Lesson 5: Where does electrical energy come from?

Previous Lesson *We used informational cards and data representations from the 2021 Texas crisis to seek additional information about specific sources of energy to help us figure out which source might be responsible for the drop in supply. We ranked the sources by reliability, but realized that this is hard to quantify. We used a Decisions Matrix to keep track of how well each source meets criteria we think are important.*

This Lesson

Investigation

3 days

We use diagrams of power plants to figure out how they transfer energy into wires, which makes us wonder what is happening inside generators. We dissect a generator, then build our own, and use compasses to investigate fields. Lastly, we model energy transfer through fields inside our generators, and make connections between matter and energy to refer to as we move forward.

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

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

5.A Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts and energy transfer at a distance through fields. (SEP: 2.3, CCC: 5.2, DCI: PS3.A.2, PS3.A.3)

5.B Design and build a generator system to transfer motion energy to light that meets agreed-upon criteria, manipulating variables and collecting data to identify failure points and improve performance. (SEP: 3.6, CCC: 4.1, DCI: PS3.A.2)

What students will figure out

- Many power plants have generators, which are loops of copper wire and powerful magnets.

- Matter changes and/or motion can cause energy transfer through contact (and vice-versa).
- The motion of a magnet can generate changing fields, which can cause energy transfer at a distance (and vice-versa).
- When moving matter (e.g., pushing wind or steam) moves the magnets inside a generator, that can cause energy transfer into wires through changing fields.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE: LOOK CLOSER AT SPECIFIC POWER PLANTS** Orient to thinking about what might be similar and different about the ways various sources are used to generate electricity, and what we could do to figure this out.	A	*Texas Power Stations* (from Lesson 4), *Source Cards Full Page* or *Energy Source Cards* (from Lesson 4) (optional)
2	20 min	☑	**INITIAL MODELS OF ENERGY TRANSFER IN POWER PLANTS** Examine diagrams of a wind turbine power plant and a natural gas power plant, then develop a model of energy transfer for the wind plant as class, then in pairs for the gas plant. Then we come back together to check our thinking on the gas plant models as a class.	B-E	*Power Plant Diagrams*, chart paper, markers
3	15 min		**MOTIVATE A CLOSER LOOK AT THE GENERATOR** Identify the spinning generator as a key similarity between wind and natural gas power plants. Demonstrate the mini-generators with an LED, then dissect a generator to create a list of its parts.	F-G	chart paper, markers, Dissecting a Generator
4	5 min	☑	**NAVIGATE: EXIT TICKET** Complete an exit ticket identifying possible ways that a generator transfers electrical energy and how to reverse engineer the generator.	H	8.5 x 11 paper
					End of day 1
5	5 min		**NAVIGATE** Revisit the exit ticket responses to motivate building a generator and poll them to see whether they think we can do it. Agree on criteria for success.	I-J	
6	27 min	☑	**BUILD A GENERATOR** Build a generator to create enough electricity to light up two LED light bulbs.	K	Building a Generator
7	10 min		**DEBRIEF THE GENERATOR INVESTIGATION** Discuss the Build a Generator investigation as a class.	L	*Generator Engineering Task*
8	3 min		**NAVIGATE: EXIT TICKET WITH A PARTNER** Point out that there is energy transfer at a distance (without parts of the generator touching), and suggest experiments to investigate this.	M	

End of day 2

9	3 min		**NAVIGATE** Make connections to magnets and energy transfer.	N	
10	5 min		**REVISIT COMMUNITY AGREEMENTS: “RESPECTFUL” CATEGORY** Consider how building the generator during the last class impacts our thinking about how to make our classroom respectful.	O	Community Agreements poster (from Lesson 1)
11	20 min		**BUILD UNDERSTANDING ABOUT MAGNETISM** Investigate changes in the direction a compass points when it is near a generator through a series of group and class demonstrations that build on each other. Debrief the results in a Building Understandings Discussion.	P-W	chart paper, markers, Compass Experiments and Demonstrations
12	10 min		**MODEL ENERGY TRANSFER IN THE GENERATOR** Individually and as a class, model energy transfer in the homemade generators based on evidence from the compasses.	X-Y	8.5 x 11 paper, chart paper, markers, whiteboard and dry erase markers (alternate)
13	5 min		**DISCUSS MATTER-ENERGY CONNECTION AND ADD TO THE PROGRESS TRACKER** Build conceptual connections between matter and energy that will serve as the foundation for deeper understanding as students progress through subsequent units. Add to Progress Trackers.	Z	
14	2 min		**NAVIGATE: EXIT TICKET** Connect the generator investigations back to what happened in Texas by completing an exit ticket.	AA	8.5 x 11 paper

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Dissecting a Generator materials			• 2 mini dissecting generators • 1 super-bright red LED bulb (2V • 20 mA) • 2 alligator clips
Building a Generator materials	• *Generator Engineering Task*	• 1 iron nail • 1 paper tube wrapped in 400-600 wraps of magnet wire (28 AWG) • 2 neodymium magnets (4mm x 8mm) • 2 alligator clips • 2 super-bright red LED bulbs (2V • 20 mA) • string • sticky tack • power strip “building” wiring • small piece of sandpaper	• hanging weights or a full water bottle to hang from string (optional)
Compass Experiments and Demonstrations materials	• science notebook	• compass • homemade generators	• hand-crank DC generator • homemade generator • 6 compasses • 8 alligator clips
Lesson materials	• science notebook • *Texas Power Stations* (from Lesson 4) • *Power Plant Diagrams* • 8.5 x 11 paper • *Generator Engineering Task*	• *Source Cards Full Page* or *Energy Source Cards* (from Lesson 4) (optional)	• chart paper • markers • Community Agreements poster (from Lesson 1) • whiteboard and dry erase markers (alternate)

Materials preparation (60 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 chart paper for the poster you will make in this lesson:

- "What we tried/What we saw" T-chart

You will also need to create several consensus energy transfer models. Prepare whiteboard space or chart paper for these models.

Day 2:
Dissecting a Generator

- **Group size:** Whole class.
- **Setup:** Have 2 generators available that are easily taken apart for dissection. Connect the super-bright red LED bulb (2V, 20 mA) to each generator using the 2 alligator clips to check that the generators are both functional.
- **Storage:** All materials can be stored and reused indefinitely.

Building a Generator

- **Group size:** 3-5 students.
- **Setup:** For each group, wrap 400-500 wraps of magnet wire (28 AWG) around two sections of a cardboard tube, and use the nail to poke a hole in the tube between the sections. See *Preparing Generator Materials* for details. Print a copy of *Generator Engineering Task* for all students. For guidance on how to work through this work, see How to prepare materials for DIY generators .
- **Safety:** The magnets are very strong and can pinch students or shatter if they come together quickly. Encourage students to keep them apart until they attach them to the nail.
- **Storage:** At the end of each class, ask students to break down their generators so you can reuse the parts with the next class. At the end of your last class, leave the generators constructed so students can use them later in the lesson, and later in the unit. All parts can be stored indefinitely from year to year.

Day 3:
Field Demonstration

- **Group size:** Whole class.

- **Setup:** Check compasses ahead of time to ensure they all point in the same direction (which does not necessarily need to be north). One tube with wire wrapped around it should be free of magnets, so it can be used as a coil of wire.
- **Storage:** All materials can be stored and reused indefinitely.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.A.2 Definitions of Energy.** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)
- **PS3.A.3 Definitions of Energy.** These relationships are better understood at the microscopic scale, at which all the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). ~~This last concept includes *radiation*, a phenomenon in which energy stored in fields moves across space.~~ (HS-PS3-2)

Note that radiation is not treated in this unit. Students will learn about radiation in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*.

This lesson introduces another detail to the energy transfer model: fields. The energy transfer model is a way to keep track of energy inputs, outputs, and transfers between subsystems. The diagrams of wind and natural gas power plants provide a way for students to begin to identify subsystems within the larger power plant system. The investigations using generators to create changing fields should build on students' prior knowledge about magnets, electricity, and fields.

Though students do not rigorously define *magnetic field* in this lesson, we uncover evidence that those fields exist and that they change when magnets move. We connect this to energy transfer by noticing that the generator only transfers electrical energy to wires when the magnets in the generator move.

At a macroscopic scale, we notice many examples of the motion of one component transferring energy to the motion of another component. These transfers occur through direct contact (wind pushes turbine blades, nail moves magnets, and so forth). We also note that lights turning on and objects getting warmer are similar evidence of energy transfer, though the specific mechanisms may be unclear to us for now.

Students encounter or co-develop definitions for the following words in this lesson: *generator, power plant, wind turbine*, *field.* **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students begin to consider the interplay between matter and energy in this lesson, but they will not figure out how matter is changing inside wires or consider matter changes on a particle level. Though students identify the field propagating down the wire into the coil of wire or light bulb, the role of electrons in that propagation is not discussed. Students may identify the role of electrons or want to discuss them in the wire, but that will be the focus of the next lesson.

It is not important that students recognize interactions as forces in this unit. Students will describe energy transfers as matter changes or motion changes (e.g., fire **heats** emissions, steam **pushes** turbine, turbine **pushes** generator), building a strong foundation for considering the relationship between forces and energy transfer in the second unit of the course.

LEARNING PLAN for LESSON 5

1 · NAVIGATE: LOOK CLOSER AT SPECIFIC POWER PLANTS

5 min

MATERIALS: science notebook, *Texas Power Stations* (from Lesson 4), *Source Cards Full Page* or *Energy Source Cards* (from Lesson 4) (optional)

Review what we know about wind and natural gas energy. Present **slide A**. Remind students that natural gas and wind were two of the sources we identified as very popular in Texas, but that we saw differences in how reliable and efficient they were, how much power they provided, and so forth. If students still have the *Source Cards Full Page* or *Energy Source Cards* from Lesson 4 at their table, consider asking them to review these cards to help them answer.

Then have students turn and talk about the prompts on the slide:

- *What do we know about how wind and natural gas produce energy transfer in wires that would help us understand what makes each more or less reliable, efficient, or powerful?*
- *How could we figure this out?*

Elicit a few student ideas. Accept all ideas for the first prompt. For the second prompt, listen for students to suggest seeing inside power plants somehow, either through video, diagrams, a field trip, or something else.

2 · INITIAL MODELS OF ENERGY TRANSFER IN POWER PLANTS

20 min

MATERIALS: *Power Plant Diagrams*, chart paper, markers

Examine diagrams of two types of power plants. Say, *It sounds like we want to know more about what is inside a power plant. I have some diagrams that show how wind and natural gas power plants actually work. We might be able to find some clues to help us figure out what is going on in these diagrams.* Distribute *Power Plant Diagrams* to each student and present **slide B**.

Model energy transfer in the wind turbine. Suggest that we start with the wind turbine together. Ask students to respond to the prompts on the slide, as shown in the table below.

Suggested prompt	Sample student response

✱ **ATTENDING TO EQUITY**

It is important to validate the ideas of students who feel like they are 10 steps ahead, and to make it clear that these ideas are important contributions. Remind them of the question we are trying to answer right now, and ask them to record their idea on a whiteboard, blackboard, or piece of chart

What do you notice?	Arrows showing wind motion and blades turning. Lots of different parts. A generator. Wires. An unlabeled box.
What do you wonder?	What is in the box? What is a generator? Why does it need to turn, and how does that make energy transfer in the wires?
How could tracing matter changes in this system help us understand energy transfer?	Motion is one example of how energy shows up. Energy and matter are connected somehow. When something is moving, it must have energy of motion, and that energy must have come from somewhere.

Look at the wind turbine system through the lens of matter. Project **slide C**. Ask students to consider the prompts on the slide:

- *How does matter move and change in the wind turbine system?*
- *What components and interactions represented in the diagram show this?*

Elicit student responses. Listen for students to identify the following matter motions/changes; as they do, point to them in the diagram:

- Wind is moving. (blue arrows)
- The blades and shaft are turning. (black arrows)
- We don't know what is happening in the wires.

paper in the classroom for us to come back to when it will help us answer our questions.

Some students may know that electrons are moving in the wires. Tell them this is an interesting idea, and ask them what evidence we see in the diagram for that matter change. Then say, *It's not in the diagram, but let's keep that idea on the table and come back to it, because it could help explain what's happening if we zoomed in on those wires. Let's think at a larger scale for now, and then we'll zoom to a particle scale afterward.*
✱

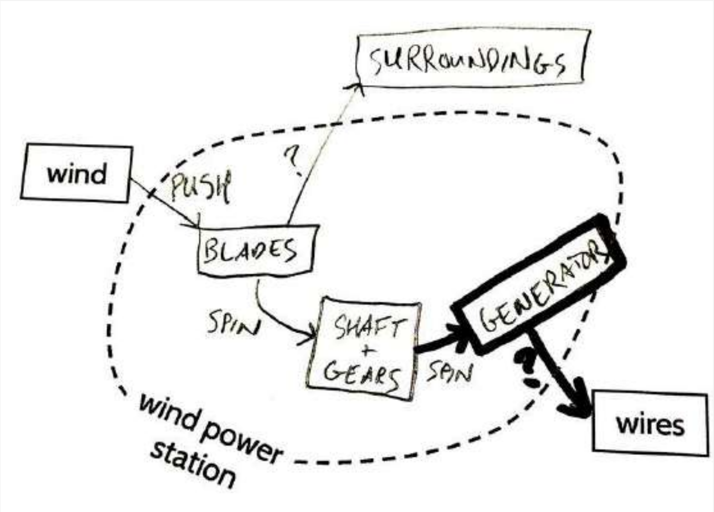
Look at the wind turbine system through the lens of energy transfer. Project **slide D**. Ask students to think about the prompts on the slide for a moment:

- *How does energy transfer between components in the wind turbine system?*
- *How do we know this from the diagram?*

Create an energy transfer diagram as a class. Elicit student ideas in response to the slide's prompts. Listen for them to suggest that energy transfers from the wind, to the blades, to the shaft. Suggest that we keep track of this using our energy transfer conventions, and begin to sketch out a class model on a blank sheet of chart paper.

Problematize how the generator works. Students' ideas will become less concrete as they describe the generator. One primary goal of this modeling is to discover that we don't yet know exactly how a generator works. To show this, put a question mark on an arrow from the generator to the wires.

The completed model may look something like the example below.



Model energy transfer in the natural gas plant in pairs. Project **slide E**. Ask students to look at the "Natural Gas Power Plant" diagram on *Power Plant Diagrams*, and then, in partners, to go through the same steps we did as a class to track how matter moves (or changes) and infer how energy transfers. Give them 5 minutes to sketch an energy transfer model on the back of *Power Plant Diagrams* and discuss the question on the slide: *How are the matter moves/changes you identified related to energy transfer?*

As students work, circulate and look closely at their progress, using their diagrams as a formative assessment. If students are having trouble getting started, prompt them to think first about matter in the system.

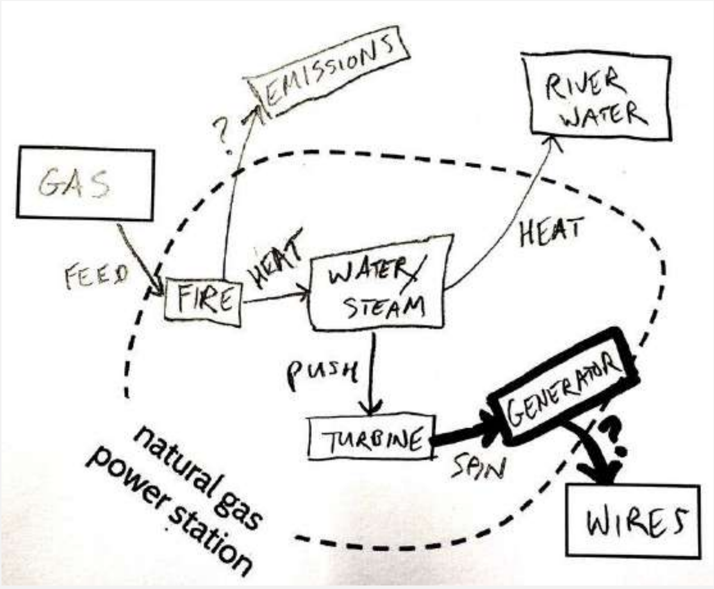
ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** • Students should use our box and arrow conventions and label the arrows with at least one action word to describe energy transfer. (SEP: 2.3) • Energy transfer arrow labels should describe interactions, even partially. These energy transfers will generally manifest as matter changes or motion changes (e.g., fire **heats** emissions, steam **pushes** turbine, turbine **pushes** generator). It is not important that students recognize interactions as forces in this unit. (CCC: 5.2, DCI: PS3.A.2) • Students will likely not yet have a clear idea of how energy transfer manifests in the wires. This uncertainty will motivate the investigations in Lesson 6. Rather than pushing them to figure this out now, encourage them to highlight this limitation of their model by putting a question mark on that arrow. (DCI: PS3.A.2) **What to do:** If students are confused about which components are important, direct them to the labeled parts of the diagram. Use probing questions for which those components are a valid answer, such as: *Where does the energy start? What does the gas transfer energy to? How does the plant use the energy from the fire--where does it transfer?* Use similar questions as in the previous discussion to elicit ideas for the model: *How do we know that there is energy in the ___?* *Where is energy being transferred from the ___ to the ___? How?* *What changes do we see in matter (or in motion of matter*)? If students begin to trace matter instead of energy (e.g., the natural gas goes into the boiler, and then into the stack through emissions), redirect them with probing questions, such as: *What do these orange arrows show? What do the blue arrows show? Is that the path of energy transfer from the gas to the wires?*

Use the third question on **slide E** to help students distinguish between energy transfer and matter transfer. Ask, *How are matter changes related to energy changes? Is energy transfer the same as matter transfer? What is one example in the gas plant where they are different?*

Building toward: 5.A.1 Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts and energy transfer at a distance through fields. (SEP: 2.3, CCC: 5.2, DCI: PS3.A.2)

Model the natural gas power plant as a class. Bring the class back together to go step by step, asking students to share how they modeled the natural gas power plant as you sketch a class model on a blank sheet of chart paper. Be sure to space out the components in your diagram to allow room for labeling energy transfer arrows with action words.

The completed diagram may look something like the image below. Listen for some agreement on valid verbs for the main transfers of energy within the system. If students have questions about any specific transfers, identify them with a question mark. As with the wind diagram, the question mark from generator to wires is essential--again, one primary goal is to discover that we don't know how the generator works.



ADDITIONAL GUIDANCE	Students may be confused about how to describe the energy transfer process arrow for natural gas heating up. Push them to draw on their knowledge from chemistry to describe the process in terms of particle motion. Say, *Heating up describes our experience of what is happening. But what do the particles of natural gas actually do when they heat up?*

3 · MOTIVATE A CLOSER LOOK AT THE GENERATOR

15 min

MATERIALS: Dissecting a Generator, science notebook, chart paper, markers

Observe that both power plants have a generator. Present **slide F**. Ask students to turn and talk about the questions on the slide:

1. *What do these power plants have in common?*
2. *What questions do we still have about how these power plants produce electrical energy?*

Have students share their ideas with the whole class. Listen for them to point out that both power plants end with the production of electrical energy in power lines, and that before this, there is something called a generator that spins. Listen for ideas and questions about how this happens.

Say, *I actually have a couple of generators right here.* Produce the 2 mini dissecting generators.

Motivate the transition to LED bulbs. Say, *In Lesson 2, we read a little bit about different kinds of light bulbs. The bulbs we used in Lesson 2 were incandescent bulbs. But many of the lights installed in modern buildings are LED bulbs, because they use less energy to create the same amount of light. In other words, they're more efficient. They're also much safer, because they don't get hot enough to burn you if you accidentally touch them.*

ADDITIONAL GUIDANCE	It is important that you use the right bulbs for the battery in Lesson 2 and for the generator in this lesson. The batteries are 1.5 volt and cannot always light up LEDs, which is why we recommend 1.2-1.5 bulbs for those. An incandescent bulb is more forgiving and will still be powered below the recommended voltage. But an LED will not work below its voltage threshold; it works better with the hand-powered generators, which will produce adequate voltage if spun quickly. These generators can light up incandescent bulbs, but it is much more difficult to do.

Demonstrate the generators with an LED, and draw attention to the snap. Attach a super-bright red LED bulb (2V, 20 mA) using alligator clips to 1 blue and 1 yellow wire to show students that they work, and then show how to pull them apart. As they click back together, draw attention to the magnet by saying, *Wow, they really snapped back together quickly, did you hear that snapping noise? See whether you can figure out what is pulling them back together so quickly when I pass them around.*

Pass around the dissecting generators. Present **slide G**. Pass the generators around the room, and ask students to record noticings and wonderings in their notebooks. After everyone has had a chance to examine a generator, ask students to help you list its parts. Record their ideas on a blank sheet of chart paper or on the board. Make sure you have recorded at least the first two of the following (the wire and the magnet) before moving on:

- coils of wire (or coils of "copper wire")
- a magnet or magnetic strip
- a shaft, axle, rod, or something else that describes a turning mechanism
- insulated wires
- a case

ADDITIONAL GUIDANCE	If students didn't notice the magnet, make sure they do now by saying, *Did anybody figure out what was making it click together so quickly? Could this black rim around the inside be responsible for that?*

4 · NAVIGATE: EXIT TICKET

5 min

MATERIALS: 8.5 x 11 paper

Navigate by motivating reverse engineering the generator. Distribute a sheet of paper to each student. Ask them to put their name on the paper and respond to the prompts on **slide H** as an exit ticket:

1. *How do you think the parts we identified in the generator might work together to transfer energy to wires?*
2. *What would we need to do to re-create this phenomenon using these basic parts?*
3. *How could this help us understand the energy crisis in Texas in 2021?*

Collect students' exit tickets as they leave class. ✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

If your students have experience with a speaker unit or another technology that uses solenoids, consider giving them a chance here to make connections between similar types of systems. Ask, *Have you seen these same parts working together in another type of system?*

End of day 1

5 · NAVIGATE

5 min

MATERIALS: None

Navigate with a Turn and Talk about the exit ticket responses. Present **slide I** and return students' exit tickets. Give students a moment to turn and talk about what they wrote. Suggest that if they have any new ideas, they can tell their partner about those as well.

After 2 minutes, if students had ideas for creating a generator, say something like:

- *You all seemed very optimistic that we could re-create this, and I agree.*

If most students responded that it could not be done, say something like:

- *Most of you seemed doubtful that we could make our own generators, but I have some ideas.*

Introduce supplies and take a quick poll. Say, *I have some materials very similar to those we identified in the generators during our last class. I have some wire wrapped around a tube, and some magnets, and a nail that we can use as a shaft. Show of hands, how many people think this is going to work?*

Define criteria for success. Present **slide J** and say, *What should we define as our criteria for success? How will we know whether our generators are successful?* Listen for responses such as:

- It should light a bulb or an LED.
- It should light up the power strip city we made earlier.
- If it can light more bulbs, then that means it's more successful.
- If it can light bulbs for longer, then that means it's more successful.

Write the class's agreed-upon criteria on the board, a whiteboard, or chart paper.

Students may also offer generator criteria such as, "It should charge our phones." If so, say, *That sounds pretty ambitious. Let's start simpler and then see where we can get.* Students should **not** connect any generators to their phones, as they could damage the internal electronics.

SAFETY PRECAUTIONS

Powerful magnets like those recommended for use here can snap together and pinch fingers. Tell students to keep the magnets far apart when not in use, and consider providing gloves to prevent pinched fingers. Keep magnets at least 20 cm away from sensitive electronic and data storage devices.

Students should **not** connect any generators to their phones or other devices. A high-quality generator can certainly damage internal electronics.

6 · BUILD A GENERATOR

27 min

MATERIALS: Building a Generator

Build the generators. Present **slide K**. Break students into groups of 3-5 to build generators. Distribute the materials for the Building a Generator lab to each group.

If your power strip city is set up, consider giving students an opportunity to rewire it with LED lights. Though they may have a hard time lighting the whole city, they should be able to light two LEDS connected to one power strip.

Distribute a copy of *Generator Engineering Task* to each student. Instruct them to follow its procedures with their group and to write down their answers to its questions. The handout is organized as a series of four Design Challenges:

- Design Challenge 1: Magnet Arrangement
- Design Challenge 2: Rotation Speed
- Design Challenge 3: Sturdy Magnets
- Design Challenge 4: Wire Wraps Constraint

If some groups spend most of their time on Design Challenges 1 and 2, that's OK. Design Challenge 1 is the most important for understanding that how the magnets **change** inside the coil is what generates electrical energy. Some groups, on the other hand, will likely finish Design Challenges 1 and 2 rather quickly and be eager to move on to making their generator work even better.

Move around the classroom with the dissecting generator and ask probing questions to make sure that students are making connections between what they are doing and our questions about how generators work.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students identify design criteria relevant to the generator's performance, transferring motion energy to light (i.e., lighting multiple bulbs, lighting a bulb for an extended time). (SEP: 3.6, DCI: PS3.A.2)
- Students evaluate their own design against the agreed-upon criteria as they build and test their

generator design. (SEP: 3.6, CCC: 4.1)
- Students use the Design Challenges on the handout to improve their designs in real life. (SEP: 3.6)
- Students describe a relationship between a specific design variable (magnet spinning speed, magnet position, number of wire coils) and the energy output (e.g., "If we spin the nail faster, the light is brighter"). (SEP: 3.6)

What to do:

- As students discuss design criteria, encourage them to decide on criteria that can be scaled up and improved. Instead of simply agreeing to the criterion "light a bulb," push students toward "light as many bulbs as we can" or "light a bulb for as long as we can."
- As students work through the Design Challenges on the handout, move from table to table and clarify which specific point in the generator design they are focusing on. Ask, *Which part of the generator are you focusing on right now?* Expect responses such as: the position of the magnets, keeping the magnets moving for more time, the number of wire coils.
- As students build and test their generator, ask them to explain why they constructed it in a particular way. Use probing questions to help them clarify their thinking about energy for each challenge, such as:
    - *Based on your testing so far, how would the generator work differently if you change the speed of the moving magnets? How might that affect the energy output of the generator?*
    - *How does the output of the generator change when the magnets get knocked out of place? How might that affect the efficiency of the generator?*
    - *What about if you wrapped half as much wire? A quarter as much wire?*

Building toward: 5.B Design and build a generator system to transfer motion energy to light that meets agreed-upon criteria,, manipulating variables and collecting data to identify failure points and improve performance. (SEP: 3.6, CCC: 4.1, DCI: PS3.A.2)

Clean up and come back together. When there is about 10 minutes left of class, ask students to clean up their areas, and then bring the class back together to debrief.

7 · DEBRIEF THE GENERATOR INVESTIGATION

10 min

MATERIALS: *Generator Engineering Task*

Debrief the investigation. Present **slide L** and elicit responses to the questions on the slide, as shown in the table below.

Suggested prompt	Sample student response
What happened when you tried to use your generator to power one LED?	We could do it! We got some flashes, and if we wrapped string around the nail, we could get it to light up for longer. (Expect some groups to have had more success at this than others.) When the magnets were facing the same poles outward, the generator didn't work at all.
More than one LED?	We couldn't do it. We could do two easily, but we had trouble lighting up three or four. We could do it, but we had to use string to spin the nail faster.
What factors seem to affect the energy output of the generator?	Position of the magnets. Speed of the nail. How many coils are wrapped around the tube.
What might cause energy loss to the surroundings?	There's probably some friction between the nail and the tube. The faster it goes, the more energy is lost to the surroundings, probably because it rubs more.

8 · NAVIGATE: EXIT TICKET WITH A PARTNER

3 min

MATERIALS: None

Assign an exit ticket to do in pairs. Close out the discussion about the generators and navigate into day 3 with the exit ticket on **slide M**. The exit ticket introduces new ideas, so have students do the work in partners to complete one exit ticket each at the bottom of the back of *Generator Engineering Task*.

Collect the exit tickets as students leave class. If students are unclear on the difference between energy transfer through direct contact and energy transfer at a distance, plan to review this briefly at the start of their next class period.

End of day 2

9 · NAVIGATE

3 min

MATERIALS: None

Make connections to magnets and energy transfer at a distance. Present **slide N**. Tell students to turn and talk with a partner about the prompts on the slide:

1. *Why did we want to know more about how energy transfers between the magnet and the coil of wire?*
2. *How do we know these parts are transferring energy?*
3. *What do we know about magnets that might help us figure this out?*

Give students a minute before asking them to share out. Listen for responses such as:

- We want to look at the magnets and the wire more closely, because they were transferring energy without touching.
- We know there is energy transfer because when we spin the magnet, energy gets to the light bulb and lights it up, so the energy must go through the wire.
- Magnets can move things without touching.

If students don't bring up fields themselves, don't bring it up. The term *field* will be defined later in this lesson. If students do bring it up, validate this idea, and then continue to reference the space around the magnet until the end of the lesson so students who do not know what a field is have the opportunity to construct a conceptual understanding.

10 · REVISIT COMMUNITY AGREEMENTS: "RESPECTFUL" CATEGORY

5 min

MATERIALS: Community Agreements poster (from Lesson 1)

Revisit the "Respectful" category of our Community Agreements. Point to the "Respectful" category of the poster and present **slide O**. Say, *There were a lot of creative ideas on how to get our generators working in the last class. I saw lots of groups respectfully sharing equipment and ideas.*

Then ask students to consider and respond to the prompts on the slide:

- *Why is it important to be respectful when working together on an engineering problem?*
- *Which agreements in the "Respectful" category were important for making that work successful?*
- *Which agreements should we work on?*

Listen for responses such as:

- Give others time to work with the equipment and share ideas.

- Provide others with support and encouragement.
- Critique ideas by testing them, don't just dismiss them.

ALTERNATE ACTIVITY	If there is time, consider asking students to gather around the Community Agreements poster and use sticky dots or check marks to indicate which agreements they think we should prioritize.

11 · BUILD UNDERSTANDING ABOUT MAGNETISM

20 min

MATERIALS: Compass Experiments and Demonstrations, chart paper, markers

Consider energy transfer at a distance. Present **slide P**, and arrange students into groups of 3-5 at their tables. Distribute a compass to each table and read the text on the slide: *A compass is a tool that can move when it is near a magnet.* Then read the prompts:

- *How do you think energy is transferring through systems when the compass moves? How do you know?*
- *How could we use compasses to determine how magnetic energy transfers?*

Elicit student ideas. Students who have just finished the OpenSciEd Chemistry course may have some ideas about fields and subatomic particles. Listen for students to suggest:

- Energy transfers through something invisible, like a field. Students might use the phrase "magnetic fields," or they may say something else like "magnetic forces," "magnetism," "energy fields," "force fields," or "magnetic pulls."
- Energy jumps in order to transfer, like static electricity, or lighting.

Accept all these ideas. Highlight that whatever is happening between the magnet and the coil, we think it's invisible, because we don't see anything happening.

Use the compass to investigate the space around our generators. Present **slide Q**. Distribute the generators students built previously. Read the prompts on the slide:

A. *Use a compass to look for changes in the space near your generator when it is not spinning. What do you notice?*
B. *Look for changes near the generator when you spin the generator, both slowly and quickly. What do you notice?*
C. *Use a compass to investigate the space around a magnet. What patterns do you notice in how the compass points?*

Instruct students to use their materials to follow these prompts in order. `

Once students have completed prompts A and B, encourage them to remove a magnet from their generator and use the compass to investigate the space around this magnet to address prompt C.

Organize our results as a class. Bring the class back together and present **slide R**. Prepare a piece of chart paper as a T-chart to keep track of our observations. On the left side, write "What we tried", and on the right side, write "What we saw." Enlist students' help in making the chart with their observations so far, with one student volunteer writing on the poster and another volunteer calling on peers.

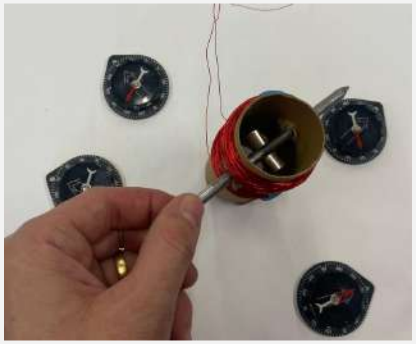
Students may add the following to the T-chart poster:

- "The compass near a generator" under *What we tried* and "The compass changes direction when the generator spins" under *What we saw.*
- "The compass near a generator spinning fast" under *What we tried* and "The compass changes direction more when the generator spins faster" under *What we saw.*
- "The compass near a magnet" and "The compass points in different directions at different places near the magnet."

Motivate investigations as a class with all the compasses. Ask students whether anybody tried moving their compass around. Ask, *What could we do to tell what the direction of the compass would be at various locations around the generator at the same time?* Listen for ideas about using more than one compass.

Conduct investigations A-C with all the compasses as a class. Gather all students around a table; ask them to bring their compasses and put them on the table. Present **slide S**. Follow the steps below to do further demonstrations.

Read the question of investigation A aloud, from **slide S**: *How do the compasses point if no magnets are nearby?* Keep the compasses at least 6 inches from each other, so they do not interact and affect each other. It is possible for a compass to get reversed. If you notice a compass pointing differently than the other compasses, remove it from the table.



Have students record these results. They may add the following to the T-chart poster:

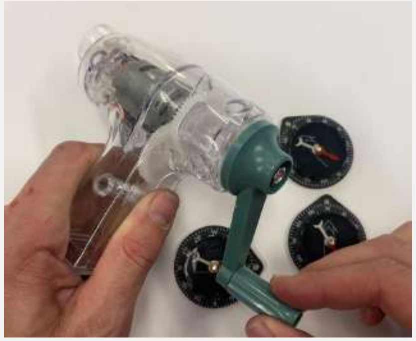
- *What we tried*: "No magnets nearby"
- *What we saw*: "Compasses all point the same direction"

Investigation B: *Do all the compasses change in the same way when we spin our homemade generator?* Hold a homemade generator close to the compasses and spin it slowly. The compasses will change direction as the magnets inside the generator move.

Have students record these results. They may add the following to the T-chart poster:

- *What we tried*: "Many magnets near the slowly spinning generator"
- *What we saw*: "Compasses all change direction as the generator spins"

Investigation C: *We have a generator that can supply much more electrical energy. Measure changes in the space around the generator again when you crank this high-output generator. What do you notice?* Hold the high-output generator close to the compasses and spin it slowly. The compasses will change direction slightly if you are spinning the generator slowly enough and if it is close enough to the compasses.



Have students record these results. They may add the following to the T-chart poster:

- *What we tried*: "Compasses near a high-output generator"
- *What we saw*: "Compasses change direction, but not as much"

Turn and talk about energy transfer at a distance. Present **slide T**. Ask students to turn and talk about the prompts on the slide with a partner they don't usually sit with.

After the Turn and Talk, call on students to share their ideas, as in the table below.

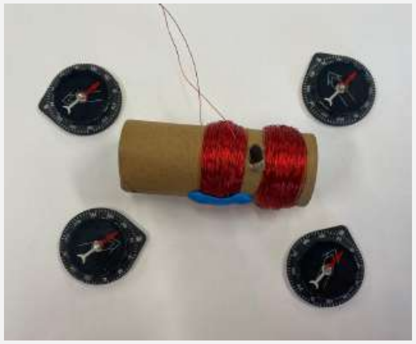
Suggested prompt	Sample student response
How far out in space do you think the magnet is able to transfer energy? How do you know?	Not very far, because the compasses have to be close. It could be really far, because the whole Earth is magnetic. The energy probably gets weaker as it gets farther away, because the compasses respond more when they are closer.
Is the energy that transfers through the coil of wire magnetic, electrical, or both? Why do you think that?	It's magnetic, because it's making the compasses move. It's electrical, because electricity travels through the wires to light up a bulb. Magnetism doesn't travel through wires.
How could we investigate this?	We could put the compasses near a coil of wire.

We could connect our coil to an energy source and use the compasses to investigate.

We could try making an electromagnet.

ADDITIONAL GUIDANCE	Students may not yet understand the distinction between electrical and magnetic energy, and that's fine. Try not to distinguish these as fundamentally different forms of energy. Instead, encourage students to focus on "magnetic changes" versus "electric changes." For example, "electrical energy" can light up a bulb, whereas "magnetic energy" can make a compass move.

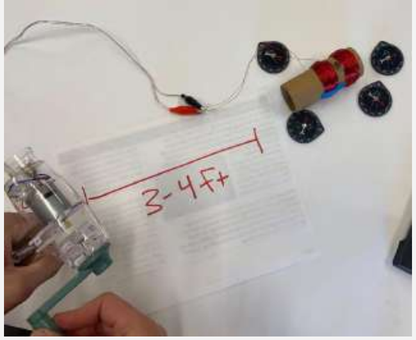
Conduct investigations D-E together as a class. Present **slide U**.



Read the directions for ***Investigation D:*** *Use compasses to measure the magnetism near a coil with no magnets nearby, not connected to anything.* Remove the nail and magnets from a generator, so it's just a tube with wire wrapped around it. Arrange the compasses so they all point in the same direction, then place the coil of wire among the compasses. Ask students what they notice. The compasses should not be affected at all.

Have students record these results. They may add the following to the T-chart poster:

- *What we tried*: "Compasses near a coil of wire with no magnets"
- *What we saw*: "Compasses aren't affected at all"



Read the directions for ***Investigation E:*** *Connect the coil to the high-output generator, at least 3 feet away from the coil and the compasses.* Connect the high-output generator to the coil, using 2-4 alligator clips to extend the distance from the generator to the coil. Ask students what they notice. Students should be convinced that any effect on the compasses is from the coil itself, not from the high-output generator. Crank the generator back and forth to see the compasses change direction back and forth. Cranking the generator steadily in one direction might cause a pattern similar to what they saw with the magnet, but this conclusion isn't essential.

Have students record these results. They may add the following to the T-chart poster:

- *What we tried*: "Compasses near a coil of wire with an energy source"
- *What we saw*: "Compasses change direction when energy transfers to the coil"

Turn and talk about energy transfer at a distance. Present **slide V**. Because students are already out of their regular seats, encourage them to find another partner they don't usually sit with for this Turn and Talk.

After the Turn and Talk, call on students to share their ideas, as in the table below.

Suggested prompt	Sample student response
Is the energy that transfers through the coil of wire magnetic, electrical, or both? Why do you think that?	The coil can cause electric changes, like lighting a light bulb. It can also cause magnetic changes, like moving a compass. If the coil is connected to a light, the wires can transfer energy to that light, but it can also cause compasses to move.
How does this help us understand how energy is transferring into our devices through the wire?	The generator has to transfer energy that's in the moving magnets to electrical energy in the wire. This experiment helps us understand that the generator is able to change magnetic energy to electrical energy--the coil can affect both.

Build understanding about fields. Present **slide W**. Ask a student to read the text on the slide aloud, and give the class a moment to read it silently: *Scientists call the space around a magnet where energy can transfer a magnetic field. When energy transfers into or out of the field, the field changes its strength and shape.* This is an opportunity for students to add the term *field* to their Personal Glossary.

Then discuss the prompts on the slide as a class. Additional prompts are suggested below to push the conversation further and draw out some of the key ideas from the lesson.

Suggested prompt	Sample student response
What matter changes have we seen today that could be evidence of changing fields?	The compasses are made of matter, and they move in response to changes in fields.

	We used compasses moving as evidence of changing fields, but the fields would have been changing even if the compasses weren't there.
How can evidence of changing fields help us explain energy transfer from the generator?	The generator only works when the magnets are moving or changing. Moving magnets changes the field. Maybe a changing field causes electricity?
Where do we think that the fields are actually changing? Just near the coil, or everywhere along the wire?	All the wires carry electricity. The coil has a lot of wire in one place, but it's still just carrying electricity. If the coil of wire is creating fields, then it would make sense, if the wire is changing fields, to transfer energy everywhere along the wire.
How does this help us explain why we need to get something spinning in order to generate electricity in the wire?	By moving the magnets, we can change the fields, which can generate electricity.
Does it matter whether we move the magnets and keep the wire still, or whether we move the wire and keep the magnets still? How do we know?	It doesn't matter, because when we dissected the generator, we moved the wires, and in our homemade generators, we moved the magnets.

KEY IDEAS

Listen for the following key ideas:

- Motion of a magnet can generate changing fields, which can cause energy transfer at a distance (and vice-versa).
- When moving matter (e.g., pushing wind or steam) moves the magnets inside a generator, that can cause energy transfer into wires through changing fields.

12 · MODEL ENERGY TRANSFER IN THE GENERATOR

10 min

MATERIALS: 8.5 x 11 paper, chart paper, markers, whiteboard and dry erase markers (alternate)

Make connections between matter changes, energy transfer, and fields. Present **slide X**, and direct students to return to their table to work in groups of 3-5 to consider the prompts on the slide:

- *Can we track how matter changes or moves within the system?*
- *What does matter tell us about how energy transfers?*
- *How can matter changes (or movement) tell us about energy transfer through fields?*

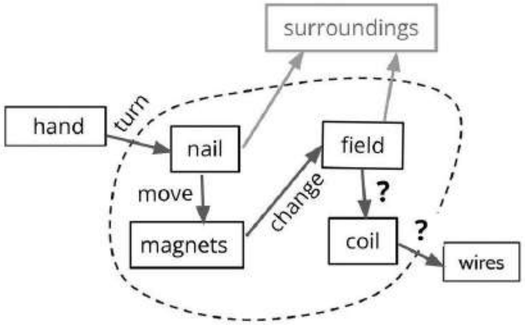
Distribute a half-sheet of blank paper to each student. Encourage them to begin sketching an energy transfer diagram to help them think through the prompts, using the key components on the diagram of the generator as a starting point. Circulate around the room, encouraging students to include fields as a component in their model.

Alternatively, students can respond to the prompts with written sentences, or even by talking through their answers out loud. If they do not draw a model, clarify that we'll use these ideas to build an energy transfer model as a class.

Model energy transfer in the generator. Present **slide Y**. Call on students to build an energy transfer model of the generator as a class on chart paper or a whiteboard. Key components of this model include: nail, magnets, field, coil, and wires.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As a class, students should model something like this:



- Students should again use our box and arrow conventions, and label the arrows with at least one action word to describe energy transfer. (SEP: 2.3)
- The class model should include energy transfer to a field with the arrow labeled as "change" (i.e., magnets **change** the field). (CCC: 5.2, DCI: PS3.A.3)
- Students will likely not yet have a clear idea of how energy transfer manifests in the wires. This uncertainty will motivate the investigations in Lesson 6. Rather than pushing students to figure this out now, encourage them to highlight this limitation of their model by putting a question mark on that arrow. (DCI: PS3.A.2)

What to do:

- If students have trouble getting started, direct them to the key components in the diagram of the generator. Write these components with arrows between them, leaving enough space to label each arrow with a verb to describe the interaction that transfers energy.
- If students have trouble suggesting verbs to describe energy transfer through contact of moving matter, ask, *How would you describe what the [hand, nail] is doing to the [nail, magnets]?*
- If students have trouble suggesting a verb to describe energy transfer at a distance through the field, ask, *How did the compasses respond when the magnets moved? What does this mean for the field? What do the magnets do to the field?*
- Don't force students to include the surroundings in their model, as we have no direct evidence that energy is lost to the surroundings here. If they want to point out that energy is lost as the nail rubs against the tube, the interaction can be labeled "heats up" or "rubs against".

Building toward: 5.A.2 Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts, and transfer at a distance through fields. (SEP: 2.3, CCC: 5.2, DCI: PS3.A.2, PS3.A.3)

ALTERNATE ACTIVITY

This modeling task can be assigned in groups or partners, or even as an individual assessment. If that is done, make sure the class gets a chance to quickly come to consensus at some point about what the model should look like.

13 · DISCUSS MATTER-ENERGY CONNECTION AND ADD TO THE PROGRESS TRACKER

5 min

MATERIALS: None

Make it explicit that changes in matter and transfer of energy tend to occur together. Present **slide Z**. Ask:

- *Based on the models we made over the past few days, how are matter changes related to energy transfer?*
- *Is there a cause-effect relationship?*

Listen for responses such as:

- Matter changes and energy changes often happened together.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

We have begun to consider the interplay between matter and energy, but the wires

- Energy transfer can cause a change in matter, or vice-versa.
- Energy and matter aren't exactly the same thing, but they're definitely related.

Clarify that matter doesn't always take the same path that energy does. ✱

Add to Progress Trackers. Give students a few minutes to add their ideas to their *Progress Trackers*.

don't obviously fit the pattern we've seen so far. Even though students should recognize the energy transfer from the generator to the wires, they may not identify that matter is changing inside the wires as well. If they have questions about this, note those as excellent questions or lines of inquiry, but try to shift focus to the visible parts of the generator itself. In Lesson 6, students will explore energy transfer at the particle level, and the pieces will fit together.

14 · NAVIGATE: EXIT TICKET

2 min

MATERIALS: 8.5 x 11 paper

Navigate with an exit ticket. Distribute a sheet of paper to each student and present **slide AA**. Ask them to put their name on the paper and respond to the prompts on the slide as an exit ticket:

- *Why do some power plants need to get something spinning in order to transfer electrical energy to the wires?*
- *What parts of our generator energy transfer model support this idea?*
- *What questions do you still have about energy transferring through the wire?*

Collect these exit tickets as students leave class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Students should say that the motion of magnets causes field changes, resulting in the transfer of energy. (CCC: 5.2, DCI: PS3.A.3)
- Students should identify parts on their model where the magnets move and where the field changes, generating electrical energy. (SEP: 2.3, CCC: 5.2, PS3.A.3)
- Students should have questions about what is happening in the wire when energy transfers through it. We haven't yet introduced electrons, but students who have taken chemistry or physics may mention electrons or electric current as a place to go next.

What to do: The reading in Lesson 6 goes more deeply into the role of fields, but students may not get much out of the reading initially if they haven't yet grasped the basics. Use this exit ticket to gauge how ready students are for the reading. If most answers show little grasp of fields, plan to do a close reading of the home learning in the next class period. If most answers show some basic understanding of fields, you may be able to skip some steps of the close reading.

Students will make their own models on a transfer task assessment in a few class periods, so use this exit ticket as a formative assessment to indicate how much practice they might need in preparation.

Building toward: 5.A.3 Develop a model based on evidence to illustrate the energy and matter changes in a generator, including energy transfer through contact between moving parts, and transfer at a distance through fields. (SEP: 2.3, CCC: 5.2, DCI: PS3.A.3)

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	A Common Core ELA standard is targeted in this lesson from the category of **Key Ideas and Details.** ● **CCSS.ELA-Literacy.RST.11-12.3.** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text. Students will follow a multistep procedure to test the effect of the configuration of the magnets and the rate of rotation of a generator on the transfer of energy in a wire. They use their results to consider the constraints for building a generator.