words as an exit ticket to summarize and help the definitions sink in.	

Lesson: Cost of Electricity

<table>
<tr><td colspan="2">Lesson Title: Understanding Electric Potential</td><td>Duration: 60 minutes or 1 class period</td></tr>
<tr><td>Key Topics:
• Power</td><td>NGSS Performance Expectations:
• HS-ESS3-2 Cost Benefit Ratios</td><td>Learning Goals:
• I can calculate the cost of electric power.</td></tr>
<tr><td colspan="3">Lesson Summary: In this activity students learn to read an electric bill and calculate the cost of electricity. While this activity isn't specifically aligned to NGSS standards, it provides a real world application- showing students how this is connected to their lives while also connecting to some of the engineering and earth science standards.
When using the Texas power outage as an example, you can also bring up how during some outages the price of electricity skyrockets because demand is high and supply is low- which left some Texans with power bills in the thousands.
Student HandOut: Activity Cost of Electricity</td></tr>
<tr><td colspan="2">Opening Activity: Problem of the Day</td><td></td></tr>
<tr><td colspan="3">

1. Which of the following describes an electromagnet? a. A magnetic field created by current b. An electric field created by magnets c. A magnetic field created by electrons d. An electric field created by current	1. Which of the following is NOT a part of a motor? a. Coils of wire b. Permanent magnets c. Axle d. A transformer	1. Alternating current… a. Consists of protons and electrons moving in wires b. Consists of electrons moving in one direction in a wire c. Consists of electrons moving back and forth in a wire d. Consists of protons moving in one direction in a wire.

</td></tr>
<tr><td colspan="2">Part 1: Analyzing an Electric Bill</td><td>5 minj</td></tr>
<tr><td colspan="3">Students read an electric bill to find pertinent information such as electricity used, what units its in, etc.</td></tr>
<tr><td colspan="2">Part 2: Calculation Practice</td><td>15 min</td></tr>
<tr><td colspan="3">Students calculate the cost of a reading lamp, dishwasher, and more based on the kilowatt hours used.</td></tr>
<tr><td colspan="2">Closing Activity: Your own home</td><td>2 min</td></tr>
<tr><td colspan="3">As a homework assignment, you can encourage students to ask their families about their own electricity use- or even to see their own bill.</td></tr>
</table>

Culminating Project & Assessment

Culminating Project

At the end of the units, students will be choosing between two options for a research project

1) Energy Source Engineering Project
    a. Students build a model of a certain type of power plant (solar, wind, geothermal, tidal), and present their model along with research how long we've been using that type of energy, the efficiency of those power plants, pros and cons of that energy type, and statistics about its use locally and nationally.

2) Local Power Plant Research Project
    a. Students pick a local power plant to research. They present their research around the history of the facility, the amount of energy it produces, how it works, and how its been improved and changed since it was first built

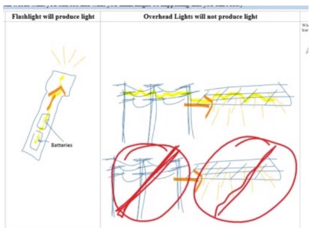
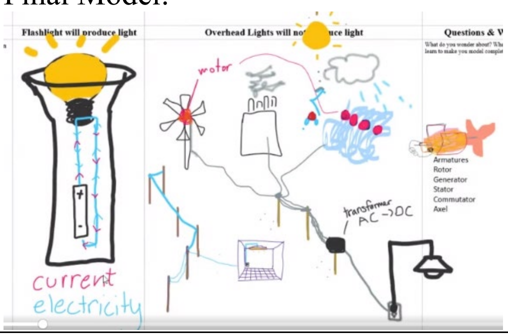
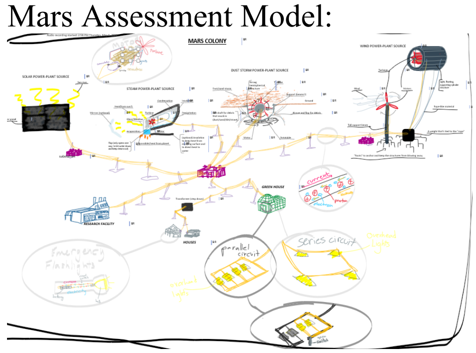
These projects will be presented and shared so students learn about the variety of types of power plants and get a general sense of the possible problems and benefits to each type of power.

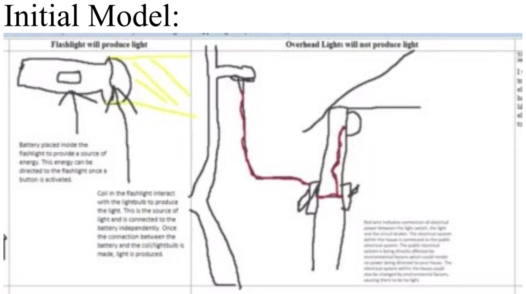
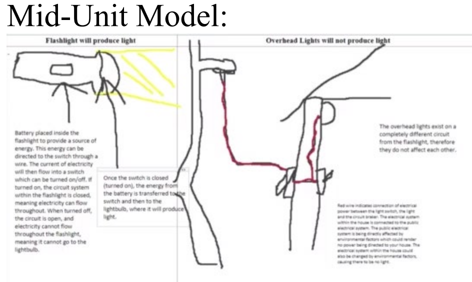
Final Assessment

In order to gather if students have understood the unit, we will ask them to apply their knowledge of our electrical system to a new problem- a colony on Mars. Students will be asked to create a model of a possible electrical system for Mars. In this open resource assessment, students must create a list of materials they would need to create an electrical system on Mars- from how they would generate the electricity, to safety measures needed, to the actual distribution process to the science facilities, living spaces, and common areas in this hypothetical colony.

Assessment Colony on Mars Model

Appendix A: Example Student Models

<table>
<tr><td>Initial Model:
</td><td>Mid-Unit Model:
</td></tr>
<tr><td>Final Model:
</td><td>Mars Assessment Model:
</td></tr>
<tr><td colspan="2">Analysis: This student, an English Language Learner, showed an amazing amount of growth in her conceptual knowledge and modeling skills throughout the unit. As you can see in her initial model, she had an understanding about batteries being a power source for a flashlight, and overhead lights using energy from the power lines, which can go down and cause an outage. In her mid-model, her scientific vocabulary grew to include voltage, current, potential, and parallel circuits, though there was still some confusion on how the large scale circuitry worked. One of the strengths of this example is how her initial ideas didn't disappear, but rather her model grew as she incorporated the new ideas- leading to an excellent assessment model.</td></tr>
</table>

<table>
<tr><td>Initial Model:
</td><td>Mid-Unit Model:
</td></tr>
<tr><td>Final Model:</td><td>Mars Assessment Model:</td></tr>
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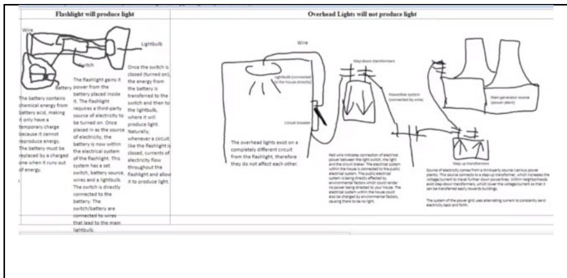
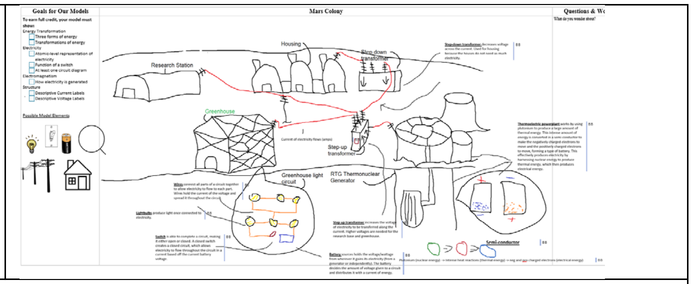
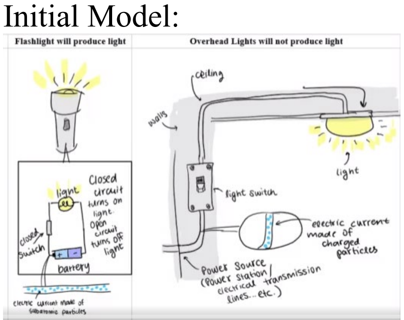


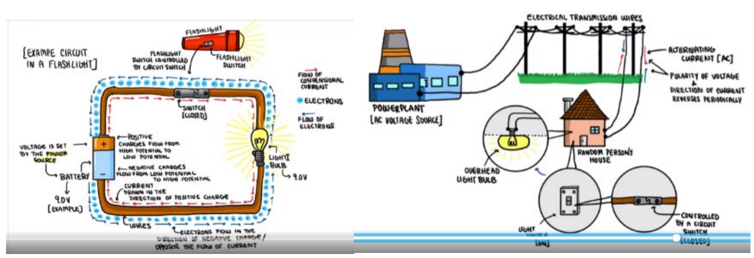


Analysis: This student, who is a student with an Individualized Educational Plan, chose to represent his knowledge primarily through writing- though by the assessment model, he did show growth in his modeling ability. This student initially had a pretty extensive vocabulary around electricity, as his father is an electrical engineer; he struggled to connect the concepts he knew about- such as a the circuit breaker- with the fundamentals we learn in class. However, this lead to rich discussions among his group, and you can see him adding in paragraphs about the function of a switch, battery, and transformers as his model progressed.

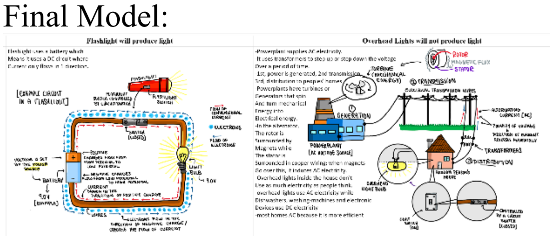
Initial Model:



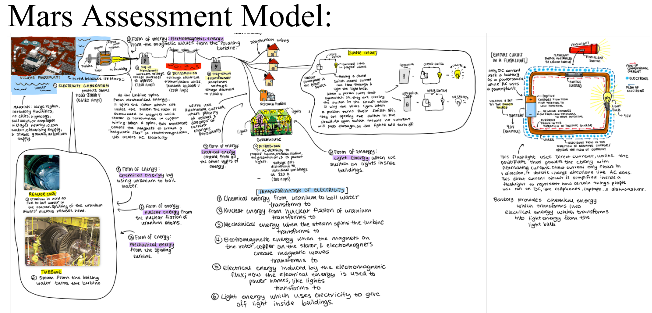
Mid-Unit Model:



Final Model:



Mars Assessment Model:



Analysis:

This student, a freshman in a class of mostly juniors and seniors, showcased exceptional modeling skills and artistic ability- definitely a standout model in the class. As you can see, she had some initial understanding of circuits, but by the mid-unit model her understanding grew to include terms and concepts such as current, voltage, and electron flow. For the overhead lights/power grid part of the model, with each iteration her model grew- initially branching to include the powerplant and transmission lines, and then electromagnetism concepts and types of current by the final. In addition, in her Mars Assessment model, she did an excellent job of color coding her concepts to show relationships and energy transformations.

*for more examples, see Student Models