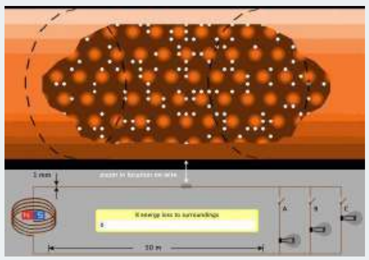
Lesson 6: How does energy transfer in wires?

Previous Lesson *We used diagrams of power plants to figure out how they transfer energy into wires, which made us wonder what is happening inside generators. We dissected a generator, then built our own, and used compasses to investigate fields. Lastly, we modeled energy transfer through fields inside our generators, and made connections between matter and energy to refer to as we move forward.*

This Lesson

Investigation

3 days


Data Source: Concord Consortium

We read about fields to help us model energy transfer more closely, focusing on transfers inside a wire. Using a simulation, we explore how characteristics of an electrical system could influence the transfer of electrical energy, and check our results using classroom equipment. We then refine our Engineering Design Trackers with ideas from the simulation.

Next Lesson *We will develop a model showing how insufficient supply entering the electrical system could lead to buildings losing power during a crisis. We will test our models using Electric City, and we will notice that to keep the lights on in one building, we need to cut power to others. We will use data to test for correlations with county-level factors, and we will consider limitations on this analysis.*

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-5, HS-ESS3-2, HS-ETS1-3, HS-ETS1-4

What students will do

6.A Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; CCC: 2.2; DCI: PS3.A.3)

6.B Use a simulation to model electron flow inside a wire in order to identify patterns, answer questions, and determine relationships between independent and dependent variables involving electrical energy transfer that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; CCC: 1.3; DCI: PS3.A.4)

Transfer Task 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. (SEP: 2.3, 6.5; CCC: 5.2; DCI: PS3.A.2, PS3.A.3, PS3.D.1)

What students will figure out

- Electric and magnetic fields change when energy transfers into or out of them.
- Electric fields can push electrons. “Electrical energy” is the energy of the movement of electrons transferring through pushes from fields.
- A turbine transfers energy through electric and magnetic fields to the electrons in a wire, causing them to slosh back and forth continuously.
- Electrons cause the atoms of the wire material to heat up, transferring energy from the system to the surroundings as “heat”.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Navigate into the lesson by connecting to the Lesson 5 exit ticket.	A	*Changing Fields*
2	15 min		**DO A CLOSE READING ABOUT FIELDS** Have the class read a summary of how electric and magnetic fields affect particle motion inside a wire. Guide them to identify and define important words, then identify evidence and answer two questions.	B-C	*Changing Fields*
3	12 min		**MODEL ENERGY TRANSFER IN THE FIELDS READING** Have partners choose a passage from the reading and model it using energy transfer diagrams. Give each pair a rubric to evaluate another pair's model and revise their own.	D-E	8.5 x 11 paper, *Changing Fields*, *Rubric for Modeling*
4	5 min		**MODEL THE TRANSFER OF MATTER INSIDE A WIRE** Have partners sketch a model that reflects how matter transfers inside a wire.	F	8.5 x 11 paper, *Changing Fields*
5	5 min		**IDENTIFY MODEL LIMITATIONS AND NEW QUESTIONS** Have students and partners mark limitations in their new models and write down any new questions.	G	8.5 x 11 paper
6	5 min		**NAVIGATE: ASSIGN HOME LEARNING** Give a home learning assignment that compares two models of electrons to prepare students for the simulation investigation in the next class period.	H	*Models of Electrons*

End of day 1

Part	Duration		Summary	Slide	Materials
7	3 min		**NAVIGATE** Discuss two questions that lead the class toward closer investigation of what is happening inside a wire when it's connected to an energy source.	I-J	*Models of Electrons*
8	10 min		**INTRODUCE THE COMPUTER SIMULATION** Use the handout to introduce the simulation and discuss the variables that can be manipulated or measured, as well as the causes and consequences of energy loss in the system. Demonstrate real-life energy loss and current measurement.	K-L	Inside Wire Simulation Investigations

9	12 min		**CONDUCT AN INVESTIGATION USING THE SIMULATION** Have students follow the handout to choose independent and dependent variables, investigate them using the simulation, and record conclusions about the relationships uncovered.	M	Inside Wire Simulation Investigations
10	5 min		**SHARE CONCLUSIONS** Have the groups share conclusions from their wire simulation investigations.	N	chart paper for Wire Sim Results poster, markers
11	10 min		**CARRY OUT REAL-LIFE EXPERIMENTS** Conduct simple classroom experiments to demonstrate that the results of the computer simulation match up with real-world results.	O	Real-Life Wire Investigations
12	5 min		**NAVIGATE: EXIT TICKET** Complete an exit ticket to connect the results of our investigations to larger themes.	P	8.5 x 11 paper, Wire Sim Results poster
					End of day 2
13	3 min		**NAVIGATE** Navigate by connecting the results of our investigations to our larger work.	Q	Wire Sim Results poster
14	8 min		**FILL IN THE ENGINEERING DESIGN TRACKER** Add to the *Engineering Design Tracker* to include the main ideas on the Wire Sim Results poster.	R	*Engineering Design Tracker* (from Lesson 3), Wire Sim Results poster
15	30 min		**ASSIGN THE MOTOR TRANSFER TASK** Introduce the assessment context and review assessment resources.	S-T	*Motors Transfer Task*, hand-crank DC generator, 1.5 volt D battery, alligator clips
16	2 min		**REVISIT "MOVING OUR SCIENCE THINKING FORWARD"** Reflect on what we have done to move our science thinking forward since the beginning of the unit.	U	Community Agreements: Moving our science thinking forward
17	2 min		**NAVIGATE: EXIT TICKET** Complete an exit ticket to consider whether it's time to put the pieces together to explain how insufficient supply affected communities in Texas.	V	8.5 x 11 paper
					End of day 3

Lesson 6 • Materials List

	per student	per group	per class
Inside Wire Simulation Investigations materials	• *Wire Simulation Investigation*	• computer	• 1.5 volt D battery • coil of wire with the ends sanded • tape • ammeter • sandpaper
Real-Life Wire Investigations materials			• 1.5 volt D battery • power strip • ammeter • alligator clips • incandescent light bulbs • hot plate OR cup of ice • wire of various lengths (like the tubes with wrapped wire from the homemade generators in Lesson 5) OR extra alligator clips
Lesson materials	• science notebook • *Changing Fields* • 8.5 x 11 paper • *Models of Electrons* • *Engineering Design Tracker* (from Lesson 3) • *Motors Transfer Task*	• 8.5 x 11 paper • *Changing Fields* • *Rubric for Modeling*	• chart paper for Wire Sim Results poster • markers • Wire Sim Results poster • hand-crank DC generator • 1.5 volt D battery • alligator clips • Community Agreements: Moving our science thinking forward

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Prepare a piece of chart paper for the Wire Sim Results poster students will make on day 2.

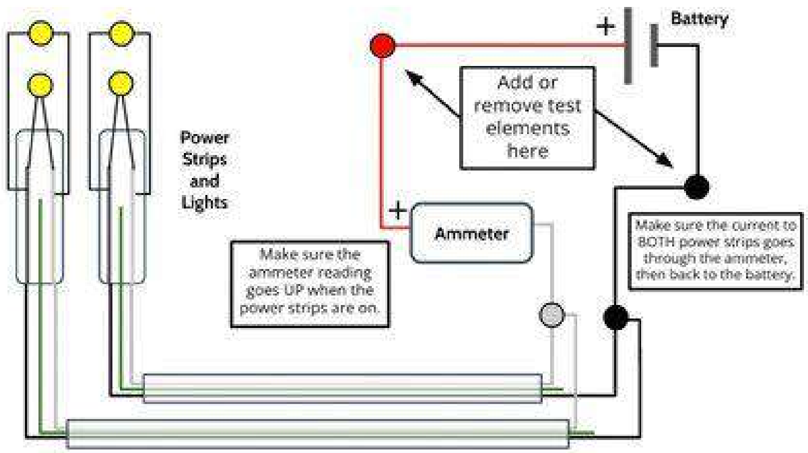
Test this simulation link for the lesson: https://www.openscied.org/general/acdc/

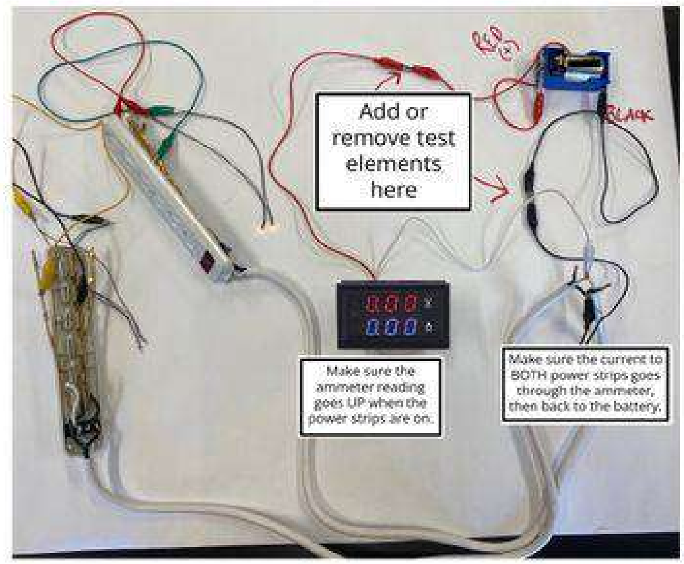
Battery and Wire Demonstration (day 2):

- 1.5 volt D battery
- coil of wire with the ends sanded
- tape

Real-Life Wire Investigations (day 2): Set up these materials as described in *Real-Life Investigations Prep*

- digital ammeter
- alligator clips
- wire of various lengths (like the tubes with wrapped wire from the homemade generators in Lesson 5) OR extra alligator clips
- hot plate and mug of water OR mug of ice





If you have an ammeter or a good-quality multimeter, you can use it in these investigations. Otherwise, refer to *Ammeter Construction Directions* for instructions on how to build your own. The video https://www.youtube.com/watch?v=F_vvuk_GjlU&list=PLSLDxqPb5NQmKp9RwUjcib82h4QO6x4G_&index=9 also shows how to build a digital ammeter.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

In previous lessons, students have explored at a macroscopic level how electrical energy is generated and how it transfers within a system. In this lesson, they shift focus to energy transfer at the level of particles and fields, using readings and a simulation. In particular, they generate data to explore factors that affect energy loss and/or current through a wire, and connect their conclusions to what happened in Texas in 2021. Thus, this lesson contributes to students' understanding that the scale at which a problem is investigated can help us identify additional causes of the problem.

In the reading, students model energy transfer involving fields, and then they incorporate the concepts of energy transfer involving changing fields into their larger energy model. In the simulation, students see firsthand how "electrical energy" connects to the motion of electrons in a wire, and how the temperature of a material connects to the motion of the atoms of that material.

In the optional *Algebra in Circuits* (and accompanying optional **slide W**), students get more firsthand experience with concepts of voltage and an algebraic relationship related to circuits, such as Ohm's Law and an operational definition of resistance.

Students encounter or co-develop definitions for the following words in this lesson: *electron, current, field*. **Do not** post any words on the Word Wall until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Similar to previous lessons, we intentionally avoid using the term "forces", as students can use the vocabulary of "pushes" and "pulls" to explain how energy transfers.

Unless they complete the extension, most students will not be solving equations that involve voltage or current, as the focus is on the core concepts of energy transfer and energy loss. The materials included here were designed to help students understand voltage, current, and power at a conceptual level. Students do not practice algebraic relationships involving resistance or make calculations involving parallel circuits.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

3 min

MATERIALS: science notebook, *Changing Fields*

Connect to the Lesson 5 exit ticket. Present **slide A**. Ask 2-3 students to share their ideas about the first prompt: *Why do many power plants need to get something spinning in order to transfer electrical energy to the wires?* Listen for suggestions that the movement can change the magnetic fields, which somehow influences the electricity.

Say, *What parts of our generator energy model support this idea? What don't we understand yet?* Listen for students to say that the only energy transfer "at a distance" was between the magnets and the coil, and that we saw the compasses changing, so we know the field was changing. If students have more questions than answers, that's OK.

Introduce the reading. Say, *There's still a lot we don't understand about what's happening in the wires, or how the fields make energy transfer without touching possible. I have a reading with details about fields and wires that I think will clear up some of our questions.* Distribute *Changing Fields* to each student.

2 · DO A CLOSE READING ABOUT FIELDS

15 min

MATERIALS: *Changing Fields*

Explain and begin the close reading. Present **slide B**. Say, *This reading has a lot of important ideas in it, but it's also very dense, so it can be hard to understand everything at first. We're going to do a "close reading," which means we will read through it several times, each time with a different goal. This first time, our goal is to circle words that seem very important, whether they are familiar or unfamiliar. After we read through the first page, we will decide which words we can already define, and which words we have more questions about.*

Have all students follow along with reading the first page while students take turns reading it aloud. You can call on students randomly ✱, or ask them to call on each other every few sentences (sometimes referred to as "popcorn"). Then, ask students what they circled. Expect them to identify words that appear frequently (magnetic field, electric field) as well as important words that may be less familiar (particle, electron, nucleus, electric current). Encourage students to use context clues to come up with our own definitions of some of these terms, as shown in the table below.

✱ ATTENDING TO EQUITY

Use explicit strategies to keep students engaged while reading: Use a strategy for calling on students to read that will keep all students engaged. For example, you can write students' names on tongue depressors or popsicle sticks, and pick a name stick randomly to choose the next person to read a few sentences.

Suggested prompt	Sample student response
What is one word that we can already define?	Field.
How would you define the word "field" as it's used in this reading?	A magnetic field is something that can make a compass change direction, but we didn't talk about electric fields.
How does the reading refer to electric fields? What does it say these fields do?	It says, "Electric fields push charged particles", so I guess that could be our definition.
What is another word that seems important?	"Electron", but we haven't talked about those.
Can we use context clues from the reading to figure out what an electron is?	It says that atoms have electrons in them, which are negatively charged, and when they flow together they make an electric current.
How can we put those ideas together?	Electrons are negatively charged particles in atoms that can flow together in an electric current.

Reread page 1, identifying evidence and answering questions. Present **slide C**. Say, *Now read the same page again, but this time, underline any evidence that connects to things we've seen in class. Then, answer the slide's two questions, writing in the margins of your reading.*

Circulate around the room and positively narrate what you see in students' work. For example, say, *I see (name) underlining evidence that connects to what we've seen. I see (name) answering the first question in the margin.*

Read page 2, identifying evidence. After 2-4 minutes, say, *If you feel done with the first page and the questions, move on to read page 2. Page 2 is a little more advanced, but it still connects to things we've seen in class, so you can keep underlining useful evidence.*

Share answers to the two questions. Look for most or all students to have underlined some passages and answered both questions. Ask a few of those students to share quick answers to both questions, as follows:

- *What happens when a magnetic field changes?* It causes a change in the electric field.
- *How does this affect charged particles in a wire?* Electric fields can push charged particles, so this can cause electrons to flow.

3 · MODEL ENERGY TRANSFER IN THE FIELDS READING

12 min

MATERIALS: 8.5 x 11 paper, *Changing Fields*, *Rubric for Modeling*

Choose a bolded passage in partners, then model it on a blank sheet of paper. Show **slide D**. The choices on page 1 are called "medium"; those on page 2 are slightly tougher, so they're called "spicy". Ask students to find a partner; distribute a blank sheet of paper to each pair.

Give students 1 minute to choose a passage, then show **slide E**. Remind them of the conventions we've used for energy transfer models, and tell them their models should relate to fields in some way, so "field" should be a component in their diagrams.

Circulate around the room and look at students' work to ensure that they are practicing our diagram conventions. Arrows should not be used to "point things out"; instead, arrows should show energy transfer from one component to another. Students can label an arrow pointing into a field component as "change", to show that changing the field transfers energy into that field.

Use a rubric to evaluate another pair's model. When a pair of students finishes their model, ask them to trade work with another pair whose model is finished. Give each pair a copy of *Rubric for Modeling* and instruct them to use it to evaluate the other pair's work. When both pairs have gone through the rubric, they should talk through and revise their own models, then prepare to hand them in at the end of class.

Add to Progress Trackers. Before collecting students' models, ask students to copy them over the model into their Progress Trackers.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Fields store and transfer energy. In their energy transfer diagram, students should label energy transfer arrows into a field with the word "change" or the like. Energy transfer arrows from a field to a particle (electron) should be labeled "push" or the like. (DCI: PS3.A.3)
- Students should connect passages from the reading to evidence from class or personal experience, including: electrical energy transfers in wires, changing magnetic fields can generate electricity, a buildup of electrical energy can cause a spark, and so forth. We can incorporate information from the reading with our own evidence to model energy transfer in wires. (SEP: 8.2; DCI: PS3.A.3)
- Students can use particle-scale mechanisms for interactions between particles and fields to identify cause-effect relationships for larger systems like a wire, and explain evidence of energy transfer we've seen in class, such as compasses moving and wires heating up. (CCC: 2.2; DCI: PS3.A.3)

What to do: If students are deeply struggling as they attempt to model passages from the reading, try to coach them with useful ideas. For example, say, *What does the reading say is happening to the field? What action word does the reading use?* If their models don't make perfect sense, that's OK, as some confusion will be cleared up in the partner conversation while using the rubric. However, it will be helpful to ensure that all students have clearly labeled the passage they are modeling.

If students are ready, encourage them to try modeling a "spicy" bold passage from page 2 of the reading.

Building toward: 6.A.1 Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; CCC: 2.2; DCI: PS3.A.3)

4 · MODEL THE TRANSFER OF MATTER INSIDE A WIRE

5 min

MATERIALS: 8.5 x 11 paper, *Changing Fields*

Model what is happening in a wire. Say, *Scientists often use multiple models to understand a phenomenon through multiple lenses. Our energy transfer models tell us a lot about where the energy comes from and where it goes. But we still have a lot of questions about how that energy transfer is happening inside the wire. How is matter changing to make energy transfer possible?*

Present **slide F**. Read the prompts on the slide aloud:

- *Imagine you could zoom into the wire to "see" what is happening inside of it when it is connected to a generator.*
- *What do we think happens to the matter in the wire that could explain how fields cause energy transfer?*
- *On the back of your partner model from the reading, draw a model that shows matter changes that you might "see" inside a wire as energy transfers.*

Give students 3-4 minutes to sketch a model on the back of their previous model of what is going on in a wire as energy transfers into it and through it. These models will help to identify shared understandings and gaps that create the need to explore, at a different scale, how electrical energy transfers within a system.

5 · IDENTIFY MODEL LIMITATIONS AND NEW QUESTIONS

5 min

MATERIALS: 8.5 x 11 paper

Stop and jot about model limitations and new questions. Show **slide G**. Ask students (still in partners) to draw question marks near the parts of their model where they would like to know more or where they think the model has limitations. Then ask them to write down any new questions that the new model raised for them and their partner about what is happening inside the wire.

Have partners write both names on their sheet with the two models and the questions so you can collect it as an exit ticket at the end of class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Look for students to integrate ideas from the reading into their responses, for example: (SEP: 8.2)

- Fields are invisible. It's possible to represent them visually in a model, but students may choose to leave them out. (DCI: PS3.A.3)
- Particles such as electrons are too tiny to be seen with light, but they can still be modeled visually. Students' models should show some cause-effect mechanism for why a wire transferring electrical energy is different from a wire that is not transferring energy. (CCC: 2.2; DCI: PS3.A.3)
- Particle-scale mechanisms for interactions between particles and fields can be used to identify cause-effect relationships for larger systems like a wire, and to explain evidence of energy transfer we've seen in class, such as compasses moving and wires heating up. (CCC: 2.2; DCI: PS3.A.3)

What to do: Don't spend too much time or effort coaching students on their model; instead, use it as a formative assessment to check their understanding of particle interactions. If students are not used to thinking at a particle scale, you will see this in their drawing. In that case, it may be important to spend more time on this concept at the beginning of the next class period.

- The reading contains many clues that can be used to visualize what is happening inside a wire. Encourage students to refer to phrases in the reading as a reference when making their model, such as:
    - Pg 1. "Atoms have a positively charged *nucleus* in the center and negatively charged particles called *electrons* at certain distances out from that center."
    - Pg 1. "In copper atoms, the pull on the outer electrons is pretty weak, and electrons can pass from atom to atom. This means that electrons can move through copper wherever they are pushed. Electric fields push charged particles, so changing the electric field inside a copper wire can cause a flow of electrons."
    - Pg 2. "If nearby electrons have a place to go (like the ground or the other end of a battery),

they will flow in the direction they are pushed."

- Pg 2. "These electrons collide with copper particles as they move, causing those copper particles to move faster. We feel these faster atoms as an increase in temperature."

Note: These passages are not all the same as the bold passages that students used in their previous modeling exercise. These passages connect to matter, while the other passages connect to energy. (Some passages connect to both matter and energy.)

Building toward: 6.A.2 Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about the motions of particles or the energy stored in fields. (SEP: 8.2; CCC: 2.2; DCI: PS3.A.3)

6 · NAVIGATE: ASSIGN HOME LEARNING

5 min

MATERIALS: *Models of Electrons*

Introduce the home learning. Present **slide H.** Distribute *Models of Electrons*. Students should use the reading to guide them through evaluating two models of electrons, using evidence we have collected in class and in the reading *Changing Fields*. Say, *This home learning will set us up to go deeper with our modeling of what is happening inside wires. This will give us more clues for how to think about what happened with energy transfer during the Texas blackouts.*

Collect the exit ticket as students leave class.

End of day 1

7 · NAVIGATE

3 min

MATERIALS: *Models of Electrons*

Turn and talk. Present **slide I** and have students turn and talk about the first two questions. They should have questions about how matter transfers inside the wire, and how this contributes to energy transfer. They should note that the home learning discussed the smallest particles of matter, and that because we can't see these particles directly, we need to model how they might behave to see whether the predictions match our evidence.

Share out briefly about connections to Texas. Keeping in mind that you want to leave plenty of time to work with the simulation, ask 1-2 pairs to share out around the third question on the slide. Students may suggest that electrical current froze, like water in a pipe freezes, or that voltage could have somehow dropped, or that the current stopped flowing. Accept all ideas.

Navigate to using a computer simulation. Show **slide J**. Read the first part of the slide aloud, then elicit responses to the prompts. Say, *What variables would we want to manipulate in a computer simulation to help answer some of our questions? What would we want to see?* Accept all responses, but listen for students to mention that the particles in a wire are too small to see, and that a simulation allows us to change things and immediately see how that affects the factors we're interested in.

8 · INTRODUCE THE COMPUTER SIMULATION

10 min

MATERIALS: Inside Wire Simulation Investigations

Orient to the simulation, answering handout questions Questions 1-3. Show **slide K**. Arrange students into partners and distribute *Wire Simulation Investigation* to each student. Point out that the image on the screen will help them see which part of the simulation to focus on for each question on the handout. Ask them to begin the simulation by clicking "Setup" and "Go/Pause".

Circulate around the room as students think through and answer Questions 1-3. Students should make a connection between the speed of the electrons and the measurement on the ammeter showing "current" through the wire in mA. Check for understanding verbally by asking, *What factors about the wire seem to connect to the number on the ammeter near the battery?*

Discuss connections between the simulation and a real wire. Once most students have completed Questions 1-3, draw the class's attention to **slide L**. First, quickly review what the measurements in the simulation actually mean. Say, *What does the "energy loss to the surroundings" percentage tell us? What do the "ammeters" measure?* Probe students until it's clear that class has a clear understanding of these ideas.

Listen for suggestions such as:

- Energy loss to the surroundings is how energy doesn't go to the light.
- Energy loss to the surroundings tells us how much heat is lost.
- The ammeter measures how much electricity is in the wire.
- The ammeter measures how fast the electrons are moving.

Say, *We know this simulation is a model, and a model is only useful if its predictions actually match results in real life. What evidence could help us figure out whether these mechanisms in the simulation are true in the real world?*

Listen for suggestions such as:

- We could connect a real ammeter in the same way it's connected in the sim, and see how it behaves.
- We could connect a wire to a battery and see whether it heats up. This would mean it's losing energy.

Demonstrate energy loss through a wire. Temporarily tape the sanded ends of a coil of wire to a 1.5 volt D battery and invite a volunteer to come up and feel it, or carry it around the classroom so everyone can feel the wire heat up. If the wire gets too hot, disconnect it.

SAFETY PRECAUTIONS	The wire should heat up very quickly. Allow students to feel the wire, but do not pass it around without supervision, as it could get hot enough to burn someone or even light something on fire.

Suggest doing similar investigations with real equipment later in class to check the conclusions students reach. Point out that you have a real ammeter in the room, and suggest that the class check the conclusions they reach with real equipment later in class. Say, *For now, use the simulation to reach what conclusions you can. Then we'll check those conclusions with a real ammeter and real wire.*

9 · CONDUCT AN INVESTIGATION USING THE SIMULATION

12 min

MATERIALS: Inside Wire Simulation Investigations

Select independent and dependent variables to investigate. Show **slide M** and instruct students that their next task is to carry out an investigation in the simulation. Say, *Now that we're pretty convinced that the simulation model makes valid predictions, let's use it to answer some of our deeper questions with a proper scientific investigation. Choose an independent variable and a dependent variable that could help us learn more about what happened in Texas, or about how to reengineer and improve our electric grid.* Instruct them to follow Questions 4-5 on the handout to select and record their group's variables. ✱ ✱

State a research question and investigate it with the simulation. Tell students to work through Questions 6-11 to identify a research question, and then conduct an investigation to answer this question. ✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Help students (1) recognize the cause-effect relationship between changing the characteristics of the wire (cause) and the percentage of energy loss of the system

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:**
	• Use *Simulation Investigation Key* as guidance.
	• Question 4: Good dependent variables are electric current (measured by the ammeter) or % energy loss to surroundings. (DCI: PS3.A.4)
	• Question 5: Good independent variables are wire length, wire width, temperature.
	• Question 6: Research questions should include the IV and DV from Question 5 and 4. (SEP: 1.3)
	• Question 8: Likely results:
	    • Increasing the wire length and/or decreasing the wire width results in less energy transfer and more energy loss.
	    • Lower wire temperatures result in slightly more energy transfer and slightly less energy loss, but the effect is small. (SEP: 1.3; DCI: PS3.A.4)
	
	What to do: Students will have different levels of familiarity with independent, dependent, and controlled variables. As you circulate among the tables, look at answers to Q4-Q6. If groups have moved on to Q7 before you've seen their research question, ask to see it to confirm that it is valid.
	
	If students haven't chosen electric current (measured by the ammeter) or % energy loss to surroundings for Q4, say, *The dependent variable should be something that could depend on another variable. What is a value that the simulation calculates that you can't simply choose a value for yourself?* (SEP: 1.3)
	
	If students haven't chosen wire length, wire width, or temperature for Q5, say, *The independent variable should be something that you choose, and that you can change directly. What is something in the simulation that you can choose to change?* (SEP: 1.3)
	
	If students obtain a result that doesn't seem right, ask them which variables they held constant as controlled variables (Q7). Ask them to show you one example of how they collected data, and look for inconsistencies with their research question that could explain their odd result. (SEP: 1.3)
	
	Building toward: 6.B.1 Use a simulation to model electron flow inside a wire in order to identify patterns, answer questions, and determine relationships between independent and dependent variables involving electrical energy transfer that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; CCC: 1.3: DCI: PS3.A.4)

(effect) and (2) consider the mechanisms at the particle level that explain this.

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

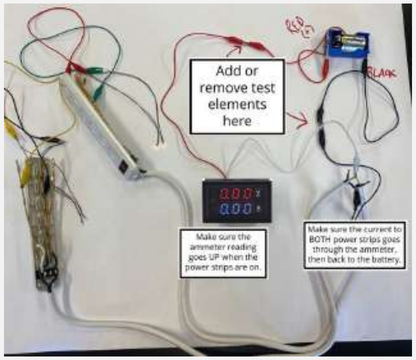
If students select variables that can't be measured quantitatively, coach them toward different variables. An experiment involving non-quantitative variables (such as wire material) can be valid, but it's more challenging to see a pattern. Contrast "As wire length/width increases..." against "As wire material increases..." Without numbers we can't identify a relationship.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Students may notice that the wire's temperature doesn't increase as energy lost to surroundings increases. Acknowledge this, and say, *Like all models, this model has limitations. I recommend that we use the values given in the simulation for now - we can check it with real wires later to see if the computer model holds up.*

Look at students' answers to Question 9, and prepare to demonstrate real-life experiments. As groups complete their investigations, some will have ideas about Question 9. You will have already prepared some equipment that will allow your class to investigate these same relationships with real equipment. If students struggle to come up with ideas for experiments, remind them of the ammeter that you pointed out earlier. Ask, *How could we use our real ammeter to investigate a relationship that's similar to what you looked at in the simulation? If current measured by this ammeter is a dependent variable, what could we choose to change as our independent variable?*

Due to the limited time allotted, set up the materials in advance so the maximum time possible is spent carrying out experiments rather than troubleshooting connections. See *Real-Life Investigations Prep* for details on how to prepare the demonstration.



Notice that the setup allows turning at least two circuits on and off, as well as adding or removing test elements as independent variables. (see activity 11 - CARRY OUT REAL-LIFE EXPERIMENTS)

10 · SHARE CONCLUSIONS

5 min

MATERIALS: chart paper for Wire Sim Results poster, markers

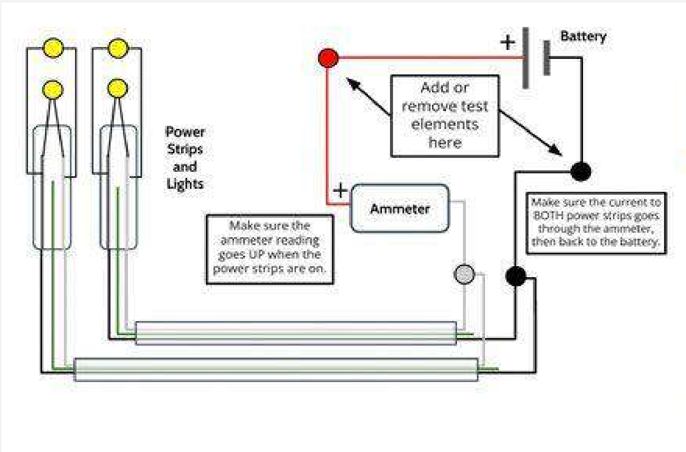
Create a public record of results. Present **slide N** and prepare a piece of chart paper as shown on the slide. As students complete their handouts, direct a representative from each group to the chart paper to write their response to Q8. Groups who worked more quickly likely made more progress with Q11 and could have uncovered relationships that no one else saw. Where possible, encourage groups who uncovered a unique result to share that result on the chart paper, to avoid redundancy. This has the added benefit of ensuring that even the groups who worked more slowly will feel that their contributions are valued.

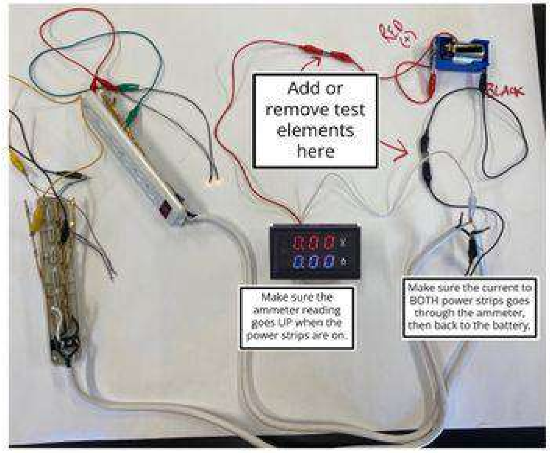
11 · CARRY OUT REAL-LIFE EXPERIMENTS

10 min

MATERIALS: Real-Life Wire Investigations

Demonstrate conclusions with real equipment. As mentioned above, due to the limited time allotted, you will want to set up the materials in advance so the maximum time possible is spent carrying out experiments rather than troubleshooting connections. A successful demonstration will clarify that the conclusions reached in the simulation connect to the real world. See *Real-Life Investigations Prep* for details on how to prepare the demonstration.





Notice that the setup allows turning at least two circuits on and off, to see the effect on the total current through the battery. Before adding or removing test elements as independent variables, point out the effect that turning on more bulbs has on the total current measured by the ammeter.

Follow students' lead--prioritize experiments they suggest themselves.

Carry out experiments using real equipment to verify simulation results. Display **slide O**. As you discuss the results of your class's real-life experiments, ask questions to help students make connections to the particle models they made on the previous day.

To show the effect of wire length on current, use two coils of wire from the generator experiment with different numbers of wire wraps (100 and 400, for example). Students will see the current decrease for longer wires.

To show the effect of temperature, use a coil of wire on a hot plate, or another source of heat or cold available in your classroom, such as a cup of ice. Though students may have concluded that "*As wire temperature increases, electric current decreases*" in the simulation, this effect is tiny in real life. Guide students to the understanding that tiny changes are usually less important than obvious ones.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** ● Flipping a switch on the power strip changes the electric field inside the wire. Electrons move inside

the wire, pushed by the electric field. This causes energy to transfer to devices like the light bulb. (CCC: 2.2: DCI: PS3.A.3)

- Electrons collide with atoms of the wire, which causes the wire to heat up. (CCC: 2.2: DCI: PS3.A.3)
- A longer wire means more particle collisions with wire atoms, which means more energy loss. (DCI: PS3.A.3)
- Changing the temperature of the wire atoms doesn't change current much, because the electrons are only loosely attracted to those atoms. (DCI: PS3.A.3)

What to do: Whenever you uncover a result with these real-life experiments, take the opportunity to connect it to the particle-scale model students made the previous day, and the energy transfer models of passages from *Rubric for Modeling*. (SEP: 8.2) The simulation visuals should have made some things clearer, and this whole-class conversation is a chance to check those connections.

If students have trouble articulating how these results connect to the particle model, ask questions to connect to particles in the simulation. Say, *What particles are the electrons interacting with as they move? Why might increasing the length of the wire decrease how quickly electrons flow through that wire?*

Building toward: 6.A.3 Integrate information from a reading alongside student-generated models and a computer simulation to examine smaller-scale mechanisms within the system and develop cause-effect relationships about motions of particles or energy stored in fields. (SEP: 8.2; CCC: 2.2; DCI: PS3.A.3)

12 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: 8.5 x 11 paper, Wire Sim Results poster

Reground students in our larger line of inquiry. Relate the results to what happened in Texas and how to reengineer and improve our electric grid. Show **slide P** and point out the two questions at the top; instruct students **not** to answer these questions on their exit ticket! They are only for reference in thinking through the question at the bottom of the slide.

Distribute a sheet of paper to each student, and direct their attention to the poster. Say, *Choose a result from our Wire Sim Results poster. Write it on your exit ticket, and then write your answer to the bulleted question on the slide: Is the result you chose more connected to question A or B? What is the connection?* Collect students' exit tickets as they leave class.

End of day 2

13 · NAVIGATE

3 min

MATERIALS: Wire Sim Results poster

Connect our simulation results to our larger engineering task. Show **slide Q**. Ask students to name a result that connects to the larger task of reengineering and improving our electric grid. As they share ideas, ask the class to connect this result to a specific detail about that task.

Listen for responses such as:

- As wire width increases, energy loss decreases. So, we should use thicker wires in our grid.
- As wire length increases, energy loss increases. So, we should keep our wires as short as possible to prevent energy loss. This also means that sources of energy like solar cells or power plants should be built next to the buildings that use this energy.
- As wire temperature increases, energy loss increases a little bit but mostly stays the same. This means we could, in theory, lose less energy by making the wires cold, but this probably isn't worth it.

14 · FILL IN THE ENGINEERING DESIGN TRACKER

8 min

MATERIALS: science notebook, *Engineering Design Tracker* (from Lesson 3), Wire Sim Results poster

Use the Wire Sim Results poster to add to the *Engineering Design Tracker*. Present **slide R** and have students get out their own *Engineering Design Tracker*s. Tell them to use the ideas on the Wire Sim Results poster to fill in another row of the tracker, and remind them that some of the new ideas are more relevant to engineering solutions than others. Rather than simply choosing the conclusion they reached with their group, encourage them to choose a conclusion that clearly connects to reengineering and improving our grid.

Students' entries may look something like this. If time is limited, it's better for students to go deeply into one new science idea to think through applications and constraints (the third and fourth columns) rather than simply listing more science ideas (the second column).

Lesson #	What are the new science ideas we figured out that could make the systems in ourcommunity more reliable?	How could engineers designing a power grid for a community **apply these ideas** in practice?	What **constraints** might make it hard for engineers to apply these ideas?
6	*Energy is lost over a wire. A thicker or shorter wire means less energy loss. The cold doesn't affect energy loss very much.*	*They could use really thick wire.*	*Having less insulation could be dangerous. Also, thick wire is probably more expensive, and building power plants closer means building more of them, which could be way*

		They should also not let the wires get too hot if possible, maybe by using less insulation. *They should also build power plants as close to the community as possible.*	*more expensive, and could annoy people in the neighborhoods where the plants would be built. Also, maybe the resources that the plants need aren't close to the community, like water, wind, or coal.*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:
Students should connect one or more conclusions from the Wire Sim Results poster to an idea that will help us reengineer the grid.

- Longer wire means more energy loss, less electric current → Power plants should be built closer to the communities they serve, so wires can be shorter. (SEP: 1.3; CCC: 1.3; DCI: PS3.A.4)
- Larger-diameter wire means less energy loss, more electric current → Large-diameter wires should be used instead of smaller wires. (SEP: 1.3; CCC: 1.3; DCI: PS3.A.4)
- Lower/higher wire temperature means about the same energy transfer, about the same energy loss. → It's unlikely that cold temperature affects wires much--if anything, more energy will flow in the cold. (SEP: 1.3; CCC: 1.3; DCI: PS3.A.4)
- These choices have trade-offs and constraints--energy sources such as coal plants can be unhealthy for residents, and thicker wire costs more money. (CCC: 1.3)

What to do: Circulate around the room and browse students' answers to the second column of the *Engineering Design Tracker*. If they have trouble getting started, point to the poster and say, *Those relationships we uncovered are new science ideas, even though they don't have a specific name. Which of those relationships could help us reengineer and improve our electric grid to lose less energy or to increase electric current to our buildings?*

If students have identified a useful idea/relationship but have trouble applying this idea in column 3, ask specific questions that help make the connection. For example, *I like that you're focusing on the width of the wire. What type of wire would you recommend we use in our electric grid?* Or, *I like that you're focusing on wire length. What would this mean about where we'd want to build our power plants, to keep wires as short as possible?*

If students struggle to think through constraints, make a counter-argument to what they wrote in column 4. For example, say, *What might make it hard for a city to choose to use thicker wire?* Or, *Why might we not want to build, say, a coal or nuclear power plant right next to people's homes?*

Building toward: 6.B.2 Use a simulation to model electron flow inside a wire in order to identify patterns, answer questions, and determine relationships between independent and dependent variables involving electrical energy transfer that can be interpreted to reengineer and improve the electric grid. (SEP: 1.3; CCC: 1.3; DCI: PS3.A.4)

15 · ASSIGN THE MOTOR TRANSFER TASK

30 min

MATERIALS: science notebook, *Motors Transfer Task*, hand-crank DC generator, 1.5 volt D battery, alligator clips

Provide context for the assessment. Say, *When we transfer kinetic energy into a system that uses magnets and a coil of wire to generate electricity by turning something in the system, we call the system a generator. In a generator, magnets transfer energy from motion into changing magnetic fields, and the energy then transfers to changing electric fields. These electric fields cause electrons to move and transfer electrical energy along the wire. Therefore, one way to think about a generator is as a device that transforms kinetic energy (motion) into electrical energy.*

Present **slide S** and pose the question as a Turn and Talk: *If you input kinetic energy to a generator, the output is electrical energy. What do you predict would happen if we input electrical energy to the system instead? Imagine you attached a generator like we used in class to a source of electrical energy (like a battery or another generator), and turned on the source so energy was transferring into the generator.*

After 1-2 minutes, elicit a few ideas. Students may say kinetic energy would come out and the crank would spin, or the wires would heat up. Accept all ideas without judgment.

Connect a high-output generator (**not** a homemade generator!) to a 1.5 volt D battery. Connect two alligator clips to the hand-crank generator, and connect it to either another generator or a battery. Allow students to observe the crank moving on its own.

Distribute the assessment. Explain that students will have the opportunity to explore this phenomenon in an assessment. Distribute *Motors Transfer Task* to each student.

Mention available resources. Display **slide T**. Remind students that they can use their science notebook, data, *Progress Tracker*, and *Progress Tracker*, from Lessons 1-5 as resources for understanding as they complete this assessment. Give them the remainder of the class period to work on the task. ✱

✱ ATTENDING TO EQUITY

Universal Design for Learning: On this assessment some students may benefit from using alternative modalities to express their thinking for any or all of the questions. Consider allowing some students to verbally explain their answers while you record their thinking on paper, or allowing some students to use gestures, images, or manipulatives to support their explanations. Especially early in the unit, encouraging students to use multiple modalities to show their thinking builds their skills, and creates equitable pathways for all students to demonstrate proficiency throughout the unit.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** See the *Motors Transfer Task Key*. **What to do:** Use the key to evaluate students' work. If a student scores low, consider giving them a chance to discuss the assessment with you and then take the other version, *Transformer Transfer Task*, which assesses the same 3-D elements in a different context. Refer to the *Motors Transfer Task Key* for ideas on how to score this similar student work. This assessment is not building toward a lesson-level performance expectation. It is designed to assess a performance expectation from the NGSS, below. **Transfer Task 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. (SEP: 2.3, 6.5; CCC: 5.2; DCI: PS3.A.2, PS3.A.3, PS3.D.1)

Collect all assessments before students leave. Determine a time for students to finish the assessment if they did not have enough time in class.

16 · REVISIT "MOVING OUR SCIENCE THINKING FORWARD"

2 min

MATERIALS: Community Agreements: Moving our science thinking forward

Reflect on what we have done to move our science thinking forward. Show **slide U**. Call students' attention to previous thinking about Community Agreements related to "Moving our science thinking forward". Say, *Many of you have clearly mastered the ideas in this transfer task. Some of you are still working through them, and that's OK. Let's reflect for a moment on how we got there. Do you think you could have shown mastery on this transfer task before we began this unit? Who is coming up with the key ideas?*

Encourage students to be honest. If they don't think that they've made much progress, this is a time to say so. If they believe that the teacher is usually the one coming up with the key ideas, this may be a chance for you to reflect on what opportunities students have to own this learning themselves.

If assessment at your school offers students multiple attempts at mastery, emphasize the third question. Say, *If you haven't shown mastery yet, what can you do next to change that? What are some resources you can use to master energy transfer models, and energy transfer through particles and fields?* A key resource here is *Changing Fields*--students should practice making energy models of a few phrases from the reading. If they can connect this thinking to their design thinking about the generator, they will be far more successful on *Motors Transfer Task*.

17 · NAVIGATE: EXIT TICKET

2 min

MATERIALS: 8.5 x 11 paper, science notebook

Connect back to Texas and navigate into the next lesson with an exit ticket. Present **slide V** and distribute a sheet of paper to each student. Ask them to respond to the prompt as an exit ticket: *Do we have all the pieces we need to model how insufficient supply could have affected energy transfer into certain communities in Texas when temperatures dropped during the storm?*

Collect the exit tickets to refer to in Lesson 7.

Additional Lesson 6 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	A Common Core ELA standard is targeted in this lesson from the category of **Craft and Structure.** • **CCSS.ELA-Literacy.RST.11-12.4.** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*. Students identify the main ideas from a reading about charged particles to determine the model that better reflects the interactions between electrons in a wire.